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Prospective Radiological Environmental Impact Assessment for Facilities and Activities

DRAFT SAFETY GUIDE **DS427**

FOREWORD

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CONTENTS

1. INTRODUCTION

BACKGROUND

1.1. In 2014, the IAEA published the Safety Requirements: Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards, General Safety Requirements Part 3 (GSR Part 3) [1]. GSR Part 3 [1] is based on the Fundamental Safety Principles (SF-1) [2] and the recommendations of the International Commission on Radiological Protection (ICRP) [3].The system of radiation protection and safety set out in GSR Part 3 [1] aims to assess, manage and control exposure to radiation so that radiation risks, including risks of health effects and risks to the environment, are reduced to the extent reasonably achievable. Protection of the public is based on the principles of justification, optimization and dose limitation, which were specified by the ICRP [3] and are incorporated in the IAEA Safety Standards [1, 2].

1.2. GSR Part 3 [1] establishes a requirement for a prospective assessment to be conducted of the radiological environmental impacts due to releases of radionuclides from facilities and activities[1]. This Safety Guide provides guidance on meeting the requirements in GSR Part 3 [1] for performing such assessments for certain facilities and activities if required by the regulatory body and, in particular, for meeting the requirement established in para. 3.9 (e) of GSR Part 3 [1], which states that "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".

1.3. The aim of a prospective radiological environmental impact assessment is to determine whether the planned facility or activity complies with current legislative and regulatory requirements on radiation protection of the public and protection the environment under all reasonably foreseeable circumstances. Such a prospective assessment includes the consideration of exposures expected to occur in normal operation and potential exposures due to accidents that are identified and characterized by mean of a safety analysis. The radiological environmental impact assessment should be as simple as possible, but as complex as necessary to achieve this aim.

1.4. In the framework of international legal instruments or national laws and regulations, States may also require that, for some activities or facilities, a governmental decision making process[2], including a comprehensive initial assessment of possible significant effects on the environment, is carried out at an early stage in the development of the facility or activity. In this case, the radiological environmental impact assessment is generally part of a broader impact assessment, which is generally referred to as an 'environmental impact assessment' or by its common abbreviation EIA. An environmental impact assessment covers not only biophysical impacts, but also assesses prospectively social, economic and other relevant impacts of a proposed activity or facility prior to major decisions being taken. Within such a framework, the results of the radiological environmental impact assessment, as described

[1] The term 'facilities and activities' is defined in SF-1 [2] and the IAEA Safety Glossary [4]. It is a general term encompassing all nuclear facilities and uses of all sources of ionizing radiation. The recommendations of this Safety Guide apply to certain facilities and activities, as described in paras 1.11 to 1.25.

[2] An explanation of the term 'governmental decision making process' is provided in Section 2.

within this Safety Guide, may be used for making informed judgements on the acceptability of the risk from the radiation protection perspective.

1.5. This Safety Guide is related to other publications in the IAEA Safety Standards Series, namely the Safety Requirements for Safety Assessment for Facilities and Activities, IAEA Safety Standards Series No. GSR Part 4 (Rev. 1) [5] and for Preparedness and Response for a Nuclear or Radiological Emergency, IAEA Safety Standards Series No. GSR Part 7 [6], and the Safety Guides on Radiation Protection of the Public and Protection of the Environment, IAEA Safety Standards Series No. DS432 [7], on Criteria for Use in Preparedness and Response for a Nuclear or Radiological Emergency, IAEA Safety Standards Series No. GSG-2 [8] and on Regulatory Control of Radioactive Discharges to the Environment, IAEA Safety Standards Series No. DS442[9]. This Safety Guide should be used in conjunction with these other safety standards[3].

1.6. This Safety Guide provides a general framework that is consistent with and can be applied as a complement to the guidance provided in other Safety Guides setting out frameworks for safety assessment for facilities and activities, in which the concept of radiological environmental impact assessment is included as part of the safety assessment but where it is described in less detail; for example, in the frameworks described in The Safety Case and Safety Assessment for Predisposal Management of Radioactive Waste, IAEA Safety Standards Series No. GSG-3 [13], and in Safety Assessment for the Decommissioning of Facilities Using Radioactive Material, IAEA Safety Standards Series No. WS-G-5.2 [14].

OBJECTIVE

1.7. This Safety Guide provides recommendations and guidance on a general framework for performing prospective radiological impact assessments for facilities and activities, to estimate and control the radiological effects on the public and on the environment. This radiological impact assessment is intended for planned exposure situations as part of the authorization process and, when applicable, as part of a governmental decision making process for facilities and activities. The situations covered include both exposures expected to occur in normal operation and potential exposures (see para 2.2).

1.8. This Safety Guide provides general guidance and recommendations about the content of a prospective radiological environmental impact assessment, its use and the procedures for its implementation, as an aid to national regulatory bodies, to persons or organizations responsible for facilities and activities and to other interested parties[4], including but not restricted to those persons or organizations applying for an authorization for or responsible for

[3] The IAEA has also issued a Safety Report on methods and models that can be used to assess the impact of releases of radioactive material to the environment [10] and Technical Reports relevant to environmental transfer parameters [11,12]. A revision of Safety Reports Series No. 19 [10] is in preparation, and will cover screening assessments of public exposure; generic models and parameters for use in assessing the impact of radioactive discharges; and generic models and parameters for assessing exposures of flora and fauna due to radioactive discharges from facilities and activities.

[4] GSR Part 3 [1] uses the term ‘interested party’ to mean, in a broad sense, a person or group having an interest in the performance of an organization. Interested parties have typically included customers, owners, operators, employees, suppliers, partners, trade unions; the regulated industry or professionals; scientific bodies; governmental agencies or regulatory bodies. It could also include other States, e.g. neighbouring States concerned with possible transboundary impacts.

the operation of facilities and conduct of activities. It is recognized in this Safety Guide that different States use different approaches to perform some aspects of the radiological environmental impact assessment. This is due to the complexity and diversity of the options for management of environmental issues, which depends on the characteristics of the facilities and activities themselves, the environmental conditions and the national circumstances.

1.9. Figures 1 to 3 and I-1 and I-2 illustrate elements of such assessments and facilitate their description, but do not represent detailed procedures. Other important aspects that should be considered when performing a radiological environmental impact assessment, such as selection of computer codes, uncertainty analysis, verification, quality assurance and quality control, are not described in this Safety Guide.

SCOPE

1.10. The Safety Guide applies to those facilities and activities for which, according to their characteristics and according to national or internationally applicable regulations, a radiological environmental impact assessment is mandatory. Guidance on how to determine the need for and complexity of a radiological environmental impact assessment is provided in Section 4.

1.11. This Safety Guide provides guidance on how to evaluate prospectively radiation exposures and radiation risks due to radioactive releases to the environment, and, when relevant, due to direct external irradiation, from new or existing facilities and activities, from which the public and the environment may be exposed to radiation[5]. It describes a radiological environmental impact assessment using generic data and models and site specific data and models, and a combination of both, as relevant.

1.12. The radiation exposures considered include those that are expected to occur as a result of normal operation (i.e. due to authorized discharges or direct external irradiation) and also exposures that may occur but are not certain to occur, as determined by means of a safety analysis[6] of events and accidents[7], as defined in GSR Part 3 [1] (i.e. potential exposures).

1.13. This Safety Guide does not provide guidance on equivalent prospective assessments of 'delayed' exposures that may occur in the post-closure period of a waste disposal facility [15], of exposures from the transport of radioactive material and of exposures from the use of mobile radioactive sources. Specific guidance on assessment of exposures for disposal and for

[5] Facilities and activities needing radiological environmental impact assessment are those in which radioactive material is produced, processed, used, handled or stored in such a form and on such a scale that consideration of the possible impact on the public and the environment is required. Examples of such facilities are: nuclear installations (including nuclear power plants, research reactors, radioisotope production facilities and source production facilities, spent fuel storage facilities and reprocessing facilities, facilities for the enrichment of uranium, nuclear fuel fabrication facilities, predisposal radioactive waste management facilities, disposal facilities during the operational period and nuclear fuel cycle related research and development facilities); some mining and raw material processing facilities, such as open-pit uranium mines; and facilities for the milling or processing of uranium ores,. Such activities may include: the use of unsealed radiation sources for industrial, research and medical purposes, and the decommissioning of certain facilities.

[6] Safety analysis is part of the safety assessment for facilities and activities [5].

[7] The IAEA Safety Glossary defines an 'accident' as any unintended event, including operating errors, equipment failures and other mishaps, the consequences or potential consequences of which are not negligible from the point of view of protection or safety [4].

transport is provided in The Safety Case and Safety Assessment for the Disposal of Radioactive Waste, IAEA Safety Standards Series No. SSG-23 [16] and in Radiation Protection Programmes for the Transport of Radioactive Material, IAEA Safety Standards Series No. TS-G-1.3 [17] respectively.

1.14. A radiological environmental impact assessment, as described within this Safety Guide, is intended to be prospective in nature. For example, it can be conducted prior to siting, as part of the application for an authorization during construction and prior to operation, or prior to decommissioning. A radiological environmental impact assessment can serve multiple purposes, including establishing the initial basis for authorization with respect to protection of the public and environmental protection, and as an important input into the process of authorizing controlled discharges. The process for authorizing discharge limits for optimizing the protection of workers and the public and safety is covered in DS442 [9].

1.15. A radiological environmental impact assessment can also be conducted for those existing facilities for which changes in their operational processes are planned before the implementation of any significant change affecting the level of discharges or potential releases to the environment; if deemed necessary, a radiological environmental impact assessment can also be conducted in the framework of a periodic safety review.

1.16. The radiological environmental impact assessment described in this Safety Guide is not intended to assess retrospectively the radiological impact from discharges during operation or the consequences of an actual accident. Nevertheless, the prospective assessment of potential exposures could provide preliminary information to be used in assessing the hazards and the related consequences for the purpose of establishing an adequate level of emergency preparedness and response [6].

1.17. The prospective assessment of potential exposures for facilities and activities, as described in this Safety Guide, may necessitate that accidents with very low probabilities of occurrence leading to radiological consequences for the public and the environment are considered and the criteria for potential exposures are met. However, even if a facility or an activity meets these criteria, it does not preclude the need for an assessment of hazards in relation to preparedness and response for a nuclear or radiological emergency, in line with requirements in GSR Part 7 [6]. Other aspects of the consequences of large accidental releases to the environment, such as societal and economic effects and non-radiological effects on the environment and on ecosystems, are outside the scope of this Safety Guide.

1.18. This Safety Guide does not describe in detail the specifications and characteristics of the events and accidents to be considered in the assessment of potential exposure of the public, nor the methodology for their selection and analysis; such specification and characterization, which should be determined by a systematic analysis, should be done in the framework of a safety assessment for facility or activity, as described in GSR Part 4 (Rev. 1) [5].

1.19. This Safety Guide defines a general framework and describes the general aspects of the methodology for performing a prospective radiological environmental impact assessment, and does not describe in detail the models to be used or the collection and use of data from radiological environmental monitoring programmes, which are normally undertaken at the

pre-operational stage and the operational stage[8] of a facility or activity. For the purposes of this Safety Guide, it is assumed that environmental and source monitoring is carried out as relevant at the pre-operational stage and the operational stage and that it provides the necessary information for adequate dose estimations and for verifying that the models and assumptions used in the prospective assessment are appropriate. The prospective assessment as described in this Safety Guide can also be used to underpin the establishment or upgrade of a site specific environmental monitoring programme. Guidance for environmental and source monitoring programmes is provided in Environmental and Source Monitoring for Purposes of Radiation Protection, IAEA Safety Standards Series No. RS-G-1.8 [18] and further information is provided in Ref. [19]. The need for and general characteristics of environmental monitoring programmes for demonstration of compliance with authorized discharge limits are addressed in DS442 [9].

1.20. This Safety Guide does not cover occupational exposures or medical exposures. Recommendations on these categories of exposure and their inclusion in the authorization process are provided in Occupational Radiation Protection, IAEA Safety Standards Series No. DS453 [20] and Radiation Protection and Safety in Medical Uses of Ionizing Radiation, IAEA Safety Standards Series No. DS399 [21].

1.21. This Safety Guide covers primarily the assessment of the risk of radiological impacts to the health of individual members of the public due to radiation exposure during normal operation and due to potential exposure, as required by GSR Part 3 [1]. In many instances, it can be concluded, on the basis of evidence such as experience or simplified analysis, that specific consideration of effects in the environment is not necessary. This may not be the case in all situations and the explicit consideration of protection of the environment may be required by the regulatory body. In other cases, explicit consideration of protection of the environment is captured in national legislation. A methodology for the explicit assessment of the radiation impacts on flora and fauna, which can be used in accordance with national or international regulatory frameworks for protection of the environment, is presented as an example in Annex I.

1.22. This Safety Guide does not address the process of 'iteration and design optimization', which is normally conducted within the framework of a safety assessment for the predisposal management of radioactive waste [13]; however a radiological environmental impact assessment as described in this Safety Guide may serve as an input for that process.

1.23. Optimization of protection and safety is required in GSR Part 3 [1]; the optimization process includes not only consideration of the protection of the public, but also consideration of the protection of workers and all the safety features of the facility or activity, such as those related to the on-site management of radioactive waste. This Safety Guide covers the assessment of the exposure of the public only. The wider aspects of optimization of protection and safety are covered in other IAEA Safety Standards, for example in GSG-3 [13] on predisposal management of radioactive waste. Optimization of the protection of the public in connection with the establishment of radioactive discharge limits for facilities and activities is

[8] Monitoring programmes at the pre-operational stage are defined, for instance, to establish 'baseline' activity concentrations in environmental media and to provide information and data for dose assessment purposes [18]. During the operation of the facility or the conduct of the activity, monitoring programmes are put in place to verify compliance with discharge limits, to check the conditions of operation, to provide warning of unusual or unforeseen conditions and to check the predictions of environmental models [18].

described in DS442 [9]. The result of a radiological environmental impact assessment, as described in this Safety Guide, is a necessary input to the optimization process to be used for establishing discharge limits.

1.24. The possible non-radiological impacts of facilities and activities, which are generally included in an environmental impact assessment, such as the impacts on people and the environment from releases of other hazardous substances (i.e. chemicals and heated water), the impacts from the construction of a facility, the impacts on places of societal significance (i.e. historical monuments and cultural places), the impacts on endangered species, the impacts on the landscape, as well as other societal and economic factors, are not considered in this Safety Guide but should be considered by States at the time of making relevant decisions.

STRUCTURE

1.25. Section 2 provides explanations of the main concepts and terms used in the Safety Guide. Section 3 presents the safety requirements for the government, the regulatory body and licensees relating to prospective radiological environmental impact assessment. Section 4 describes the framework in which such assessments are done. Section 5 describes the methodology needed to carry out a prospective radiological environmental impact assessment for protection of the public for normal operation and for potential exposures, and addresses the protection of the environment. The Appendix presents risk criteria established by relevant international organizations, which could be used as the basis to define national criteria for consideration of potential exposures. Annex I presents an example of a methodology for assessing and controlling the exposures of flora and fauna. Annex II presents considerations on the risk of health effects and the assessment of potential exposure of the public.

2. EXPLANATION OF CONCEPTS AND TERMS

2.1. This section provides an explanation of some of the concepts and terms used in this Safety Guide. Unless otherwise mentioned, concepts or terms are to be understood as defined in GSR Part 3 [1] or in the IAEA Safety Glossary [4].

PLANNED EXPOSURE SITUATIONS: EXPOSURES EXPECTED TO OCCUR IN NORMAL OPERATION AND POTENTIAL EXPOSURES

2.2. Paragraph 1.20 (a) of GSR Part 3 defines a 'planned exposure situation' as "a situation of exposure that arises from the planned operation of a source or from a planned activity that results in an exposure due to a source… In planned exposure situations, exposure at some level can be expected to occur. If exposure is not expected to occur with certainty, but could result from an accident or from an event or a sequence of events that may occur but is not certain to occur, this is referred to as 'potential exposure'" [1]. The magnitude and extent of these exposures can usually be predicted. Both exposures expected to occur and potential exposures can and should be taken into account at the planning or design stage [7].

GOVERNMENTAL DECISION MAKING PROCESS

2.3. In the context of this Safety Guide the term 'governmental decision making process' refers to the procedures carried out at all planning, pre-operational, operational and decommissioning stages by the government or governmental agencies, including the regulatory body, in deciding whether a project for a facility or an activity may be undertaken, continued, changed or stopped. The term could also apply to areas of national policy, such as whether to embark on a nuclear power programme [22].

2.4. A governmental decision making process is normally conducted at the early stages of a programme of development and, mainly, for activities or facilities for which it is foreseen that a thorough assessment of their possible impact on the environment is necessary. For some nuclear installations and facilities, this decision making process is described in national or international regulations by the term 'environmental impact assessment'[9] (see paras 2.7 to 2.9).

AUTHORIZATION PROCESS

2.5. 'Authorization' is defined in GSR Part 3 as "The granting by a regulatory body or other governmental body of written permission for a person or organization (the operator) to conduct specified activities" [1].

2.6. The authorization for a facility or an activity, in the form of registration or licence [1], could be granted for the design, siting, construction and operation of the facility or activity,

[9] The term 'governmental decision making process' encompasses or is related to different terms used in some States with similar or equivalent meanings, such as 'decision in principle', 'environmental impact statement', and, in some cases, 'justification'.

for decommissioning activities and when modifications in the conditions of operation of the facility or the conduct of the activity are considered.

ENVIRONMENTAL IMPACT ASSESSMENT

2.7. The term 'environmental impact assessment' is included in many international instruments and national legislation and regulations [23–30]. In the context of this Safety Guide, an environmental impact assessment refers to a procedure within a governmental decision making process for identifying, describing and assessing prospectively the effects and the risk of effects of a particular proposed activity or facility on aspects of environmental significance[10].

2.8. The effects relating to radioactive releases from facilities and activities to the environment likely to be considered in an environmental impact assessment generally include radiological effects on human health and, where required by States, radiological effects on flora and fauna. Non-radiological impacts included in an environmental impact assessment are not considered in this Safety Guide but are subject to national and internationally applicable regulations.

2.9. In general, an environmental impact assessment requires the involvement of the applicant of the proposed activity or facility, relevant governmental agencies, the regulatory body and a number of interested parties, including, in some States, the public [22-30].

ENVIRONMENT AND PROTECTION OF THE ENVIRONMENT

2.10. GSR Part 3 [1] defines the environment as the "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". Usually, the environment includes ecosystems that comprise biotic and abiotic components.

2.11. GSR Part 3 [1] further states in the definition of the environment that "Protection of the environment includes 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, such as carbon, nitrogen and water cycles".

2.12. Furthermore, the introduction of GSR Part 3 [1] in para. 1.35 notes that "the protection of the environment [is identified] as an issue necessitating assessment, while allowing for flexibility in incorporating into decision making processes the results of environmental assessments that are commensurate with the radiation risks" [1].

[10] Reference [31] provides information on environmental impact assessment in the framework of the development of a new nuclear power programme.

RADIOLOGICAL ENVIRONMENTAL IMPACT ASSESSMENT

2.13. For the purpose of this Safety Guide, a radiological environmental impact assessment is a prospective assessment of the expected and analytically conceivable radiological impacts, which is quantified in terms of effective dose to members of the public, and which is conducted as part of the authorization process. The results of a radiological environmental impact assessment are compared with predefined radiological criteria defined in GSR Part 3 [1]. A radiological environmental impact assessment may be seen as one component of an environmental impact assessment (as described in paras 2.7 to 2.9) in the context of planning for a particular facility or activity.

MEMBERS OF THE PUBLIC

2.14. GSR Part 3 [1] defines a member of the public as "in a general sense, any individual in the population except when subject to occupational exposure or medical exposure". SF-1, Principle 7, states that "safety standards apply not only to local populations but also to populations remote from facilities and activities". In addition, "where effects could span generations, subsequent generations have to be adequately protected without any need for them to take significant protective actions" [2].

3. SAFETY REQUIREMENTS RELEVANT TO PROSPECTIVE RADIOLOGICAL ENVIRONMENTAL IMPACT ASSESSMENT AND PROTECTION OF THE PUBLIC

3.1. This section contain extracts from the SF-1 [2], GSR Part 3 [1] and GSR Part 4 [5] setting out the relevant safety requirements for protection of the public and the environment that are required to be considered in the conduct of prospective radiological environmental assessments for planned exposure situations. Recommendations on how to meet these requirements are provided in Sections 4 and 5 and in the Appendix of this Safety Guide.

LIMITATION OF DOSE AND CONSTRAINT OF DOSE AND RISK

3.2. SF-1 [2] establishes principles for ensuring the protection of the public and the environment, now and in the future, from harmful effects of ionizing radiation, and states that "doses and radiation risks must be controlled within specified limits". These principles apply to situations involving exposure to, or the potential for exposure to, ionizing radiation[11].

3.3. GSR Part 3 [1] states that, for planned exposure situations, exposures of and risk to members of the public are required to be subject to control (paras 2.11, 3.26, 3.27, 3.120 (c) and 3.123 (b)).

3.4. Requirement 12 of GSR Part 3 [1] states that "The government or the regulatory body shall establish dose limits for… public exposure, and registrants and licensees shall apply these limits".

3.5. Paragraph 3.120 of GSR Part 3 [1], which relates to responsibilities specific to public exposure, states that "The government or the regulatory body shall establish or approve constraints on dose and constraints on risk to be used in the optimization of protection and safety for members of the public". Paragraph 3.123 of GSR Part 3 [1] states that:

> "The regulatory body shall establish or approve operational limits and conditions relating to public exposure, including authorized limits for discharges. These operational limits and conditions: …
>
> (e) Shall take into account the results of the prospective assessment for radiological environmental impacts that is undertaken in accordance with requirements of the regulatory body…".

ASSESSMENT FOR PROTECTION OF THE PUBLIC AND PROTECTION OF THE ENVIRONMENT

3.6. Principle 7 of SF-1 [2] states that: "People and the environment, present and future, must be protected against radiation risks".

[11] The principle of dose and risk limitation is not applied to emergency exposures situations and existing exposures situation, for which reference levels are used instead.

3.7. Paragraph 3.28 of SF-1 [2] states that "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)".

3.8. Paragraph 3.9 of GSR Part 3 [1] states that

> "Any person or organization applying for authorization: […]
>
> (e) 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".

Section 4 of this Safety Guide provides guidance on the context in which an assessment is done and Section 5 describes the methodology for assessment of the level of protection of the public and the environment.

3.9. Paragraph 3.15 of GSR Part 3 [1] establishes the responsibilities of registrants and licensees in planned exposure situations. It states that

> "Registrants and licensees: […]
>
> (d) Shall, for the sources for which they are authorized and for which the regulatory body requires a prospective assessment to be made for radiological environmental impacts…, conduct such an assessment and keep it up to date."

3.10. Requirement 31 of GSR Part 3 [1] relates to radioactive waste and discharges. Paragraph 3.132 of GSR Part 3 [1] 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 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".

ASSESSMENT AND CONTROL OF POTENTIAL EXPOSURE

3.11. Paragraph 3.15 (e) of GSR Part 3 [1] states that:

> "Registrants and licensees: […]
>
> (e) Shall assess the likelihood and magnitude of potential exposures, their likely consequences and the number of persons who may be affected by them".

3.12. Paragraph 3.24 of GSR Part 3 [1] states that:

> "registrants and licensees shall ensure that all relevant factors are taken into account in a coherent way in the optimization of protection and safety to contribute to achieving the following objectives:
>
> (a) To determine measures for protection and safety that are optimized for the prevailing circumstances, with account taken of the available options for protection and safety as well as the nature, likelihood and magnitude of exposures;
>
> (b) To establish criteria, on the basis of the results of the optimization, for the restriction of the likelihood and magnitudes of exposures by means of measures for preventing accidents and for mitigating the consequences of those that do occur".

3.13. Requirement 6 of GSR Part 4 (Rev. 1) [5] states that "The possible radiation risks associated with the facility or activity shall be identified and assessed". These include "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".

3.14. Paragraph 3.31 of GSR Part 3, [1] states that:

> "Safety assessment shall be conducted… so as:
>
> (a) To identify the ways in which exposures could be incurred...;
>
> (b) To determine the expected likelihood and magnitudes of exposures in normal operations and, to the extent reasonable and practicable, make an assessment of potential exposures".

GRADED APPROACH

3.15. Paragraph 3.24 of SF-1 [2] states 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".

3.16. Paragraph 3.1 of GSR Part 4 (Rev. 1) [5] states that to apply Principle 5 of SF-1 "a graded approach shall 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".

3.17. Requirement 6 of GSR Part 3 [1] states 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 likelihood and magnitude of the exposures".

3.18. Paragraph 3.4 of GSR Part 4 (Rev. 1) [5] states that "Other relevant factors, such as the maturity or complexity of the facility or activity, shall also be taken into account in a graded approach to safety assessment". GSR Part 4 (Rev.1) [5] also states (paragraph. 3.6) that "The application of the graded approach shall 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 safety assessment are then modified as necessary and the level of resources to be applied is adjusted accordingly".

TRANSBOUNDARY IMPACTS

3.19. Requirement 29 of GSR Part 3 [1] addresses the issue of exposure outside the territory of the State in which the source is located[12]. Paragraph 3.124 of GSR Part 3 [1] states that:

> "When a source within a practice could cause public exposure outside the territory or the area under the jurisdiction or control of the State in which the source is located, the government or the regulatory body:
>
> (a) Shall ensure that the assessment of the radiological impacts includes those impacts outside the territory or other area under the jurisdiction or control of the State;
>
> […]
>
> (c) Shall arrange with the affected State the means for exchange of information and consultations, as appropriate".

[12] The consideration of the protection of public and protection of the environment from possible transboundary impacts and the obligations for assessing the impacts and sharing information between States should also be addressed within the broader context of relevant international agreements and conventions (e.g. Espoo 1991 [23], UNCLOS 1982 [24], Aarhus 1998 [25] and Article 37 of the EURATOM Treaty [32]).

4. FRAMEWORK FOR PROSPECTIVE RADIOLOGICAL ENVIRONMENTAL IMPACT ASSESSMENT FOR FACILITIES AND ACTIVITIES

4.1. The government or the regulatory body should specify in advance the types of facility and activity for which a radiological environmental impact assessment is required or should specify criteria for deciding, on a case-by-case basis, whether such an assessment is needed. In general, such an assessment should not be required for X ray generators, small laboratories, diagnostic radiology, industrial applications using sealed sources, and any other facilities or activities where radiation sources or generators are used, processed or stored in a form and at a scale that impacts on the public and the environment are not expected in normal operation or accidents.

4.2. The required level of complexity of the radiological environmental impact assessment should also be defined by the government or the regulatory body in the national legal framework or regulations. Account should be taken on the characteristics of the activity or facility, based on considerations of the risk to the public and the environment due to exposures expected in normal operation and potential exposures. Facilities and activities that are exempted[13] without further consideration should not require a radiological environmental impact assessment for authorization, even if a generic assessment of the impact on the public and the environment may have been performed to support the conclusion on exemption. Where exemption is granted subject to conditions, the need for a radiological environmental impact assessment should be considered.

4.3. The methods used to perform a radiological environmental impact assessment (e.g. the assumptions, the conceptual models, the mathematical models and the input data) may differ according to the complexity of the facility or activity and the associated exposure scenarios, and should be selected by taking into account the requirements for a graded approach. In general, it is often more practical to start with a simple conservative assessment, using, for example, generic input data and assuming a cautious exposure scenario according to which the public and the environment are exposed to ionizing radiation, and then to increase the complexity of the assessment as necessary, for instance, using site specific data and more detailed and realistic exposure scenarios, until a clear and defensible conclusion is reached. For the sake of clarity, assessments described in this Safety Guide are sometimes categorized as either simple or complex. However, these terms are intended to convey the two ends of a range of possible assessments and there are a large number of activities and facilities for which an assessment falling between these two types will be appropriate.

ASSESSMENT FOR THE AUTHORIZATION PROCESS

4.4. Factors that are important for determining the need for and complexity of the radiological environmental impact assessment within an authorization process include the following: the source term[14]; expected doses; the characteristics of the activity or facility; the

[13] The concept of exemption and the general criteria for exemption of practices are set out in schedule I of GSR Part 3 [1].

[14] The source term is the amount and isotopic composition of material released (or postulated to be released) from a facility and the concept is used in modelling releases of radionuclides to the environment [4]. It is also

characteristics of the location; the national licensing regulations for the particular facility of activity; and the stage in the authorization process (see Table 1). The applicant should consider those factors when submitting an application to the regulatory body for review and agreement. For certain facilities or activities, the level of detail of the assessment can be defined a priori by the regulatory body.

4.5. The factors and elements set out in Table 1 should be used as general guidance as to whether a simple or complex radiological environmental impact assessment might be appropriate[15]. In general, an assessment in support of the authorization of a nuclear facility will require a high degree of complexity, while for an activity or facility operating with a small inventory of radionuclides, a simpler analysis may be justified.

TABLE 1. EXAMPLES OF FACTORS AFFECTING THE REQUIRED LEVEL OF COMPLEXITY OF A PROSPECTIVE RADIOLOGICAL ENVIRONMENTAL IMPACT ASSESSMENT

Factor		**Element**
Characteristics of the facility or activity	Source term	Radionuclides
		Quantity (both activity and mass/volume)
		Form (chemical/physical make up)
		Geometry (size, shape, height of release)
		Potential for release: the source term differs significantly for normal operation and for accidents
	Expected doses from normal operation or projected doses from potential exposures	Preliminary assessments or previous assessments for similar facilities
	Safety characteristics of the activity or facility	Types of safety barriers and engineering features present in the design
		Potential for severe accidents
Characteristics of the location		Characteristics of the facility site relating to dispersion of radionuclides in the environment (for example, geology, hydrology, meteorology, morphology, biophysical characteristics)
		Presence and characteristics of receptors (for example, demography, living habits and conditions, flora and fauna)
		Exposure pathways
		Land use and other activities (for example agriculture, food processing, other industries)
		Characteristics of other installations in the vicinity and possible natural and human induced external events (for example, earthquakes, flooding, industrial accidents, transport accidents)
Characteristics of the authorization process for the particular activity or facility		Requirements or regulations (licensing requirements)
		Stage of the authorization process

applicable to certain activities and, together with the physical and chemical properties of the material released, can be relevant for modelling environmental dispersion.

[15] The list provided in Table 1 is not exhaustive, and judgement on the significance of these factors when selecting the type of assessment will need to be made by experts in nuclear and radiation safety in the applicant's organization and by the national regulatory body.

4.6. For facilities or activities with relatively standardized practices, small inventories of radionuclides and a low potential for accidental releases to the environment, but which still can produce some impact on the public and the environment, for example, a hospital with a nuclear medicine department, the regulatory body may provide generic guidance identifying the necessary elements that should be included in the radiological environmental impact assessment.

4.7. For nuclear installations, for example nuclear power plants and nuclear fuel reprocessing facilities, there are likely to be a number of stages in the authorization process [33]. During these stages, the radiological environmental impact assessment may be updated as more specific data are obtained; the applicant or the operating organization of the installation should ensure that the updates of the results of the radiological environmental impact assessment are provided at each different stage, for consideration by the regulatory body.

4.8. Figure 1 has been adapted and modified from figure 1 in SSG-12 [33] and it presents schematically the stages in the lifetime of a nuclear installation. The radiological environmental impact assessments conducted prior to and during the operation of a nuclear installation will all be very similar, although they will incorporate successively more detail and specific data to reduce the level of uncertainty, where possible, and a review of the models and assumptions used, when this is deemed necessary. The vertical arrows in full in Fig. 1 indicate the point at which the radiological environmental impact assessment may be submitted to the regulatory body for discussion and, finally, submitted for approval, prior to the start of operation of the facility or the start of decommissioning. The vertical dashed lines indicate where an updated assessment may be submitted to the regulatory body if there are significant changes in the postulated level of releases or the potential exposure scenarios in the operational stage. The horizontal arrow indicates the evolution of time.

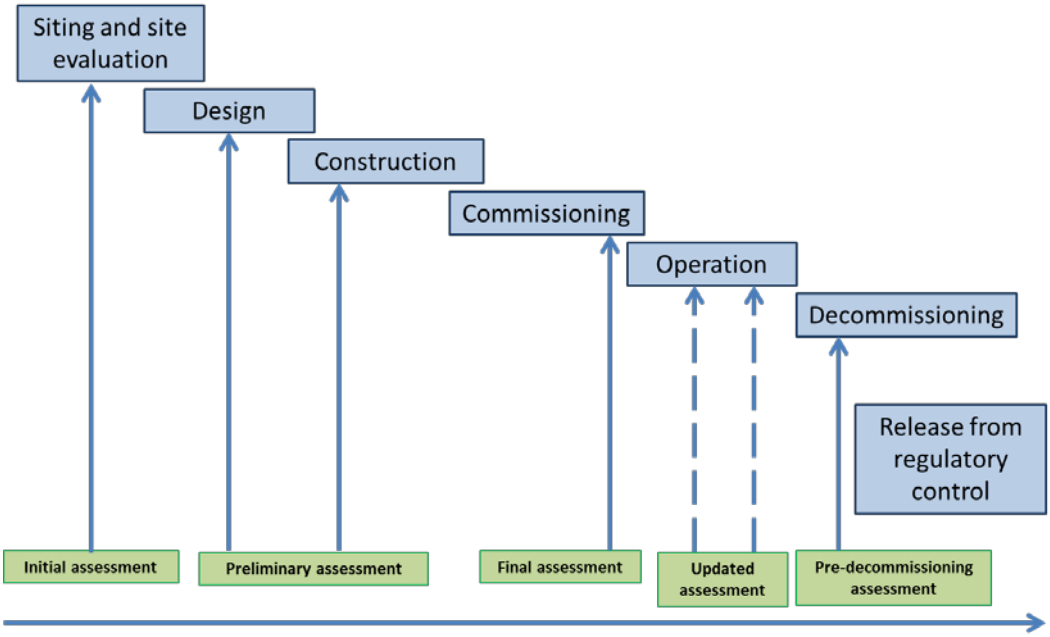

FIG. 1. Stages in the lifetime of a nuclear installation where a prospective radiological environmental impact assessment might provide input into the authorization process.

4.9. An initial radiological environmental impact assessment that makes use of generic data should be conducted during the stage of siting and site evaluation to identify potential regions or sites for the facility or activity. This assessment should include site characteristics and regional characteristics that could affect safety, the exposure of people, current and future land use, considerations of cultural significance and economic significance, and demographic considerations. At this stage, different designs of the facility may still be under scrutiny and the information available on the systems and safety analyses of the design may be limited.

4.10. Once a site or a number of sites have been shortlisted and the design of the facility is more clearly defined, a preliminary radiological environmental impact assessment for the particular location(s) should be carried out using available site specific data. In general, during the construction period more information relevant for the assessment should be collected, including, where this is deemed necessary, the results of environmental measurements and results from surveys on living habits and conditions carried out at and around the site. The assessment should be refined as the project evolves and more information becomes available, in order to be able to produce a well substantiated final radiological environmental impact assessment at some point in the commissioning stage, before the operating organization submits its final application for authorization to the regulatory body. SSG-16 [22] provides guidance on the submission and updating of a radiological environmental impact assessment in the framework of establishing the safety infrastructure for a nuclear power programme.

4.11. The radiological environmental impact assessment performed before the start of the operation of a facility or conducting an activity should be used as one of the inputs to determine authorized discharge limits and any other operational quantities relating to protection of the public. Guidance on establishment of authorized discharge limits is presented in DS442 [9].

4.12. For facilities already in operation and activities being conducted, the safety assessment should be periodically reviewed and updated at predefined intervals, in accordance with regulatory requirements [5]; this review should include the consideration of possible changes in the assumptions used to perform the radiological environmental impact assessment and the results of source monitoring and environmental monitoring programmes conducted during operation. The radiological environmental impact assessment may need to be revised if there are significant changes in characteristics of the facility or activity or in the characteristics of the location (see Table 1).

4.13. A prospective radiological environmental impact assessment carried out for a new installation should take account of the contribution to public exposures due to other facilities already operating or planned to be constructed at the site or the vicinity of the site under consideration.

4.14. Prior to the conduct of decommissioning actions, for certain facilities and activities such as nuclear installations, radioactive waste management facilities and uranium mining and milling facilities, a prospective radiological environmental impact assessment should be conducted for planning purposes [34].

4.15. Before release of a site from regulatory control after decommissioning, a review of the radiological environmental impact assessment could be necessary, depending on the final radiological conditions of the former facility. However, for most facilities and activities after decommissioning, typically, exposures expected to occur and potential exposures will be

negligible or non-existent, and the methods used to estimate those exposures and determine the associated radiological criteria will differ. For example, in the estimation of exposures more relevance should be given to the results of a final environmental survey, and the radiological criteria could be the release criteria for unrestricted use after decommissioning, as set by the regulatory body [35].

4.16. A particular situation may arise after decommissioning of some facilities and activities that extend over large areas, such as uranium mines and mills, where the residual source term may not be negligible and radiological impact on the public and the environment is expected after the facility or activity has closed down. The radiological environmental impact assessments for such situations should be conducted on a case by case basis, should take account of the particular characteristics of the source term and should use the results of a final survey, including radiological environmental monitoring data. The regulatory body should consider the need to define limitations on the use of the land, based on radiological release criteria for restricted use, and to identify responsible entities and specify arrangements for institutional control [35].

ASSESSMENT AS PART OF A GOVERNMENTAL DECISION MAKING PROCESS

4.17. A radiological environmental impact assessment is required as part of a governmental decision making process for certain facilities and activities, and may be included, for example, within an environmental impact assessment process. The facilities and activities for which a radiological environmental impact assessment is required as part of a governmental decision making process, and the level of complexity of the radiological environmental impact assessment, should be defined by the government with assistance of the regulatory body, on the basis of the level of risk due to exposures expected to occur in normal operation and from potential exposures, and other factors set out in Table 1. An environmental impact assessment should normally be conducted in the initial phase of the development of a nuclear power programme (see SSG-16 [22]).

4.18. The government or the regulatory body should set the thresholds or criteria for exemption from the requirement for a radiological environmental impact assessment at a level such that all projects of a certain type of facility or activity would be exempted if no radiological impact is expected either for normal operation or for accident conditions[16]. Alternatively, if the regulations specify that a radiological environmental impact assessment is required in all cases, the assessment should start with a very simple conservative methodology followed by increasing levels of complexity as necessary to reach to a defensible conclusion. This approach will ensure a high level of transparency and is consistent with the concept of a graded approach.

4.19. A radiological environmental impact assessment done as part of a governmental decision making process is normally done at the early stages of development of the project and, typically, has a lower level of detail and uses less specific data than a radiological

[16] Some international directives, such as the Convention on Environmental Impact Assessment in a Transboundary Context [23] and the EU Directive on the Assessment of the Effects of Certain Public and Private Projects on the Environment [26], specify the types of facility and activity for which an environmental impact assessment is necessary.

environmental impact assessment conducted as part of an authorization process; however, both radiological environmental impact assessments should be consistent with one another.

4.20. For some types of facility or activity, for example hospitals using radionuclides for diagnosis only or research laboratories using small amounts of radionuclides, there may be no requirement for a detailed radiological environmental impact assessment to be carried out as part of a governmental decision making process, because no significant impact to the environment is expected either for discharges during normal operation or for accidental releases; however, the national competent authority may establish its own requirements for the need for a radiological environmental impact assessment for such activities and facilities.

4.21. A radiological environmental impact assessment as part of a governmental decision making process may be carried out in a single phase or in multiple phases. The initial assessment may be relatively descriptive in nature and based on generic data and cautious assumptions, whilst further assessment may include more realistic models and site specific information. Generic assessments for similar facilities already in operation at other sites can provide useful information.

ASSESSMENTS FOR OTHER PURPOSES

4.22. The operator of a facility or an activity can conduct a radiological environmental impact assessment with the objective of introducing improvements in the safety systems of the facility or activity. For example, as part of a process to evaluate the safety performance of a facility or an activity, the operator can evaluate the efficiency of the systems to reduce radioactive discharges to the environment (e.g. aerosol filters or decay tanks used during normal operation) or the systems to reduce releases in an accident (e.g. emergency filters). For such assessments, the approaches described in this Safety Guide should be applied to ensure that all the aspects of public protection and environmental protection are considered.

COMMUNICATION OF RESULTS

4.23. Requirement 36 of GSR Part 1 (Rev. 1) [36] states that the regulatory body, either directly or through the operator of a facility or activity, is required to establish effective mechanisms of communication to inform interested parties about the possible radiation risks associated with the facility or activity and about the processes and decisions of the regulatory body. The factors in Table 1 should be considered when establishing the content and the level of detail in the information to be provided to the relevant interested parties. Depending on the national prominence of the facility or activity, both governmental authorities and the regulatory body should be involved, particularly when such communication is considered necessary for effectively informing the public. DS460 [37] provides guidance on communication and consultation with interested parties by the regulatory body.

4.24. A prospective radiological environmental impact assessment is generally published in technical documents that are intended to be read by individuals with expertise in the matter. Normally these individuals are experts in nuclear safety and radiation protection in the regulatory body, technical support organizations, public health agencies or environment agencies. The radiological environmental impact assessment should be well documented and transparent to enable it to be understood by a broader audience, which may not have a highly specialized expertise, such as the public and government departments and ministries not directly involved in safety and radiation protection issues. Information on the assessment

should be made available in appropriate technical language. In addition, a non-technical summary that condenses the relevant chapters of the more technical reports and outlines the key findings from the assessment could be useful for some interested parties.

4.25. Communication of the results is equally as important as the completion of a technically sound radiological environmental impact assessment. In order to put the results in an appropriate perspective, essential information on radiation effects and the safety aspects relating to design, operation, maintenance and surveillance of facilities and activities should be included, together with the specific results of the assessment.

4.26. Where the results of an assessment indicate that the information is relevant across national boundaries, this information should be shared with the States concerned. The State where the activity or facility is located should arrange with the States concerned the means for exchange of information and consultations, as appropriate.

4.27. The information used as a basis for the radiological environmental impact assessment should be, as much as possible, made available to all interested parties, in order to promote transparency and to build confidence and trust. However, some information could have commercial implications or nuclear safety and security implications (e.g. plans of the facility layout and information on plant accident sequences). Such information should be made available only to the regulatory body and other governmental agencies and should be treated confidentially. Normally the government, in consultation with the national regulatory body and other relevant national organizations, should establish which information can be made available to the public. The reason for restriction of access to certain sensitive information should be clearly explained so that it is not perceived by interested parties as concealing information that is relevant for estimating and understanding the radiation risks to people and to the environment. The responsibility of ensuring the technical soundness of any restricted information used as a basis for the assessment should remain with the government agencies with functions relating to nuclear safety and nuclear security.

5. METHODOLOGY FOR THE ASSESSMENT

GENERAL CONSIDERATIONS

5.1. This section presents a methodology for assessing the radiological impact on the public from exposures expected to occur in normal operation of facilities and activities and from potential exposures due to accidental scenarios at facilities and activities, and addresses whether and how protection of the environment can be considered in the assessment.

5.2. Since a radiological environmental impact assessment described in this Safety Guide is prospective in nature, reliance will have to be placed on mathematical modelling to evaluate, for example, the dispersion of radionuclides in the environment, the transfer of radionuclides through environmental compartments[17], the uptake of radionuclides by humans and biota in the human food chain and, finally, the radiation doses to humans resulting from external and internal exposures. The models should be appropriate for the situation in which they are being applied, and should be verified[18]. Model assumptions and parameter choices should be described in sufficient detail and should be referenced to be transparent and to allow independent verification.

5.3. Where possible, the selected models should be validated through comparison of the results of calculations made using the models with actual data resulting from measurements for similar exposure scenarios or, if this is not possible, by means of benchmarking procedures against other appropriate models. Environmental monitoring programmes for the operational phase of a facility or activity can be used not only to verify compliance with discharge limits and dose limits but also to confirm that the environmental models used in the prospective assessment were adequate.

5.4. Various methods, including different calculation tools and input data, can be used to carry out a radiological environmental impact assessment. Information on generic conservative methods is presented in Ref. [10]. The applicant should determine the level of complexity and details in the proposed methods, in accordance with the characteristics of the facility or activity and the location (see Table 1 in Section 4). The applicant is responsible for selecting the most appropriate methods, in accordance with guidance provided by the regulatory body. The national regulatory body should decide, in discussion with the applicant and other interested parties, which methodology is suited to carrying out a particular assessment and should agree that the methodology adopted is adequate for its proposed purpose.

5.5. One consideration when deciding on the methods for a radiological environmental impact assessment is the balance between the amount of effort practicable and the level of detail required. For example, for a facility or an activity with low levels of discharges, resulting in doses close to the exemption criteria, and a low potential for an accident with

[17] Environmental compartments are, for example, air, water, sediment and biota.

[18] There exist a number of ‘state of the art’ models applicable to radiological environmental impact assessment that have been developed and used by various States and, in some cases, provided by commercial companies. The IAEA regularly conducts international projects for validation of models and data, in which some of these models are used in test cases and for benchmarking. Information on models applied within the IAEA project EMRAS can be found in Ref. [38]; reports on models applied within the IAEA projects EMRAS II and MODARIA are in preparation.

consequences for the public and the environment, the use of detailed methods would not generally be necessary. For these types of facilities or activities, the regulatory body, vendors or professional associations may develop generic guidance setting out simple and conservative methods that can be used by applicants for their assessments. These methods should be adequate for the task and should consider all the environmental transfers aspects, such as bio-accumulation, appropriately.

5.6. For facilities for which complex assessments are warranted, the level of detail in the models and the data used for the assessment may evolve during the governmental decision making process or the authorization process.

ASSESSMENT FOR PROTECTION OF THE PUBLIC IN NORMAL OPERATION

5.7. Facilities and activities that use or process radioactive sources or materials are designed, constructed, commissioned, operated or conducted, maintained and decommissioned, and are regulated throughout all these stages, in order to prevent or minimize releases of radioactive materials to the environment. However, very low amounts of radionuclide residues can be found in some of the gaseous or liquid effluents resulting from normal operation. Owing to the large volumes involved, it could be technically difficult to store all this residue material on the site, and, in view of the low activity concentrations, the cost of doing so would likely be excessive and unjustified from a radiation protection perspective. In some cases, a facility or activity can also cause exposure due to direct irradiation. In order to control the doses to the public, in accordance with the safety requirements in GSR Part 3 [1], a prospective assessment of the possible dose to members of the public from gaseous and liquid discharges and from direct irradiation should be conducted, and the results should be compared with defined criteria.

Approach to the assessment

5.8. The radiological environmental impact assessment for the public in normal operation uses estimations of the dose to the public due to the discharges resulting from the operation of the facility or the conduct of the activity. Figure 2 summarizes the components of such an assessment[19]. In general terms, the first element of the assessment should be to characterize the source of radiation as it relates to public exposure. Next, dispersion in the environment and the transfer of radionuclides in the environmental compartments relevant for the identified exposure pathways and the location should be considered. The activity concentrations estimated in a number of environmental media should be then combined with relevant data on living habits and conditions (e.g. breathing rates, water consumption, food consumption) and time occupation factors (e.g. the time spent in a particular location or inside or outside buildings) to calculate intakes of radionuclides (internal exposure) or external irradiation (external exposure) for the representative person[20]. Intakes of radionuclides and external irradiation should be combined with dosimetric data to calculate doses to the representative person for comparison with relevant criteria, for example dose constraints. The

[19] The figure is not intended as a detailed step by step procedure and is presented to illustrate the elements of the assessment and facilitate its description.

[20] The concept of and the characteristics of the representative person for normal operation are set out in paras 5.32-5.35.

different components of the assessment presented in Fig. 2 are described in the paras 5.9 to 5.42.

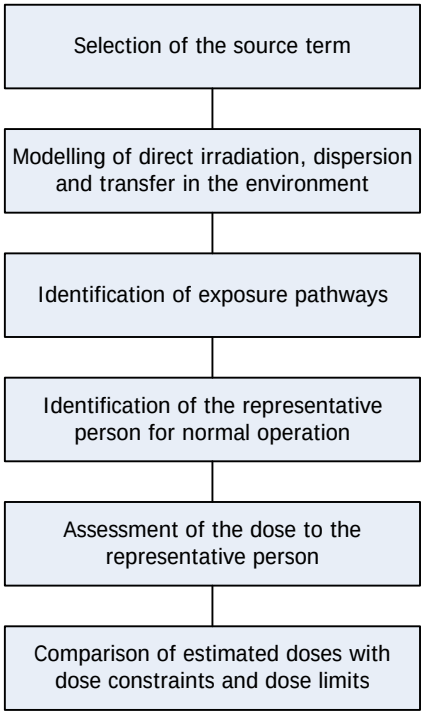

FIG. 2. Components of a radiological environmental impact assessment for protection of the public in normal operation.

Selection of the source term

5.9. The source term selected for a radiological environmental impact assessment should be representative of the type of facility or activity being assessed. The composition and amount of relevant radionuclides, from a radiation protection point of view, should be selected, along with the discharge path and the physical properties (i.e. gas, aerosol or liquid) and chemical properties relevant for environmental transfers and dosimetry of the radionuclides. Discharges to the atmosphere and to the aquatic environment and direct irradiation should be considered separately, as appropriate.

5.10. In some cases, for instance in the case of a radiological environmental impact assessment for a governmental decision making process or at the initial stages of an authorization process, a generic source term for the proposed facility or activity could be used, based on preliminary estimations, published data or experience from similar facilities or activities. Information on generic source terms for normal operation of nuclear power plants and other facilities and activities can be found in reports published by the UN Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) [39, 40]. Later, when more details are known about the design and operation of the facility or activity, the source term should be more accurately characterized by means of appropriate engineering analysis.

5.11. The amount of the discharges should be integrated over the period required by the regulatory body; this is generally given in terms of activity released per year of operation. For most facilities and activities, a radiological environmental impact assessment typically assumes that the discharges are continuous and constant during the operational period, for example 30-50 years. This assumption may not be always valid, because significant variation

in the discharges over a short time period are expected, as in the case of pulsed release patterns from facilities or activities, such as discharges of iodine-131 to the sewerage system from hospitals and discharges from reprocessing facilities and materials processing facilities, which usually operate in batches. The effects of such pulsed release patterns should be considered in the assessment, if significant. It should also be considered that discharges to the environment can continue after operation ceases owing to the presence of residual radionuclides at the facility.

Modelling of direct irradiation, dispersion and transfer in the environment

5.12. Direct gamma irradiation from the facility or activity and, in some cases, sky scattered gamma ray radiation (sky shine), which can contribute to the external exposure of the public in the close vicinity, should be included in the assessment and, if necessary, should be estimated using models or experience from similar facilities or activities (e.g. the results of monitoring programmes). For facilities and activities using only sealed radioactive sources or radiation generators, such direct irradiation could be the only source of radiation or the most important source of radiation in determining the exposure of the public. For other facilities and activities, direct irradiation could be a contribution to the external dose to the public in the close vicinity of the facility.

5.13. A variety of models and data are necessary to predict the dispersion and transfer of radionuclides through the environmental media and to the representative person. The processes that are more relevant to dose estimation should be identified and a conceptual model should be elaborated in the form of a representation that captures the key elements or components of a complex system, such as the relationship between the released radionuclides and the environment. The conceptual model should represent the identified relevant dispersion pathways and transfer pathways.

5.14. Activity concentrations in environmental compartments (e.g. air, sediments, soil, water and biota) resulting from the postulated discharges of radioactive materials should be estimated by means of mathematical models. Mathematical models for assessing dispersion and transfers of radionuclides at different levels of complexity have been developed and are described in Ref. [10].

5.15. Two possible approaches to the use of models and data for the assessment are: a generic and simpler methodology, which takes account of dilution, dispersion and the transfer of radioactive material into the environment with cautious assumptions; or a specific and more detailed methodology, using partial or fully site specific data to estimate activity concentrations in different environmental media, with more realistic assumptions. In some situations, a combination of generic models with site specific data could also be suitable for the assessment. In all cases, the models selected should be suitable for estimating the spatial distribution and temporal variation of activity concentrations in the environment. The complexity of the model used should be commensurate with the likely level of environmental impact from the facility or activity and should be proposed and justified by the applicant and should be subject to agreement by the regulatory body.

5.16. The models selected should be suitable for simulating the dispersion, dilution, transfer and accumulation of radionuclides and their decay or other removal mechanisms, as necessary, with account taken of the characteristics of the releases expected during normal operation of the facility or activity. This includes the following processes:

(a) Atmospheric dispersion;

(b) Deposition of radionuclides from the atmosphere onto the ground or other surfaces and subsequent resuspension of the radionuclides;

(c) Dispersion of radionuclides in surface water (freshwater, brackish water or marine water) and groundwater;

(d) Accumulation and subsequent remobilization of radionuclides in aquatic sediments;

(e) Transfer of radionuclides to and their accumulation in plants and animals in the human food chain.

5.17. The models used to estimate activity concentrations in environmental media should take account of the physicochemical properties of the radionuclides being released, for example, by assessing the effective release height, the effects of nearby buildings on the dispersion of effluents or, in water bodies, the effects of local bathymetry, and removal or accumulation mechanisms, such as decay of parent radionuclides and growth of radioactive progeny, wet and dry deposition and sedimentation.

5.18. For facilities or activities necessitating simple assessments, the data on meteorological and hydrological conditions used as an input to the models could be of a generic character and based on published data or national records. The meteorological and hydrological conditions used for more complex assessments should be appropriate and specific for the site in question and should preferably be averaged over several years of data (at least three to five years). Such data may be available for the site itself or may be obtained from nearby meteorological or hydrological stations.

5.19. In general, Gaussian type atmospheric dispersion models can be used [10], particularly where the geographical characteristics of the sites under consideration mean that simple dispersion scenarios can be assumed (e.g. in the case of relatively flat terrain) and the individuals more likely to receive the highest doses live or are postulated to live within 10−20 km of the release point. However, for more complex dispersion conditions, for example for facilities located close to mountainous regions or areas where complex local atmospheric circulations are expected, more complex dispersion models may be necessary. In any case, the predictions should be based on realistic assumptions as far as possible and on cautious assumptions when uncertainties or variability in the data prevent those realistic assumptions from being taken into account. If the location of the facility is known at the time of the assessment, these assumptions should take account of site specific conditions. If the location of the facility is not known, generic information at a regional level should be used until more details about the exact location are known.

5.20. Radionuclides may be discharged to a freshwater, estuarine or marine environment. Radionuclides discharged to water bodies are dispersed or concentrated by environmental processes such as water movement and sedimentation. Much depends on the local characteristics of the aquatic environment, and as such it is not possible to have a totally generic model for aquatic releases. For example, the information used in modelling aquatic dispersion by a river should comprise at least the size of the river and its flow rate [10]. Models should be suitable for estimating the activity concentrations in water and in sediment. From these estimations, activity concentrations in aquatic food, such as fish, molluscs and crustaceans, as relevant, can be calculated, together with external irradiation due to sediments on the shore or on riversides.

5.21. For some facilities and activities, discharges of radioactive liquid effluents to the sewerage system may occur, with sewage then being carried to treatment plants. When assessing the doses from such discharges, the models should be suitable for estimating the transfer of the radionuclides through the sewerage system (for example, using compartmental models[21]) and their subsequent release into the environment. Radionuclides could be discharged with the treated effluent to rivers or coastal waters, where the models with the features indicated in para. 5.20 should be used. In addition, radionuclides may be associated with sewage sludge, which is managed in various ways, including its reuse as a soil conditioner and fertilizer on agricultural land, its treatment or disposal by incineration or its transfer to a municipal waste landfill site. Adequate models should be used to estimate the transfer of radionuclides through terrestrial food chains and to the atmosphere as a result of resuspension, as relevant. It may also be necessary to assess the exposure of workers involved in the operation of the sewerage systems and at the treatment plants.

5.22. When radionuclides are continuously discharged, they accumulate in the environment up to the point at which equilibrium conditions can be assumed. Dose estimates should be calculated for the time at which the highest radiation exposure is expected. The activity concentrations in environmental media that are used to estimate doses should be representative of the conditions when accumulation can be assumed to be a maximum. For example, if a facility is expected to be operational for 30 or 40 years, maximal activity concentration occurs at the end of the operational life and accordingly the dose should be assessed for the 30^{th} or 40^{th} year to take accumulation in the environment into account. For facilities or activities from which long-lived radionuclides are discharged, the maximum exposures can occur well after operations cease, for example as a result of slow migration processes of radionuclides in the environment beyond the period of operation. The assessment should take this possibility into account.

5.23. The contribution to the dose from radioactive progeny in radioactive decay chains should be taken into account. In some cases, the decay products may be radiologically more significant than the parent radionuclide and therefore it is important to consider the ingrowth of such decay products. Examples of this are the uranium decay series and plutonium-241, which decays into americium-241. The assumptions and approaches used to deal with radioactive progeny, including the exclusion of progeny from consideration if applicable, should be justified.

5.24. The transfer of radionuclides from environmental media to the plants and animals in the human food chain should be estimated using generic transfer parameters, such as the transfer factors for food in the terrestrial, marine and freshwater ecosystems provided in Refs [10 - 12]. If there is a need to refine the assessment, for instance when the doses initially estimated using generic transfer factors are above or close to the selected dose criteria, the use of transfer factors based on site specific measurements could be necessary; however, this could be difficult for a prospective assessment. The regulatory body should decide if site specific data based on measurements should be used in an assessment. The uncertainties in transfer parameters resulting from a lack of site specific data can be compensated for by the use of generic data with cautious assumptions, whilst noting the need not to be grossly pessimistic in such assumptions.

[21] Models used to represent different transfer processes between the compartments of a system, with each compartment assumed to be a homogenous entity.

5.25. For facilities necessitating a complex assessment, a preliminary estimation of the dispersion and transfer to the environment at the initial stages of an authorization process can be done using simple conservative models and meteorological and hydrological data that is generic for the region (e.g. from published data or from records from the closest meteorological or hydrological stations, which may sometimes be located at tens to hundreds of kilometres from the sites). At later stages of the authorization process, meteorological and hydrological data from measurements conducted on the site or very close to the location of the facility should be used, as they become available. Such local measurements are usually made at the site survey and construction stages. Requirements and recommendations on the type and detail of that which should be available at the later stages of licensing process can be found in Site Evaluation for Nuclear Installations, IAEA Safety Standards Series No. NS-R-3 (Rev. 1) [41], Meteorological and Hydrological Hazards in Site Evaluation for Nuclear Installations, IAEA Safety Standards Series No. SSG-18 [42] and 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 [43].

Identification of exposure pathways

5.26. Doses should be calculated for a number of exposure pathways that are considered relevant for discharges to the environment in particular scenarios. Possible exposure pathways for both internal exposure and external exposure that could be considered are given in the following paragraphs.

5.27. The possible exposure pathways for releases of radionuclides to the atmosphere and surface waters in normal operation (typically, for nuclear installations such as nuclear power plants) are the following:

(a) Inhalation of radionuclides in an atmospheric plume (gases, aerosols);

(b) Inhalation of resuspended material;

(c) Ingestion of crops;

(d) Ingestion of animal food products (milk, meat, eggs);

(e) Ingestion of drinking water;

(f) Ingestion of aquatic food (freshwater or seawater fish, crustaceans, molluscs);

(g) Ingestion of forest food (wild mushrooms, wild berries, game);

(h) Ingestion of breast milk or locally prepared food for infants;

(i) Inadvertent ingestion of soil and sediments;

(j) External exposure from radionuclides in an atmospheric plume (cloud shine);

(k) External exposure from radionuclides deposited on ground (ground shine) and surfaces;

(l) External exposure from radionuclides in water and sediments (i.e. from activities on shores, swimming and fishing).

5.28. The possible exposure pathways for releases to the sewerage system in normal operation (typically for hospitals with nuclear medicine departments) are the following:

(a) Inhalation of resuspended dried sewage sludge;

(b) External exposure from radionuclides in dried or wet sewage sludge.

5.29. For some facilities or activities, sources of radiation could contribute to doses to members of the public living in the close vicinity of the facility or working[22] on site. Additional exposure pathways to be considered are the following:

(a) External exposure due to direct irradiation from sources of radiation stored at the facility (e.g. from spent fuel or radioactive waste);

(b) External exposure due to direct irradiation from sources used in the facility (e.g. from industrial irradiators);

(c) External exposure due to direct irradiation from the facility (e.g. from nuclear or radioactive components of the facility or secondary components such as stored wastes, coolant systems or steam systems).

5.30. Depending on the exposure scenarios and the site characteristics, not all the exposure pathways listed in the paragraphs above may need to be included in the assessment. In particular cases, additional pathways might be identified. The contribution of an exposure pathway to the overall dose depends on the radionuclides involved, the habit data, the time spent at a location 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 them are evaluated to be non-existent or negligible. The decision to exclude particular exposure pathways from consideration should be justified.

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

Identification of the representative person for normal operation

5.32. The dose to the representative person[23] should be calculated using characteristics selected from a group of individuals representative of those more highly exposed in the population. ICRP Publication 101 [44] gives guidance on the characteristics of the representative person.

5.33. The characteristics of the representative person should be specified by the applicant in accordance with national regulations and in agreement with the regulatory body. For example, the regulatory body may require the use of more detailed and site specific habit data for assessments carried out for certain types of facilities or at later stages in the authorization process.

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[22] This may refer to workers for whom the exposures incurred are not considered occupational exposure, and who then, for the purposes of the radiological environmental impact assessment and control of exposures, are considered as members of the public.

[23] The concept of representative person is defined by ICRP for radiation protection purposes. GSR Part 3 [1] defines the representative person as "an individual receiving a dose that is representative of the doses to the more highly exposed individuals in the population". The representative person is not an actual member of the population but is rather a reference individual defined using dosimetric models and habit data characteristic of those individuals more highly exposed and is used to determine compliance or in prospective assessments. The representative person to be used for the purpose of the assessment and control of exposures due to discharges in normal operation is defined in national legislation or regulations of some States.

5.34. Habit data of the representative person should represent habits typical of the population living in the region where the facility is located or in the State at large. Habit data used in an assessment can be obtained from statistics collected at national, regional or international levels 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 and inhalation rates. Important characteristics when assessing doses to the representative person are the assumed location of the representative person (e.g. their distance and direction from the point of release of radionuclides). It is also important where the representative person obtains food; the fraction of the food consumed that is of local or regional origin; the occupancy times at different locations and the fractions of time spent outdoors and indoors. The location where the representative person lives can be based on an actual person or group of persons, or on a postulated person or group of persons living at a location selected using cautious assumptions (e.g. close to the fence or in a region where the highest deposition of radionuclides in the ground can be expected).

5.35. Account should be taken of factors that reduce the level of exposure where people live, such as the degree of shielding or filtering offered by buildings assumed to be inhabited.

Assessment of the dose to the representative person

5.36. The assessment of radiological impact on the public should be estimated using the individual effective dose to the representative person, which is the sum of the committed effective dose from intakes of radionuclides[24] (i.e. from internal exposure by ingestion and inhalation) and the effective dose from external exposure [1, 3]. Doses from internal exposure are calculated using dose coefficients from intakes of radionuclides by ingestion and inhalation, which provide the committed effective dose 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, 45]. The period of commitment assumed by the ICRP to calculate the dose coefficients presented in Refs [1] and [45] is 50 years for intakes by adults and up to 70 years of age for intakes by children. Standard models exist to calculate the effective dose from external exposure, as well as compilations of dose coefficients [1, 46].

5.37. Dose coefficients for internal exposure are provided for different age groups [1, 45]. If there are factors that may result in a particular age group being more highly exposed, then this age group should be considered in the assessment. The application of different dose coefficients for different age groups should be weighed in relation to the ability to predict concentrations of radionuclides in the environment from a source and the ability to account for uncertainties in habit data for the exposed individuals. Uncertainties in estimates of dose, particularly for prospective calculations, are generally not reduced significantly by increasing the number of age groups for which dose coefficients are provided [44]. The specification of the age groups should be based on the exposure scenarios for the facility and activity at the site under consideration. Generally, calculation of doses for between two and four age groups should be sufficient in most cases (for example, 1 year old infants, 10 year old children, and adults). Exposures of the embryo or fetus and of breast fed infants may need to be considered separately, in particular if discharges of radioiodine are significant.

[24] The committed dose is the lifetime dose expected to result from an intake.

Comparison of estimated doses with dose constraints and dose limits

5.38. For the purposes of comparison with the dose estimations, the government or the regulatory body is required to establish or approve a dose constraint below the dose limit for members of the public [1]. DS432 [7] provides guidance on the definition and use of dose constraints for protection of members of the public in planned exposure situations.

5.39. GSR Part 3 [1] requires an annual effective dose of 1 mSv to be set as a limit for members of the public in planned exposure situations. In special circumstances, a higher value in a single year could apply if the average dose during five consecutive years does not exceed 1 mSv. Dose constraints should be selected to fall within the range of 0.1 to < 1 mSv in a year and could be different for different facilities and activities or exposure scenarios [7]. The government or the regulatory body may define a generic value for the dose constraint for certain types of facility or activity and a specific dose constraint (above or below the generic constraint) for a particular case [9].

5.40. Because dose constraints refer to a single source, the regulatory body, when setting the specific dose constraint for a facility or activity, should take account of the possible contribution to the dose to the representative person from other facilities or activities located in the vicinity or on the same site.

5.41. As part of a governmental decision making process or at an early stage of an authorization process, a generic value of a dose constraint for different types of facility or activity (i.e. for nuclear fuel cycle facilities) [7, 9] could be used for comparison with the results of the initial radiological environmental impact assessment. Later, the results of the radiological environmental impact assessment should be compared with the specific dose constraint for the facility or activity under consideration, as defined by the regulatory body.

5.42. When considering transboundary impacts, the criteria used for the assessment of the level of protection in other States should be in line with the criteria set out in this Safety Guide and, should be the same as those used for the State where the facility or activity is located.

ASSESSMENT FOR PROTECTION OF THE PUBLIC AGAINST POTENTIAL EXPOSURES

5.43. Facilities and activities are designed, constructed, commissioned, operated or conducted, maintained and decommissioned, and are regulated throughout all these stages, in order to prevent accidents and mitigate their consequences, and, thereby, to avoid or minimize the risk of significant radiological consequences for the public, such as deterministic effects and increases in stochastic effects, and adverse effects on the environment and on property [1, 2, 47, 48].

5.44. As part of the safety assessments required to be carried out for facilities and activities [1, 5], various types of accidents are postulated in order to identify engineered safety features and operational actions to reduce their likelihood and, if an accident does occur, to mitigate its consequences. These safety assessments enable analysis of whether adequate defence in depth has been achieved and give insights into the probability of various accidents and the potential source terms (if any) for such accident scenarios, taking into account the safety measures in place and their effectiveness. In order to assess prospectively the potential exposures of members of the public, as required in GSR Part 3 [1], SF-1 [2], and Safety of Nuclear Power

Plants: Design, IAEA Safety Standards Series No. SSR-2/1 (Rev.1) [47], those accident scenarios, with the probability of such accidents occurring, should be considered.

Approach to the assessment

5.45. The prospective assessment of potential exposures should use estimations of doses to members of the public resulting from postulated accidents identified through safety analysis, or should determine a measure of the risk of health effects[25] based on the estimation of such doses. The elements of such an assessment are summarized in Fig. 3[26]. In general terms, the first phase should be to identify the potential exposure scenarios[27], on the basis of the safety assessment. Next, the related source term for each accident scenario, including quantities and relevant physical and chemical characteristics of the releases that will determine the behaviour of the radionuclides released in the environment, should be considered as the input to the environmental dispersion and transfer models. The environmental dispersion and transfer should then be estimated with relevant models, considering the defined environmental conditions, on the basis of meteorological and hydrological information. The relevant exposure pathways and the representative person should then be identified. Finally, the estimated dose, or a measure of the risk of health effects based on the estimated dose, should be derived and compared with the applicable established criteria.

Identification and selection of potential exposure scenarios

5.46. For facilities or activities having by design a very small number of engineered safety features, the identification and selection of potential exposure scenarios generally involves the consideration of frequently observed accidents, such as typical industrial accidents or similar events such as fires and accidental spillages.

5.47. For facilities having many engineered safety features, for which complex analysis is necessary to determine the likelihood and the characteristics of events that may lead to potential exposures, a greater number of accident scenarios may need to be considered and analysed in detail. For such facilities, complex safety assessment techniques may be necessary, combining deterministic and probabilistic methods and, in some cases, expert judgement.

[25] The concept of a measure of the risk of health effects due to exposure to radiation resulting from postulated accidents is explained in more detail in Annex II.

[26] The figure is not intended as a detailed step by step procedure and is presented to illustrate the elements of the assessment and facilitate its description.

[27] For the purposes of this Safety Guide, the expression ‘potential exposure scenarios’ is used to include the characteristics of all the events or sequences of events that may lead to an accident, including their source term characteristics and, when applicable, their frequency of occurrence or probability.

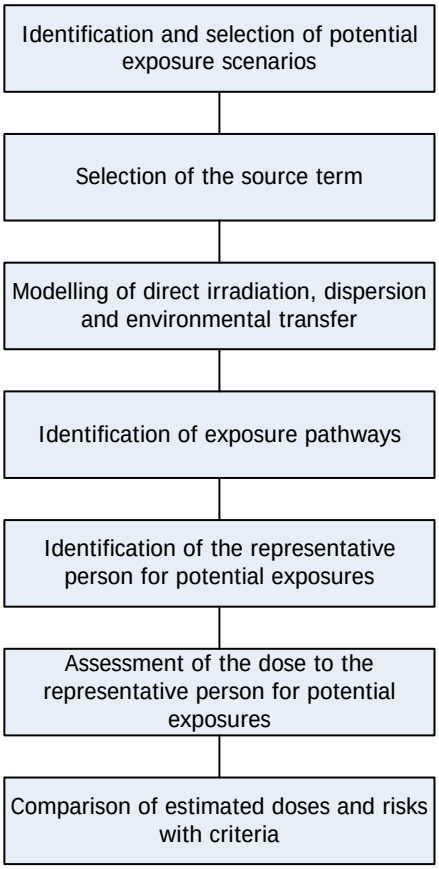

FIG. 3. Components of an assessment for consideration of potential exposures.

Selection of the source term

5.48. The types and amounts of radionuclides and the physical and chemical characteristics of the radionuclides released in an accident may differ considerably from those discharged in normal operation. The characteristic source term for an accident[28] should be estimated in consideration of the events or sequence of events leading to the accident and the safety measures in the facility or activity aimed at limiting the magnitude of the source term.

5.49. For facilities or activities having reduced inventories and small number of engineered safety features, such as hospitals using radioisotopes in medicine, small research laboratories and applications with radioactive sources in the industry, the listing accidents, as described in para. 5.46, should be combined with conservative or simple safety analysis techniques to determine the associated source terms.

[28] Characteristic accident source terms are those that can be considered to be a comprehensive representation of the characteristics of the specific facility or activity under accident conditions. The accident source terms identified as characteristic of the facility or activity can be divided into different categories in accordance with their annual frequency or likelihood of occurrence and their magnitude. Characteristic accident source terms do not necessarily include the worst case scenario, which is typically a very cautious assumption involving estimations of unrealistic potential consequences. For further information see Annex II.

5.50. For nuclear facilities that have large inventories of radioactive material and complex engineered safety features and where the physical, chemical or nuclear characteristics of the radionuclides at the facility may lead to a large release in the event of an accident, detailed safety analysis techniques should always be applied to estimate more realistic potential source terms. Further guidance on estimation of the source term in the event of an accident can be found in Refs [49] and [50].

5.51. In estimating the source term, consideration should be given to the physical and chemical processes occurring during the accident sequence, the behaviour of any safety features or the effects of any mitigatory measures, and the behaviour of radionuclides within the facility before it is released to the environment. A time profile for the release should be provided if necessary. For example, in accidents at a nuclear power plant, initially noble gas radionuclides may be released to the atmosphere, followed then by volatile radioactive material and subsequently by other radioactive material in aerosol or particulate form. The time profile for the release may be developed by separating the source term into different time phases.

5.52. In general, the source term should include the composition and amounts of radionuclides, the physical form (i.e. gas or aerosol) and chemical form, the release point and its height (for an atmospheric release) or depth below surface (for an aquatic release). The flow speed and the thermal energy associated with the release may be also necessary to determine the effective height of the radioactive plume.

Modelling of direct irradiation, dispersion and environmental transfer

5.53. An accident at a facility or an activity could result in a loss of shielding or inadequate shielding and, in some cases, significant external exposure of people living in the close vicinity of the premises. In general, large facilities are situated at some considerable distance from residential areas and therefore the probability that members of the public are exposed to direct irradiation, even in the event of an accident, is low. On the other hand, facilities such as hospitals or small industrial estates tend to be closer to residential areas, or can be occupied by members of the public transitorily, although the radiation sources located in such facilities are smaller. The contribution of direct irradiation to potential exposures of members of the public due to accident scenarios at all relevant facilities should be considered and analysed using models for assessment of external exposure.

5.54. For facilities and activities for which simple conservative radiological impact assessments are warranted, cautious assumptions about the meteorological and hydrological conditions should be made to be used as input to dispersion models. For example, a uniform wind direction for atmospheric dispersion, low atmospheric dilution conditions and precipitation by raining at the time of the postulated accident may be assumed. Such assumptions would give conservative results and avoid the need to obtain site specific data. However, assumptions that are considered conservative for a particular exposure pathway may not be conservative for other exposure pathways (e.g. for inhalation it might be assumed that all the release from the facility or activity goes to the atmosphere and no radionuclides are released to aquatic media; however, this assumption may not be conservative for pathways such as ingestion of food, if the food is produced using irrigation). When different pathways are involved, it might not be so easy to identify a priori the most cautious assumption and a careful compromise should be evaluated.

5.55. If the estimated doses or risks are above the selected criteria because of the use of assumptions in which the dose is largely overestimated, the assessment should be refined using, whenever possible, more realistic models and data. For example, the applicable meteorological, hydrological and other parameters should be based on local measurements or surveys to reduce the level of uncertainty. The use of meteorological and hydrological data in environmental models is described in more detail in paras 5.18 to 5.25.

5.56. For nuclear facilities or activities for which complex, realistic assessments are warranted, meteorological and hydrological data collected locally, over at least 3 to 10 years, should be used to specify characteristic accident dispersion conditions [41, 43]. Site specific meteorological and hydrological data for nuclear facilities are generally collected during the site evaluation stage; detailed guidance on the type and characteristics of these data is provided in NS-G-3.2 [43]. Meteorological and hydrological data may also be collected to be used for a prospective assessment of exposures during normal operation. However this information may not be sufficiently comprehensive to be used for accident analysis; for instance, data on the long range transport of radionuclides in the atmosphere or in aquatic media may be missing or may be available only in the form of monthly records. In this case, more detailed data, such as hourly data if necessary, should be obtained from relevant regional records or meteorological centres. Data could also be derived from dynamic numerical atmospheric or aquatic prediction models.

5.57. For nuclear facilities and other facilities necessitating a complex assessment, in order to reduce the calculation efforts, the time of occurrence of the accident could be selected by means of statistical sampling techniques, such as cyclic sampling or stratified sampling. Alternatively, an assessment should be performed by using a comprehensive set of hourly meteorological data over a full year; in any case, the resulting selected dispersion conditions should be associated with a frequency of occurrence or a probability. For facilities necessitating simpler assessments, a particular time or a small set of times for the occurrence of the release should be selected; care should be taken that the meteorological data for the selected time are conservative for the site under consideration.

5.58. Environmental transfer models should be suitable for taking account of non-equilibrium conditions usually associated with accidental releases from facilities and activities. In addition, there can also be significant short-term variations in the source term and in the assumed meteorological conditions. If there is potential for a large release, models to estimate the transfer and the dispersion of radionuclides in the environment at longer distances should be used. Applicable dispersion models for short-term releases and the long range transport of radionuclides should be used when necessary to estimate the dispersion and distribution of radionuclides in the environment.

Identification of exposure pathways

5.59. The exposure pathways that are major contributors to the dose from accidental releases may be very different from those for normal operation. For example, consumption of fresh milk or vegetables immediately following an accident at a nuclear power plant could be an important pathway for exposures due to short lived iodine radionuclides. Care should therefore be taken to adequately identify and represent by models the relevant exposure pathways.

5.60. A list of possible exposure pathways relevant for estimation of potential exposures that should be considered in the assessment is given in the following:

(a) External exposure due to deposition of radionuclides on the skin;

(b) External exposure due to direct irradiation from the source;

(c) External exposure due to direct irradiation from the atmospheric plume (cloud shine);

(d) External exposure due to deposition on the ground (ground shine) or other surfaces;

(e) Inhalation of radionuclides from the atmospheric plume;

(f) Inhalation of resuspended material from deposits;

(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 contaminated food and water.

5.61. Depending on the assumptions adopted for the assessment of the accident scenarios, the exposure due to ingestion of contaminated food may be reduced or averted by the prompt implementation of protective actions. Estimated doses from other exposure pathways, such as inhalation and external exposure, can also be significantly reduced if emergency protective actions such as sheltering, evacuation and provision of iodine thyroid blocking, are assumed to be implemented. For example, the shielding and filtering provided by dwellings can greatly reduce doses to people who are sheltering during an accident. The exposure pathways, the shielding factors and the assumptions of protective actions should be clearly indicated and properly justified in the assessment, in agreement with the actual off-site protective actions planned to be taken for the facility or activity under consideration.

Identification of the representative person for potential exposures

5.62. On the basis of data from actual or hypothetical individuals likely to be most highly exposed in an accident, a representative person[29] should be identified for the assessment of doses and risks associated with potential exposures. The representative person identified for potential exposures may be different from the representative person for exposures in normal operation.

5.63. Different exposed population groups may be identified, depending on the characteristics of the accident or event and the time of day or time of year of the postulated release, in accordance with, for instance, the prevailing meteorological or hydrological conditions, possible temporary occupancy (e.g. different occupancy during day and night, existence of summer campsites and schools, presence of workers near the facility) and seasonal variations in habits and in consumption of food products. An alternative approach may be to consider average occupancy factors, and habits and food products for each season.

5.64. The end points[30] of the assessment of the potential exposures could differ, depending on the type of the assessment and the criteria specified. For instance, instead of specification of the dose to the representative person as an end point, the dose at a specific location (e.g. the

[29] The ICRP uses the term ‘representative person’ for the consideration of both normal discharges and accidental releases [44]. Despite the use of the same term and the applicability of the general definition to both situations, the particular characteristics of the representative person in each case, such as their location, habits and age group, may be different.

[30] The IAEA Safety Glossary [4] defines ‘end point’ as a radiological or other measure of protection or safety that is the calculated result of an analysis or assessment. Common end points include estimates of dose or risk and predicted environmental concentrations of radionuclides.

nearest town in the region), at a fixed distance (e.g. 1 km, 5 km or 10 km) or a distance where a certain relevant projected dose is exceeded (for example, 100 mSv in the first 7 days, if such value is the threshold reference level for protective measures [8]) could be used as an end point. In some States, the distribution of doses or risks among larger affected populations is used as an end point. Although there is flexibility in the ways that potential exposures are considered, and different States adopt different approaches, the use of particular end points and criteria should be clearly defined and justified in the relevant regulations or in the assessment, to avoid misunderstanding and misinterpretation of the results.

Assessment of the dose to the representative person for potential exposures

5.65. When considering potential exposures, the mean absorbed dose to the organ or tissue, weighted by an appropriate relative biological effectiveness for the biological end point of concern should be calculated for doses in the range of deterministic effects. For doses in the range of stochastic effects, the effective dose resulting from the sum of the committed effective dose from internal exposure pathways and the effective dose from external exposure should be calculated. The equivalent dose to certain organs (e.g. thyroid) can also be used for consideration of potential exposures.

5.66. Doses should be calculated for different age groups, owing to the different exposure conditions and the different associated radiation effects for different age groups. Experience has shown that infants receive higher doses via some exposure pathways, such as exposure of the thyroid gland due to the intake of radioactive iodine, which could potentially be released in a nuclear reactor accident [51].

5.67. The relevant time periods over which exposures could occur and the relevant exposure pathways to be used in the assessment should be defined. For example, estimated doses due to inhalation of the radioactive plume in the first 24 hours following an accident or estimated doses due to the ingestion of green vegetables over the initial three month period could be used as indicators of the main potential radiological impact. In other cases, doses over longer periods could be estimated; for instance, from the time of an accident to one year afterwards. When comparing the estimated doses with criteria, the time periods and exposure pathways considered in the assessment should be clearly indicated.

Comparison of estimated doses and risks with criteria

5.68. GSR Part 3 [1] states that the likelihood and magnitude of potential exposures are required to be assessed and that restrictions are required to be established by the regulatory body[31]. For consideration of potential exposures that uses as an end point a dose or a measure of the risk of health effects, the restrictions established by the regulatory body should be a reference dose criterion or risk criterion, as relevant.

5.69. For facilities and activities necessitating a simple assessment based on a conservatively defined potential exposure scenarios (e.g. facilities with small inventories of radioactive material and sources with a low capacity for a radioactive release in an accident), for consideration of potential exposures the dose on the representative person due to

[31] Paragraph 3.15 of GSR Part 3 [1] additionally states that the number of individuals who may be affected by potential exposures is required to be assessed; however, the scope of this Safety Guide is limited to effects on individuals.

characteristic accidents is normally estimated, and doses of 1 to a few mSv, typically 5 mSv should be used as the decision criteria.

5.70. The dose which is estimated to the representative person, combined with the probability determined in the specification of the source term and with probability determined by the characteristics of environmental transfer (e.g. by the fraction of the time during the year that the winds blow toward the location of the representative person), can be converted into an indication of the risk of health effects by means of risk coefficients provided by, for example, the ICRP [52]. The use of an indication of the risk of health effects should be applied in accordance with national practices and regulations. Such indications of the risk of health effects should be used only in the framework of a prospective radiological environmental impact assessment as described in this Safety Guide and not for attributing health effects for individuals Annex II provides more information about risk estimation.

5.71. The government or the regulatory body is required to establish or approve constraints on risk [1], as appropriate, for the consideration of potential exposures. Risk constraints could be established on the basis of recommendations by INSAG [53] or ICRP [3, 52]. Guidance for establishing risk criteria for consideration of potential exposures is provided in the Appendix. Further information on the definition of a measure of the risk and the use of risk constraints are provided in Annex II and guidance is provided in DS432 [7].

5.72. When an assessment of potential exposures for a nuclear facility is performed, which makes use of defined characteristic accident scenarios, the dose corresponding to a reduced set of accidents is normally estimated. In this case, the criteria for deciding whether the risk of potential exposures is acceptable should be defined in terms of dose (e.g. a dose in the range 10 – 100 mSv could be used, because these are values that trigger the implementation of certain protective actions [8]). Different values for the dose criteria could be defined within that range, depending on the different annual frequencies of those characteristic accident scenarios: for accidents with estimated higher frequencies the dose criteria should be lower than for accidents with very low frequency. Although the end points and the criteria for this type of assessment are stated in terms of doses, owing to the fact that frequencies of accidents are involved in setting the criteria, there is an implicit notion of risk and the results can be related to the criteria set out in the Appendix.

5.73. Nuclear facilities having numerous engineered safety features may also use complex safety assessment techniques combining deterministic and probabilistic methods and expert judgement to assess the likelihood and magnitude of the doses to the representative person, which can be converted in an indication of risk and compared to a risk criterion. The criteria described in the Appendix should be considered by the regulatory body in order to define the relevant risk criteria for this approach. Annex II describe the basic aspects of these types of assessment of potential exposures.

5.74. Another option may be to express the criteria qualitatively, in terms of whether a certain consequence to the public would be unacceptable. For instance, a criterion could be that very disruptive protective actions, such as a large and prolonged evacuation or relocation, as a result of a potential accident scenario specified for the facility or activity would not be

acceptable[32]. Although this is in principle a qualitative criterion, the need for such protective actions should be determined using estimations of projected doses (or related operational quantities) and by comparing these estimations against emergency response decision criteria, for instance the reference levels provided in GSG-2 [8]. If this approach is used, the regulatory body should define the decision criteria for the implementation of protective actions to be used for the assessment of the potential exposures in line with the requirements established in GSR Part 7 [6].

5.75. When considering transboundary impacts, the criteria used for the consideration of potential exposures in other States should be in line with the criteria set out in this Safety Guide and, in principle, should be the same used in the State where the facility or activity is located.

CONSIDERATIONS RELATING TO THE ASSESSMENT OF THE PROTECTION OF THE ENVIRONMENT

5.76. The high level aim of protection of the environment set by the ICRP is to provide for the maintenance of biological diversity and to ensure the conservation of species and the health of natural habitats, communities and ecosystems [3, 54]. SF-1 acknowledges that "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)" [2]. Considerations for protection of the environment may differ between States and should be subject to the regulations and guidelines of the national competent authorities, including regulatory bodies.

5.77. Paragraphs 1.6 to 1.19 in the introduction of GSR Part 3 [1] describe the system of protection and safety, which aims to assess, manage and control exposure to radiation for humans, and which generally provides for appropriate protection of the environment from harmful effects of ionizing radiation. Paragraphs 1.32 to 1.35 in the introduction of GSR Part 3 [1] on protection of the environment acknowledge that some national regulations require the explicit demonstration (rather than the assumption) of the protection of the environment. Paragraph 1.34 of GSR Part 3 [1] also notes that "the assessment of impacts on the environment needs to be viewed in an integrated manner with other features of the system of protection and safety" and that "the approach to the protection of people and protection of the environment is not limited to the prevention of radiological effects on humans and on other species".

5.78. Some States, on the basis of experience or simplified analysis, may consider that specific assessment of effects in the environment is not necessary. In these cases, the regulatory body may decide that the radiological environmental impact assessment does not need to include explicit consideration of exposures of flora and fauna.

5.79. Other States may consider that it is necessary to include in the radiological environmental impacts assessments for certain facilities and activities the estimation and control of exposures of flora and fauna. In any case, the requirement of the graded approach

[32] This is consistent with the safety objective for accidents with significant off-site consequences, for which only protective actions that are limited in terms of lengths of time and areas of application would be acceptable and that off-site contamination would be avoided or minimized [47].

[1] should be applied to ensure that the effort spent in performing the assessment is commensurate to the expected level of risk.

5.80. Given that the radiation risk to populations of flora and fauna from normal operation of facilities and conduct of activities is expected to be low, the methods used for the assessment of the impact on flora and fauna should be practical and simple, based on the scientific knowledge of radiation effects, and should not impose an unnecessary burden on the operator or the regulatory body. The ICRP [54, 55] provides a practical approach to assessing and managing the effects on flora and fauna due to radioactive releases to the environment.

5.81. For national or international frameworks in which the explicit consideration of the protection of flora and fauna is required[33], Annex I of this Safety Guide presents an example of a methodology for assessing the impact on flora and fauna in normal operation[34], based on the ICRP approach for protection of different ecosystems in the environment [54, 55].

[33] For example, the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (see: http://www.imo.org/OurWork/Environment/LCLP/Pages/default.aspx) requires the explicit assessment of the radiological impact on marine flora and fauna resulting from the dumping of materials containing radionuclides. The IAEA has developed a radiological assessment procedure for this purpose [56].

[34] Potential exposures of flora and fauna are not taken into account, since those are not amenable to regulatory control under accident conditions.

6. CONSIDERATIONS ON VARIABILITY AND UNCERTAINTY IN RADIOLOGICAL ENVIRONMENTAL IMPACT ASSESSMENTS

6.1. Uncertainty reflects the state of knowledge about the system being investigated and relates to how accurately the doses or the risk can be estimated. The main sources of uncertainty in a radiological environmental impact assessment arise from the incomplete knowledge of the conditions of exposure of the representative person and from the variability of model parameters. The latter includes both variations in the processes of transport of radionuclides due to atmospheric and aquatic dispersion and in the transfer of radionuclides between the different environmental compartments and, for the case of humans, variations in the location and living habits among individuals within a group (e.g. food intake and time spent at different locations). Other sources of uncertainty may be in the source term and in demography. When defining the methodology, including the decision criteria, the regulatory body or the applicant should consider aspects relating to variability and uncertainty, as appropriate.

6.2. The level of uncertainty in a prospective radiological environmental impact assessment should still allow for a conclusion to be drawn on whether the actual doses to members of the public would or would not exceed the dose limits or dose constraints set by the national regulatory body. When insufficient information or data are available, conservative assumptions should be used [44]. However, use of a large number of conservative assumptions can result in unrealistic overestimation of doses and this should be avoided [44].

6.3. The ICRP discusses in its Publication 101 [44] the characteristics of an approach using "reasonable conservative and plausible assumptions" to estimate doses to members of the public, using single values for parameters and habit data relevant for dose assessment. For these assessments, in some cases high percentiles in the distribution of the habit data could be used (e.g. the 95^{th} percentile), although it is not reasonable to assume high percentile habit data for all exposure routes. As a default or for an initial assessment, single recommended values for environmental transfer parameters can be taken from the available literature [10 - 12] or average measured values, when available, could be used. The dose resulting when applying this reasonable conservative approach should be compared directly to the radiological criteria.

6.4. Another approach described in ICRP Publication 101 [44] is the use of frequency distributions of the model parameters combined with statistical methods, such as the Monte Carlo method, as input for the dose assessment, which will then result in a distribution of the estimated dose. For assessments in which a distribution of the habit data is to be used, the approach should involve comparing a high percentile of the resulting distribution of dose (e.g. the 95^{th} percentile) with the dose criteria established by the regulatory body. In cases where there is a lack of data about the variability of transfer parameters, the use of frequency distributions should not be applied systematically as such use does not always lead to conservative results.

6.5. The existence of variability and uncertainty in a radiological environmental impact assessment should not necessarily imply the need for very complex and sometimes inconclusive studies. The applicant and the regulatory body should be aware of the limitations of the results of this type of assessment and should proceed with reasonable caution when selecting the models and parameters and when drawing conclusions from the results, as necessary, particularly when the results are very close to the decision criteria.

6.6. Programmes for source monitoring and environmental monitoring are required to be established once the facility is operating or the activity is being conducted [1]. Such programmes are necessary to check whether the discharges comply with the authorized limits and whether the models and data used are adequate and contribute to reducing the uncertainties in the radiological environmental impact assessments. Guidance on environmental monitoring and source monitoring programmes for purposes of radiation protection is presented in RS-G-1.8 [18]

6.7. Sensitivity studies should be carried to identify the most important sources of uncertainty and the processes contributing most to the uncertainty. On this basis, further research, modelling, or collection of experimental data may be carried out, if the reduction of the level of uncertainty is deemed necessary.

6.8. Addressing variability and uncertainty in the assessment of potential exposures is more complex. Reasons for this include the following:

(a) The scenarios selected for the assessment, including the source terms and environmental conditions at the time of the accident, may not be representative of what might actually happen.

(b) The probability or frequency of the accident scenarios assumed in the assessment can be highly uncertain. Conservative deterministic analysis seeks to avoid the issue by assuming certain bounding representative initiating events and system failures. If, for example, probabilistic safety analysis techniques are used to estimate accident frequencies, these frequencies are determined by combining many events and/or failure probabilities, each with its own uncertainty.

(c) Unlike the estimations of exposures resulting from discharges in normal operation, which usually occur more or less continuously and can be averaged over a year in order to smooth out fluctuations, potential exposures will usually be variable in time and the impact will be dependent on the actual exposure conditions at the time of the accident (e.g. the meteorological conditions and the location of members of the public).

(d) Unlike the estimations of exposures resulting from discharges in normal operation, which can be validated retrospectively by means of the environmental monitoring programmes established at the operational stage, this is not possible for potential exposures.

6.9. The uncertainties should be taken into account in the definition and use of the criteria to make decisions on the acceptability of the potential exposures from a facility or an activity. The criteria used for potential exposures should be expressed preferably in ranges or as orders of magnitude (see the Appendix).

APPENDIX.
RISK CRITERIA FOR THE ASSESSMENT OF POTENTIAL EXPOSURE OF THE PUBLIC

I.1. This Appendix presents criteria established by relevant international organizations, which should be used by the regulatory body as guidance for defining national criteria. The criteria set out in this Appendix are for the risk of health effects to individual members of the public. Other types of effects of accidents with large releases to the environment, such as social, economic and environmental effects, are out of the scope of this Safety Guide. Further considerations and information on definitions of risk and assessment of potential exposures presented in Annex II.

INTERNATIONAL NUCLEAR SAFETY ADVISORY GROUP

I.2. The International Nuclear Safety Advisory Group (INSAG), in 1995, considered safety goals for potential exposure [53]. Reference [53] states that 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 also states that "It seems reasonable to expect that accidents that require simple, local countermeasures should have an annual probability of not more than about 10^{-4}." These types of accidents are expected to deliver doses to most highly exposed members of the public in the range of 10 to 100 mSv. For more severe accidents that may deliver a dose to most highly exposed members of the public of 1 Sv, Ref. [53] states that "An annual probability of such an accident of 10^{-5} is likely to be required because of the societal consequences."

I.3. INSAG, in 1999, also provided risk targets for nuclear power plants [57]. It recommends that the frequency of occurrence of severe core damage should be less than 10^{-4} events per plant operating year for existing nuclear power plants, and suggests that application of all safety principles could lead to an improved goal of not more than 10^{-5} events per year for new nuclear power plants. It also indicates that severe accident management measures and mitigatory measures should reduce by a factor of at least ten the probability of large off-site radioactive releases requiring off-site response in the short term. Reference [53] states that these targets 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 plants and 10^{-6} for new plants.

INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION

I.4. The ICRP recommends that for the assessment of potential exposures, the risk constraints related to a source should be of the same order of magnitude as the health risk implied by the dose constraints for the same source (ICRP Publication 103, published in 2007 [3]). ICRP Publication 64, published in 1993 [52] states that "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.5. ICRP Publication 64 [52] provides a range of probabilities in a year that may be used to

define risk constraints; the maximum probability of a severe accident with some deterministic consequences or for the occurrence of severe health effects should range from 10^{-6} to 10^{-5} per year. The complete scheme is reproduced in Table 2 below. For complex systems, similar sequences of events should be grouped by combining their probabilities and taking the worst consequence from any individual sequence to represent the group as a whole. Reference [52] states that the values in Table 2 are intended to illustrate the types of constraint that might be imposed based on past experience, with account taken of the benefits derived from the particular practice. It adds that the values in Table 2 might also be imposed as tentative constraints in the absence of operating experience, but subject to revision as experience is gained, and in such cases the constraints may be regarded as upper bounds. Reference [52] emphasizes that these constraints refer to potential exposure of an individual, rather than a population as a whole.

TABLE 2. RANGE OF PROBABILITIES IN A YEAR FROM WHICH A RISK CONSTRAINT MAY BE SELECTED [52]

Impact	**Probability Range**
Sequences of events treated as normal exposure	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	$< 10^{-6}$

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ANNEX I.
EXAMPLE OF A GENERIC METHODOLOGY FOR ASSESSING EXPOSURES OF FLORA AND FAUNA IN NORMAL OPERATION OF FACILITIES AND ACTIVITIES

I-1. This annex presents as an example a generic methodology for assessing and controlling the radiation exposure of flora and fauna due to discharges during normal operation of facilities and conduct of activities. The methodology presented here is based on the ICRP approach for protection of the environment [I-1, I-2]; this annex also describes the key aspects of the ICRP approach and the basis for this methodology.

I-2. The need for the explicit assessment of protection of flora and fauna is subject to the national or internationally applicable regulations and depends on the characteristics of the facility or activity and the environmental conditions under consideration. The methodology described in this annex may be used, if deemed necessary, as a complement to the assessment of exposures of humans, described in Section 5 of this Safety Guide, within a prospective radiological environmental impact assessment.

I-3. Often, for activities or facilities necessitating a simple radiological environmental impact assessment, the explicit consideration of exposures of flora and fauna is deemed not to be necessary, on the basis that a significant radiological impact on the environment having effects on populations of flora and fauna is not expected, owing to, for example, the limited radionuclides inventory in the facility or the intrinsically safe characteristics of the facility or activity.

I-4. For facilities and activities for which a more complex radiological environmental impact assessment is required, for example for nuclear installations and for uranium mining and processing, the explicit consideration of the radiation exposure of flora and fauna may be deemed necessary by the government or the regulatory body, depending on national or internationally applicable regulations. In these cases, the ICRP approach to assessing and controlling the effects of radiation on flora and fauna [I-1, I-2] can be used, which is consistent and compatible with similar approaches used in some States [I-3 – I-5]. The ICRP approach uses the concepts of ‘reference animals and plants’, a ‘representative organism’ and criteria in the form of ‘derived consideration reference levels’. These concepts and criteria are described below.

I-5. The methodology presented in this annex is of a generic character. For most facilities and activities in normal operation and for most environmental conditions, a generic assessment as described in this annex would be sufficient to demonstrate the level of radiation protection of flora and fauna. However, a generic approach may not be appropriate for the assessment of the impact on flora and fauna in particular circumstances, for example when dealing with protected species or endangered species. For these cases, a more specific assessment may be required.

I-6. The regulatory body or other competent authority could identify such specific environmental situations that warrant special consideration, different from those more generic situations as presented in this annex. The assumptions and types of assessment for situations necessitating special consideration should be determined in agreement with the applicant, the regulatory body and other authorities with responsibilities for environmental protection. In any case, the methods described in this annex could be used as a screening tool for those particular circumstances.

KEY ASPECTS OF THE ICRP APPROACH FOR PROTECTION OF THE ENVIRONMENT

I-7. The ICRP recommends that the aims of environmental protection should be 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 [I-1, I-2, I-6]. This is in line with the Fundamental Safety Principles [I-7], in which para 3.28 states "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)".

I-8. Owing to the complexity of the interactions between different species, it is very difficult to model and predict radiological effects on ecosystems exposed to very low increments of the levels of radiation in the environment. However, conclusions in respect of the radiological impacts on populations of species and ecosystems, which can be applied prospectively for managing radioactive sources in planned exposure situations, could be extrapolated from the assessment of the exposures of a reduced number of individual organisms of a species, used as reference organisms [I-6].

I-9. For this purpose, the ICRP identified species that can be considered to be representative of marine, terrestrial and freshwater ecosystems[35] and have a wide geographical variation [I-1]. These species are called the 'reference animals and plants'[36]. In selecting these species, ICRP used a pragmatic approach (e.g. the existence of sufficient information on the species to be used as reference animals and plants) and also considered which species would be more affected by exposure to radiation present in environmental media [I-1]. The ICRP approach for protection of flora and fauna considers effects of radiation at an individual level that could have an impact on the structure of the population of a species (e.g. early mortality, some forms of morbidity, effects on reproduction, induction of chromosomal damage) [I-1, I-2].

I-10. The ICRP defined criteria for assessing and managing the radiological impact on flora and fauna in the form of 'derived consideration reference levels' [I-1]. Derived consideration reference levels are a set of dose rate bands[37] within which there is either no evidence (for most of the reference animals and plants) or only some evidence of deleterious effects of ionizing radiation on individuals of the species which may have implications for the structure of the population. Detectable effects in some single individuals of a population would not

[35] With regard to the need for reference models to represent typical farm animals for the purpose of their protection, primarily large mammals that live essentially in a human environment, the ICRP considered that the use of an assessment of the radiological impact on humans was sufficient for such managed environmental or ecological situations [I-1].

[36] A reference animal or plant is 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-1, I-2].

[37] The combination of radiation weighting factors with tissue weighting factors for estimating effective doses to humans expressed in Sv is not applied in assessing the risk of effects due to exposure of biota; the key quantity used for the assessment of the effects of exposure 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) and depends on the amount and type of radiation [I-1]. Owing to the consideration of different species of flora and fauna, with different life spans, it is convenient to express the criteria in terms of a dose rate, in Gy/d or its subunits, for instance mGy/d [I-1, I-8].

necessarily have consequences for the population as a whole [I-1]. For very low increments of doses at the local level, such as those resulting from the normal operation of facilities and activities, impacts at the level of population can hardly be observed [I-1]. Derived consideration reference levels span one order of magnitude; for dose rates below the lower level of the bands, no effects have been observed or no information on effects is available [I-1, I-2].

I-11. Derived consideration reference levels do not represent limits; rather, they should be considered as points of reference for informing the appropriate level of effort that should be expended on environmental protection, dependent on the overall management objectives, the actual fauna and flora present, and the numbers of individuals thus exposed [I-2].

I-12. The ICRP also introduced in Publication 124 the concept of 'representative organism' which is equivalent to the concept of representative person used in assessments of radiological effects for humans [I-2]. The representative organism is a particular species or group of organisms selected for use in a radiological environmental impact assessment for a specific facility or activity, taking account of their assumed location with respect to the source of radiation [I-2]. The representative organisms are those representative of the flora and fauna more highly exposed [I-2]. The derived consideration reference levels apply to the representative organisms.

I-13. Because derived consideration reference levels are not limits, when the estimated doses to the representative organisms are within the band or close above the upper boundary of the band, the radiological situation can still be considered acceptable. However, such a result would likely warrant a closer examination of the possible impacts on the environment, which would need to take account of a number of factors. Factors that may be considered when making decisions based on impacts on flora and fauna when the estimated doses are above the upper boundary of the bands include: 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 specific legislation; whether the flora or fauna are considered as a resource, such as for human consumption (for example, as in the case of fisheries management and forest food management); the presence of additional environmental stressors; whether or not the assessment is related to an actual species present in the area or to generalized types of plants and animals; and the degree of precaution considered necessary [I-1].

THE GENERIC METHODOLOGY FOR ASSESSING EXPOSURE OF FLORA AND FAUNA

I-14. For the generic methodology described in this annex, the representative organism is selected directly from the ICRP reference animals and plants relevant for the specific major ecosystem (e.g. terrestrial, marine, freshwater), located in the area where the exposure conditions lead to the highest doses.

I-15. In accordance with the concept of representative organisms, the dose rate to be estimated in the assessment of the impact on populations of flora and fauna would not be the dose rate of the most exposed individual; rather the dose rate would be characteristic of the dose rates received by a group of individual organisms located in the area where the highest exposures may occur.

I-16. The selection of the area where the group of individuals representative of those more highly exposed are located needs to take account of the typical spatial distribution of

radionuclides released into the environment. In general, facilities and activities can be considered as point sources and the highest activity concentrations in environmental media resulting from discharges during normal operation are normally found within the first few kilometres from the source. This typical behaviour of materials released to the atmospheric and aquatic environments from a point source is illustrated in Fig. I-1. The incremented activity concentration in the environment resulting from discharges, indicated with a curve in full in Fig. I-1, decreases significantly with the distance after the location where the highest concentrations are measured. After a certain distance only background activity concentrations can be detected (e.g. activity due to past global fallout, natural radioactivity).

I-17. Owing to the annual distribution of wind directions and, for aquatic dispersion, the directions of the water flows in rivers, lakes and oceans, it is reasonable to assume that the highest activity concentrations would be detected in any direction within a radius of up to 10 km. Therefore, a reference area of approximately 100–400 km^2 located around the release point can be used for generic assessments as described in this annex. The highest environmental activity concentrations due to discharges in normal operation can then be assumed to be found within that area and, consequently, the reference animals and plants within that area would normally receive the highest assumed radiation doses. The size of this recommended reference area is indicative; different sizes can be adopted for certain facilities or activities, different locations and environmental situations to take account of local conditions.

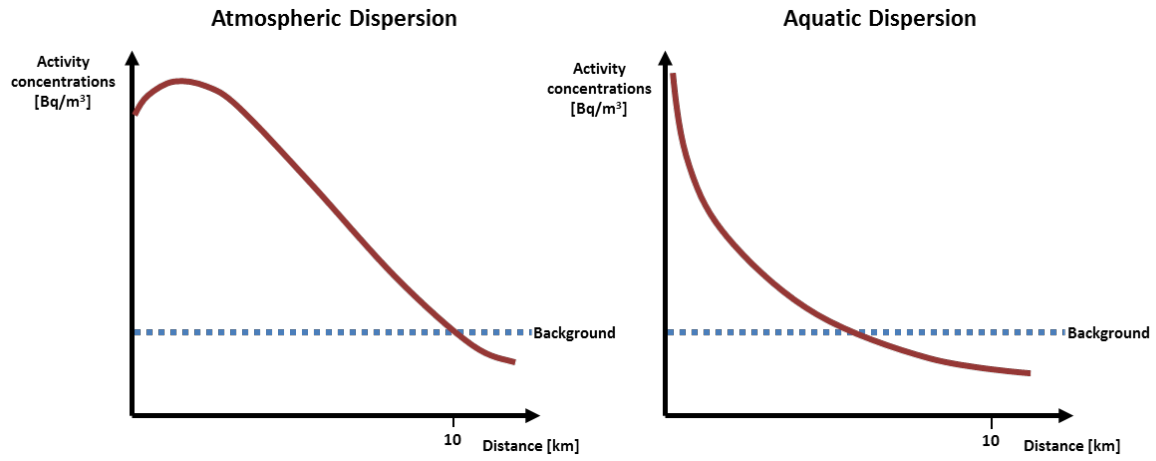

FIG. I-1. Typical patterns of environmental activity concentrations as a result of atmospheric and aquatic dispersion of discharges from facilities and activities in normal operation.

I-18. The reference area around the source as described in para. I-17 is sufficiently large to ensure that mixing of the effluents with the environmental media occurs and that the number of individuals of the species considered in the assessment is suitably large. This ensures that the estimated dose rates calculated in the assessments are representative of the dose rates being received by the fraction of the population more highly exposed, rather than those received by the most exposed individual organism in the population.

ASSESSMENT FOR PROTECTION OF FLORA AND FAUNA IN NORMAL OPERATION

Approach to the assessment

I-19. Figure I-2 summarizes the components of a generic radiological environmental impact assessment for protection of flora and fauna in normal operation[38]. First, using the estimated source term for normal operation and environmental dispersion and transfer models, activity concentrations in a number of environmental media relevant for flora and fauna are estimated; then, combining activity concentrations with dosimetric data as well as information on the times spent in different habitats (e.g. on or above soil, in the water or in aquatic sediments), dose rates from internal and external exposures of reference animals and plants relevant for the ecosystems under consideration are estimated. Finally the resulting dose rates are compared to the derived consideration reference levels.

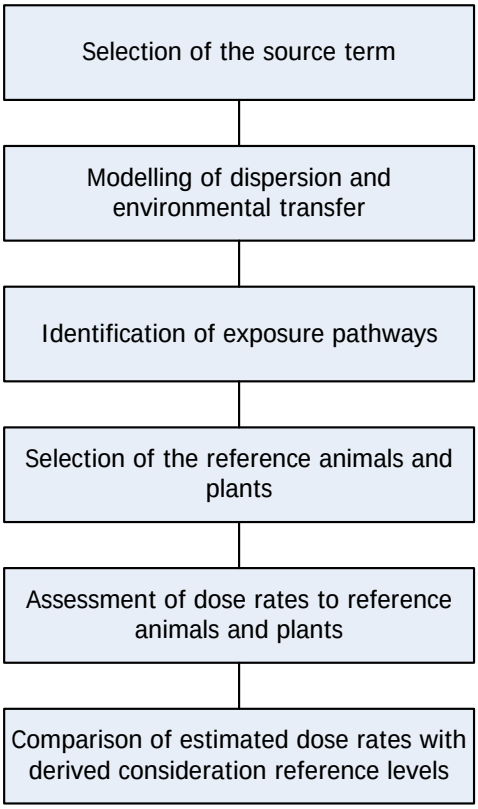

FIG. I-2. Components of a generic assessment for protection of flora and fauna in normal operation.

Selection of the source term and modelling of dispersion and environmental transfer

I-20. The characteristics of the source term and the models to simulate the dispersion and

[38] The figure is not intended as a detailed step by step procedure and is presented to illustrate the elements of the assessment and facilitate its description.

environmental transfer of radionuclides applicable for flora and fauna (the first two boxes in Fig. I-2) would be similar to or the same as those described in the assessment of exposures of humans for normal operation in Section 5 in this Safety Guide, ensuring that the environmental media considered are relevant for estimating exposures of flora and fauna. For instance, the models would need to be suitable for predicting the activity concentrations in the environmental media, such as air, freshwater, seawater, aquatic sediments and soil, and the environmental transfer parameters would need to be relevant for assessment of the exposures of flora and fauna[39]. Reference [I-9] provides models and data for estimating the environmental dispersion[40] of radionuclides. References [I-10] and [I-11] provide transfer parameters for radionuclides applicable for flora and fauna.

Identification of exposure pathways

I-21. The exposure pathways that need to be considered when assessing doses to populations of flora and fauna are:

(a) External exposure due to radioactive material in the atmosphere, water, soil and sediments;

(b) Internal exposure from radioactive material absorbed by plants or ingested or inhaled by animals.

Selection of the reference animals and plants

I-22. The representative organisms in a generic assessment are selected from the types of animals and plants for major ecosystems (terrestrial, freshwater and marine) that are relevant to the location being assessed. These types of animals and plants for the different ecosystems and the related reference animals and plants defined by the ICRP [I-1] are presented in Table I-1[41].

TABLE I-1. TYPES OF ANIMALS AND PLANTS FOR THREE MAJOR ECOSYSTEMS TO BE USED IN GENERIC ASSESSMENTS OF RADIOLOGICAL IMPACT ON FLORA AND FAUNA AND RELEVANT DERIVED CONSIDERATION REFERENCE LEVELS [I-1]

Ecosystem of interest	Type of animal or plant	ICRP reference animals and plants	Derived consideration reference level, mGy/d
Terrestrial	Large plant	Reference pine tree	0.1–1
	Small plant	Reference wild grass	1–10
	Insect	Reference bee	10–100
	Annelid	Reference earthworm	10-100
	Large mammal	Reference deer	0.1–1

[39] The transfer parameters used to estimate exposures of humans due to the ingestion of some biota, such as fish, are different from the transfer factors used to estimate exposures of biota, such as fish themselves. The former consider only the activity concentration in the edible part of the fish, while the latter consider the activity concentration in the full fish, including in the bones.

[40] A revision of Safety Reports Series No. 19 [I-9] is in preparation, and will cover screening assessments of public exposure; generic models and parameters for use in assessing the impact of radioactive discharges; and generic models and parameters for assessing exposures of flora and fauna due to radioactive discharges from facilities and activities.

[41] A different but equivalent set of reference organisms is recommended by the EC ERICA project [I-4].

	Small mammal	Reference rat	0.1–1
	Aquatic bird	Reference duck	0.1–1
Freshwater	Amphibian	Reference frog	1–10
	Fish	Reference trout	1–10
	Seaweed	Reference brown seaweed	1–10
Marine	Crustacean	Reference crab	10–100
	Fish	Reference flatfish	1–10

I-23. In order to assess their exposure conditions, the selected reference animals and plants need to be located in a reference area around the source, normally around the release point, where the highest environmental activity concentrations typically occur. The dose rates characteristic for this group are estimated using, for example, the average activity concentrations within this reference area. Although ecological characteristics may differ, in general, an area surrounding the effluent release point in the order of 100–400 km^2 could be used for most exposure scenarios relating to normal operation of activities or facilities[42].

Assessment of dose rates to reference animals and plants

I-24. Dose rates due to exposure via internal and external pathways are calculated for the selected reference animals and plants located in the reference area around the source, as described in para. I-17. The absorbed dose rate can generally be estimated by using environmental transfer models based on concentration factors from an environmental medium to biota and the corresponding dosimetric factors for internal and external exposures. References [I-10] and [I-11] provide environmental media to biota concentration ratios for different flora and fauna and Ref. [I-1] provides dosimetric factors for the estimation of dose rates to reference animals and plants[43].

Comparison of estimated dose rates with derived consideration reference levels

I-25. In a generic assessment as presented in this annex, if the dose rates to the selected representative animals and plants are below the lower boundary of the relevant derived consideration reference levels, such as those presented in Table I-1[44], the impact on populations of flora and fauna can be considered negligible and the level of protection of flora and fauna can be considered adequate. In the case where the estimated dose rates are within the lower and upper boundary of the bands, the level of protection can still be considered acceptable, but the regulatory body could decide whether additional considerations (i.e. improvement in the level of details of the assessment) or practical mitigatory measures would be needed, bearing in mind that derived consideration reference levels are reference points, not limits. If the resulting dose rates are above the upper boundary of the relevant derived consideration reference level band, the regulatory body would need to decide if more control of the source or further protection efforts need to be considered.

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

[43] The revision in preparation of Ref. [I-9] will provide practical methods for estimating dose rates to representative animals and plants using generic environmental dispersion scenarios and the dosimetric factors set out in Ref. [I-1].

[44] Some States have defined and used different approaches to assessing the radiological impact to flora and fauna, including their own radiological criteria, which are generally compatible with the ICRP approach and derived consideration reference levels [I-3 – I-5].

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ANNEX II.
CONSIDERATION ON THE RISK OF HEALTH EFFECTS AND THE ASSESSMENT OF POTENTIAL EXPOSURES

II-1. The estimation of potential exposures requires the assessment and quantification of the impact of accidents or events that might happen with very low probability. Generally there is a whole spectrum of possible potential exposure scenarios, ranging from those with little or no impact to those with a very high potential impact. A large number of facilities and activities have a potential of only minor or negligible radiological consequences, even under accident scenarios, owing to their very limited inventories of radioactive material or the intrinsically safe characteristics of the facility or activity. In accordance with Principle 7 of the Fundamental Safety Principles on the prevention of accidents, measures have to be taken to ensure that the likelihood of an accident having harmful consequences is extremely low [II-1]. Consequently, facilities are designed and operated and activities are conducted such that accidents with high impact have lower probability than events with minor impact.

II-2. A measure of the risk of health effects due to the unplanned or accidental release of radionuclides to the environment from facilities and activities is a useful indicator to be considered when assessing potential exposures. Control of the risk of health effects due to potential exposures starts at the design stage of facilities and activities by the adoption of provisions for protection and safety (e.g. defence in depth) that are commensurate with the likelihood and the magnitude of the potential exposures [II-2].

PROBABILITY OF HEALTH EFFECTS FOR USE IN PROSPECTIVE ASSESSMENTS

II-3. The estimation of radiation dose to the public resulting from postulated accidents, in terms of the effective doses, combined with a health-risk coefficient, can be interpreted, in the framework of a prospective assessment, as an indication of the risk that detrimental health effects will materialize. In this model it is assumed that the probability of the eventual occurrence of a stochastic effect is proportional to the dose received, with no threshold. A generic risk coefficient for stochastic effects on humans, which can be used in prospective radiological environmental impact assessments, is 5×10^{-2} Sv^{-1} [II-2].

DEFINITION OF A MEASURE OF THE RISK

II-4. The term ‘risk’ is often introduced to express a combination of an impact of an event or scenario and the likelihood of that impact. GSR Part 3 [II-2] defines ‘risk’ as “A 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.” Confusion can arise between this term with a defined meaning and mathematical definition, and the everyday meaning of the word ‘risk’, which is sometimes taken to be synonymous with hazard. Various schemes have been developed to quantify the risk associated with an event or scenario and thus, to allow the risks associated with various events to be directly compared.

II-5. As explained in the Section 5 of this Safety Guide, paras 5.43 to 5.75, when using an approach for assessing prospectively the impact of potential exposures, for each accident scenario, a consequence (e.g. a dose to the representative person) and the associated probability of that consequence is determined.

II-6. For assessment for radiation protection purposes, it could be useful to define a single quantity that gives a measure of the individual risk of health effects[45] [II-3]. Since the consequence of a radiation dose can be expressed as an increased probability of health effects (e.g. death from cancer)[46], an indication of the risk can be obtained by combining the probability p_i of the occurrence of accident scenario i, and the probability of a particular health effect if the accident scenario i occurs C_i, namely

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

such that R_i is the risk of a particular health effect due to potential exposure scenario i.

II-7. If several mutually independent events are to be considered and the probabilities of the events are low, the risks of health effects due to all potential exposure scenarios under consideration could then be summed to give the overall probability of health effects on the representative person:

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

II-8. As described in the previous paragraphs, the risk estimated within a prospective radiological environmental impact assessment as described in this Safety Guide applies for an individual (i.e. the representative person for potential exposures). For large facilities, such as nuclear power plants, which may potentially affect many individuals and which could cause other non-radiological impacts, such as social stress caused by evacuation and restriction of land use of large areas, possible societal risk could also be quantified and assessed against a criterion. The consideration of societal risk is not included in the present guidance and is subject to national approaches.

II-9. Criteria that could be used for the comparison with the estimation of the risk of health effects resulting from potential exposures are presented in the Appendix of this Safety Guide.

BASIC ASPECTS OF THE PROBABILISTIC ASSESSMENT OF POTENTIAL EXPOSURES OF THE PUBLIC

II-10. As described in Section 5 of this Safety Guide, for facilities having many engineered safety features and therefore necessitating complex assessments to determine the likelihood of events and the magnitude of the source terms and the associated consequences, complex safety assessment techniques may be necessary, combining deterministic and probabilistic methods and, in some cases, expert judgement.

II-11. In a probabilistic assessment of potential exposures, frequencies of occurrence of postulated initiating events are estimated and the possible fault sequences or a representative

[45] The definitions of 'risk' presented 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, in the estimation of the possible exposures and in the quantification of the associated radiological consequences.

[46] 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, by 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 take into account not only fatal but also non-fatal cancers in different organs, leukaemia and heritable effects. The details of these considerations are out of the scope of this annex.

sub-set that encompasses the responses of plant and safety systems, including the actions of operators, are determined. The overall probability or frequency of the fault sequence or scenario is calculated by combining the frequency of occurrence of the postulated initiating events with probabilities of each system failure. The use of probabilities and frequencies of occurrence implies a definition of a period of time, which can be selected arbitrarily in order to perform the analysis. A period of one year is usually selected.

II-12. The source term for each sequence is then calculated. In some cases a reduced set of source terms encompassing similar source terms may be used for a set of fault sequences, to reduce the calculation effort required.

II-13. The dose to the representative person for potential exposures is then calculated by using a set of meteorological conditions and other environmental transfer conditions along with the probabilities of these conditions occurring, along with site specific factors that may affect the dose and the probabilities of the particular conditions occurring, such as the probability that the wind is blowing from the source to the target, the probability of other meteorological conditions such as Pasquill stability class, wind speed and rainfall, and the probability that the representative person is outdoors or indoors.

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