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IAEA SAFETY STANDARDS SERIES

Safety Assessment for Near Surface Disposal of Radioactive Waste

SAFETY GUIDE

No. WS-G-1.1

INTERNATIONAL
ATOMIC ENERGY AGENCY
VIENNA

IAEA SAFETY RELATED PUBLICATIONS

IAEA SAFETY STANDARDS

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SAFETY ASSESSMENT FOR NEAR SURFACE DISPOSAL OF RADIOACTIVE WASTE

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The Agency's Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world''.

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FOREWORD

by Mohamed ElBaradei

Director General

One of the statutory functions of the IAEA is to establish or adopt standards of safety for the protection of health, life and property in the development and application of nuclear energy for peaceful purposes, and to provide for the application of these standards to its own operations as well as to assisted operations and, at the request of the parties, to operations under any bilateral or multilateral arrangement, or, at the request of a State, to any of that State's activities in the field of nuclear energy.

The following advisory bodies oversee the development of safety standards: the Advisory Commission on Safety Standards (ACSS); the Nuclear Safety Standards Advisory Committee (NUSSAC); the Radiation Safety Standards Advisory Committee (RASSAC); the Transport Safety Standards Advisory Committee (TRANSSAC); and the Waste Safety Standards Advisory Committee (WASSAC). Member States are widely represented on these committees.

In order to ensure the broadest international consensus, safety standards are also submitted to all Member States for comment before approval by the IAEA Board of Governors (for Safety Fundamentals and Safety Requirements) or, on behalf of the Director General, by the Publications Committee (for Safety Guides).

The IAEA's safety standards are not legally binding on Member States but may be adopted by them, at their own discretion, for use in national regulations in respect of their own activities. The standards are binding on the IAEA for application in relation to its own operations and to operations assisted by the IAEA. Any State wishing to enter into an agreement with the IAEA for its assistance in connection with the siting, design, construction, commissioning, operation or decommissioning of a nuclear facility or any other activities will be required to follow those parts of the safety standards that pertain to the activities to be covered by the agreement. However, it should be recalled that the final decisions and legal responsibilities in any licensing procedures rest with the States.

Although the safety standards establish an essential basis for safety, the incorporation of more detailed requirements, in accordance with national practice, may also be necessary. Moreover, there will generally be special aspects that need to be assessed by experts on a case by case basis.

The physical protection of fissile and radioactive materials and of nuclear power plants as a whole is mentioned where appropriate but is not treated in detail; obligations of States in this respect should be addressed on the basis of the relevant instruments and publications developed under the auspices of the IAEA. Non-radiological aspects of industrial safety and environmental protection are also not explicitly considered; it is recognized that States should fulfil their international undertakings and obligations in relation to these.

The requirements and recommendations set forth in the IAEA safety standards might not be fully satisfied by some facilities built to earlier standards. Decisions on the way in which the safety standards are applied to such facilities will be taken by individual States.

The attention of States is drawn to the fact that the safety standards of the IAEA, while not legally binding, are developed with the aim of ensuring that the peaceful uses of nuclear energy and of radioactive materials are undertaken in a manner that enables States to meet their obligations under generally accepted principles of international law and rules such as those relating to environmental protection. According to one such general principle, the territory of a State must not be used in such a way as to cause damage in another State. States thus have an obligation of diligence and standard of care.

Civil nuclear activities conducted within the jurisdiction of States are, as any other activities, subject to obligations to which States may subscribe under international conventions, in addition to generally accepted principles of international law. States are expected to adopt within their national legal systems such legislation (including regulations) and other standards and measures as may be necessary to fulfil all of their international obligations effectively.

PREFACE

Radioactive waste is produced in the generation of nuclear power and the use of radioactive materials in industry, research and medicine. The importance of the safe management of radioactive waste for the protection of human health and the environment has long been recognized, and considerable experience has been gained in this field.

The IAEA's Radioactive Waste Safety Standards (RADWASS) programme is aimed at establishing a coherent and comprehensive set of principles, requirements and recommendations for the safe management of radioactive waste and formulating the guidelines necessary for their application. This is accomplished within the IAEA Safety Standards Series in an internally consistent set of documents that reflect an international consensus. The RADWASS publications will provide Member States with a comprehensive series of internationally agreed safety standards to assist in the derivation of, and to complement, national criteria, standards and practices.

This Safety Guide addresses the subject of safety assessment for near surface disposal of radioactive waste. It provides recommendations on how to meet the requirements related to safety assessment in the Safety Requirements publication on Near Surface Disposal of Radioactive Waste and guidance on approaches to performing safety assessments in the context of near surface repositories.

This Safety Guide was developed through a series of Consultants and Technical Committee meetings and reviewed by the Waste Safety Standards Advisory Committee (WASSAC), the Advisory Commission for Safety Standards (ACSS) and by Member States.

The IAEA wishes to express its appreciation to all those who assisted in drafting and review.

EDITORIAL NOTE

An appendix, when included, is considered to form an integral part of the standard and to have the same status as the main text. Annexes, footnotes and bibliographies, if included, are used to provide additional information or practical examples that might be helpful to the user.

The safety standards use the form 'shall' in making statements about requirements, responsibilities and obligations. Use of the form 'should' denotes recommendations of a desired option.

The English version of the text is the authoritative version.

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1. INTRODUCTION

BACKGROUND

1.1. Radioactive waste should be managed in accordance with the safety principles set out in the RADWASS Safety Fundamentals [1]. The safety requirements for disposing of wastes in near surface repositories are set out in Ref. [2]. The ability of the chosen disposal method to isolate the waste from the human environment should be commensurate with the hazard and the longevity of the waste. Near surface disposal is an option used for disposing of radioactive waste containing short lived radionuclides, which would decay to radiologically insignificant levels within a time period ranging from a few decades to a few centuries, and acceptably low concentrations of long lived radionuclides [2, 3]. Near surface repositories fall into two main categories: (1) facilities consisting of disposal units located either above (mounds, etc.) or below (trenches, pits, etc.) the original ground surface, and (2) rock cavity facilities. In the first case the cover on top of the waste is usually several metres thick, while in the second case the layer of rock above the waste can be as much as some tens of metres thick.

1.2. Near surface disposal has been practised in a number of countries, in some cases since the 1940s, with a wide variation in sites, in types and amounts of waste and in facility design. With proper siting, design and construction, a near surface repository provides cost effective and safe isolation of certain radioactive wastes. The safety of a repository and the public's confidence in it can be enhanced by, or depend partly upon, appropriate post-closure institutional controls (which include active controls, such as monitoring, surveillance and remedial work, and passive controls, such as control of land use and record keeping). Planning of such controls, if required as a part of the isolation system of near surface repositories, should receive careful consideration. The duration of controls needed to ensure safety will depend on factors such as characteristics of the waste, institutional issues, economics, site characteristics and facility design. However, active institutional controls for near surface disposal facilities are generally considered to have an effectiveness of up to a few hundred years.

1.3. Safety assessment is a procedure for evaluating the performance of a disposal system and, as a major objective, its potential radiological impact on human health and the environment. The safety assessment of near surface repositories should involve consideration of the impacts both during operation and in the post-closure phase. Potential radiological impacts following closure of the repository may arise from gradual processes, such as degradation of barriers, and from discrete events that may affect the isolation of the waste. The potential for inadvertent human intrusion can be assumed to be negligible while active institutional controls are considered fully effective, but may increase afterwards. The technical acceptability of a repository will greatly depend on the waste inventory, the engineered features of the repository and the suitability of the site. It should be judged on the basis of the results of the safety assessments, which should provide a reasonable assurance that the repository will meet the design objectives, performance standards and regulatory criteria. These are specified in the Safety Requirements [2] and further discussed in this and a companion [4] Safety Guide.

OBJECTIVE

1.4. The objective of this Safety Guide is to provide recommendations on how to meet the requirements for assessing the safety of near surface repositories. The Guide summarizes the most important considerations in assessing the safety of near surface repositories and recommends the steps to be followed in performing such assessments.

SCOPE

1.5. This Safety Guide covers safety assessment of near surface repositories for the disposal of radioactive waste in solid form. It includes consideration of the operational and post-closure phases but emphasizes post-closure issues, since the assessment of operations of near surface repositories is similar to that for operations at other waste management facilities. This Safety Guide does not cover safety assessments for geological disposal, for mine and mill tailings or for residual waste arising from restoration activities and remaining on the site.

1.6. Although radioactive waste may contain potentially hazardous non-radioactive components, this Safety Guide explicitly considers only the radiological hazard associated with the waste.

STRUCTURE

1.7. Guidance contained here includes recommendations on general considerations for safety assessment relevant to the near surface disposal option (Section 2) and guidelines for the major activities comprising a safety assessment (Section 3). In addition, the activities necessary for confidence building and for developing the basis for reasonable assurance that regulatory standards have been met by the waste disposal system are considered (Section 4).

2. GENERAL CONSIDERATIONS FOR SAFETY ASSESSMENT

SAFETY REQUIREMENTS AND ISSUES

Operational phase

2.1. The requirements in Ref. [2] state that the radiation protection of persons who are exposed as a result of operations at the waste repository shall be optimized and the exposures of individuals kept within dose limits. Elaboration on radiological protection policy for the disposal of radioactive waste is given in Ref. [5].

2.2. During the operational phase of a near surface repository, radiation exposure of the public may occur, albeit at low levels, both directly and due to discharges of liquid and gaseous effluent from the site. Any discharge to the environment should be controlled and limited so that exposures of workers and members of the public are kept as low as reasonably achievable, economic and social factors being taken into account, and within appropriate limits and constraints, given in the Basic Safety Standards [6] and Ref. [5].

2.3. In addition to the routine exposure of workers and members of the public, consideration also needs to be given to potential exposures in non-routine or accident situations. These might include, for example, a fire involving waste packages or their damage during handling on the site. Requirements for the management of such hazards are given in Ref. [6].

Post-closure phase

2.4. For the post-closure phase of near surface repositories, the major safety issue is the possibility of radiation exposure and environmental impacts over time periods far into the future. Some effects may be assumed to occur, for example, owing to gradual leaching of radionuclides into groundwater and subsequent migration through environmental media and transfer to humans. Assessments may therefore need to project the behaviour of the site and facility for time periods of the order of hundreds or even thousands of years. The difficulties associated with projecting the behaviour of the site and the repository for these time periods (see paras 3.34 and 3.38) are what distinguish post-closure assessments from more typical operational safety assessments. The post-closure assessments should also take account of other types of exposure which may occur only following certain events. Examples of such events are disruption of isolation barriers and unusual weather conditions. The aim of post-closure assessments is to obtain reasonable assurance that the disposal system will provide a sufficient level of safety, rather than to predict its future performance in any specific way.

2.5. Events induced by human activities may also lead to exposure but are difficult to predict. One or several of the following measures can be efficient in limiting the consequences associated with human activities: limitation of the concentration of specific radionuclides; effecting institutional control; or setting design criteria such as a minimum depth for the repository.

2.6. Requirements for safety in the post-closure period are set out in Ref. [2]. The numerical criteria are expressed in terms of radiation dose or risk constraints and are intended to be applicable to the assessment of both the normal or gradual releases and the disruptive processes described in paras 2.4 and 2.5.

2.7. The eventual decision on the acceptability of a repository should be based on reasonable assurance that safety requirements have been met [2]. Practical approaches to providing reasonable assurance of compliance with regulatory requirements are based on the safety assessment and include recognized technical and managerial principles such as defence in depth, sound engineering, quality assurance, safety culture and institutional controls.

USES OF SAFETY ASSESSMENTS

2.8. Safety assessments have different purposes at various stages of the development, operation and closure of a repository. At an early stage, safety assessments should be used to determine the feasibility of major disposal concepts, to direct site investigations and to assist in initial decision making. Their use is of greater importance in the stages following early concept development and site selection. Such assessments should then be developed to assist in system optimization and facility design by carrying out comparative assessments for various combinations of alternative waste packages, disposal modules and site management and closure measures.

2.9. The completeness and robustness of the safety assessment will in turn depend on the extent and quality of the data in terms of all relevant information on waste characterization, on site characterization, waste package performance and the function and performance of other engineered barriers. Close co-ordination of the safety assessment and the supporting data acquisition programmes is therefore necessary, with the safety assessment being a valuable means of identifying and prioritizing supporting research and development work.

2.10. A principal function of the safety assessment is in the licence application and approval process. This includes both radiological and environmental aspects. Such safety assessments for regulatory purposes may be required at various stages in the licensing process, including approval to construct, operate and close the repository, and whenever there are significant changes in the state of the repository. The safety assessment, therefore, should be performed and updated throughout all relevant stages of development of the repository by using appropriate models and data.

2.11. Results of safety assessments are an important means for confirming the acceptability of inventory and/or concentration levels for specific radionuclides in the waste [7] and provide one way of developing waste acceptance requirements for the near surface repository. Acceptable inventory levels are usually dependent on the analysis of scenarios of radionuclide release to the environment and transfer along environmental pathways. Consideration of human intrusion scenarios is also important and often determines the acceptable levels of long lived radionuclides in the repository. It should be noted, however, that large quantities of short lived radionuclides can present potential problems for operational and post-closure safety, and this should be considered in the safety assessment and in setting inventory and concentration limits (see para. 2.5). In addition, safety assessments should also be used to determine the levels of chemical substances in the waste that would cause degradation of the barrier system.

2.12. The safety assessment and the associated licence conditions determine, to a large extent, some of the principal controls and requirements on the repository. For example, in establishing waste acceptance requirements for the repository, the safety assessment should be used to determine requirements for waste packages and inventory levels, both for individual packages and for the site in total. The safety assessment should also be used in evaluating potential exposure pathways and in establishing and reviewing the environmental monitoring programme for the site and the surrounding area. The safety assessment should be based on design(s) actually used or proposed for the disposal facility and the management of the site through the operational phase and the period of active institutional control, if established, after its closure [2].

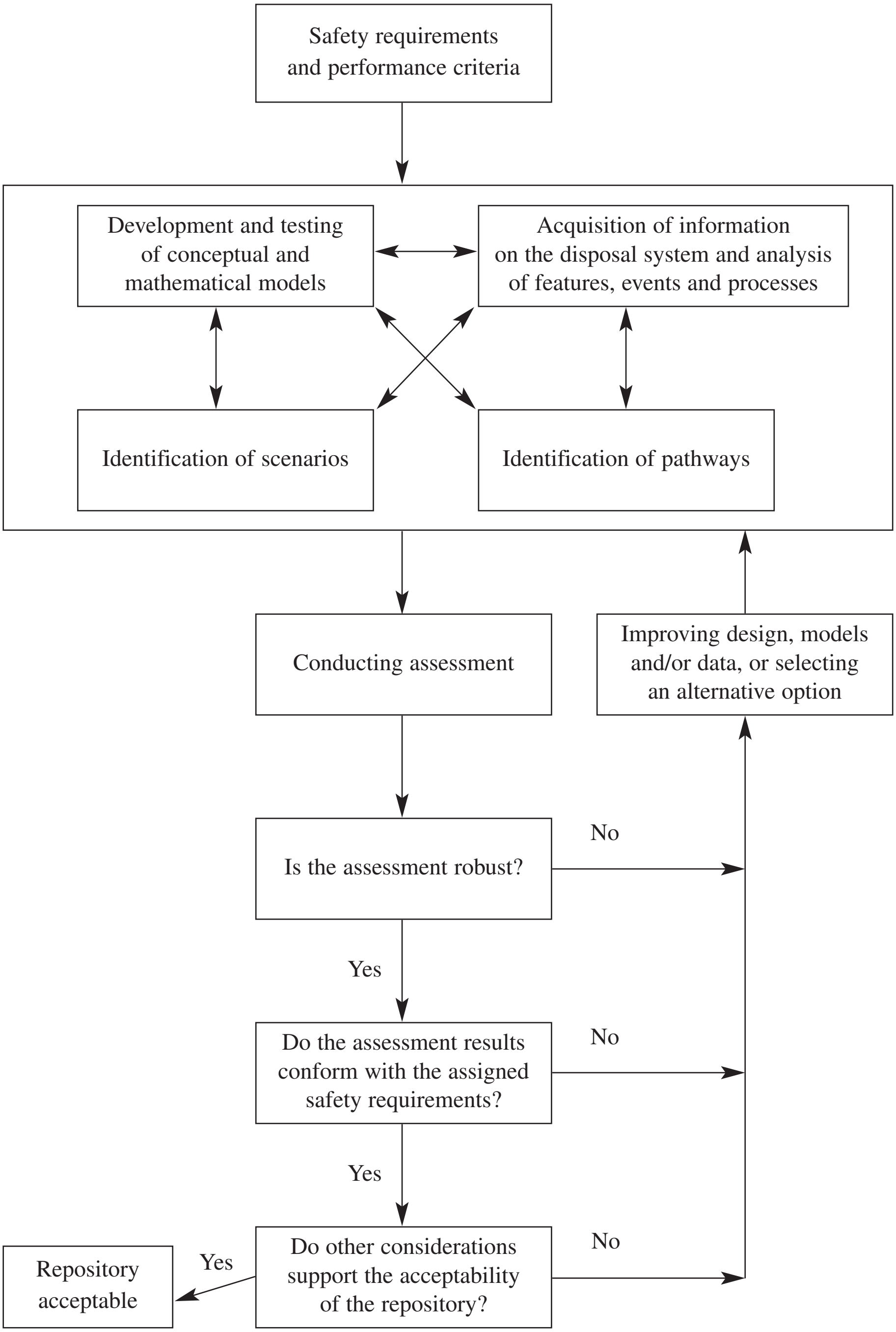

FIG. 1. Iterative approach to safety assessment.

ITERATIVE APPROACH TO SAFETY ASSESSMENT

General considerations

2.13. A schematic presentation of the recommended safety assessment approach is shown in Fig. 1. This approach involves the following activities which usually iterate and/or overlap:

— definition of the objectives of the assessment, safety requirements and performance criteria;
— acquisition of information and description of the disposal system, including waste form, site characteristics and engineered structures;
— identification of features, events and processes (FEPs) which might influence long term performance;
— developing and testing of conceptual and mathematical models of the behaviour of the system and its components;
— identification and description of relevant scenarios;
— identification of the pathways potentially leading to the transfer of radionuclides from the repository to humans and the environment;
— conducting the assessment by conceptual and mathematical modelling;
— evaluation of the robustness of the assessment;
— comparison of the assessment results with the assigned safety requirements; and
— additional considerations.

2.14. A key issue in safety assessments for the repository is to develop confidence in the results of modelling. A conceptual model of the near surface disposal system is a description in terms of the general features present and their detailed characteristics. Among the most important features are those that identify the relative significance of possible radionuclide transfer routes, known as pathways. Over time, natural phenomena and human activities are expected to alter the characteristics of the system. A description of future events is called a scenario. Scenarios deal with natural phenomena and gradual or abrupt changes in conditions that may lead to changes in the repository's performance over time. These future situations are usually assessed for near surface disposal by modelling the performance of the facility under assumed conditions [8, 9]. Safety assessment for the repository should be robust, i.e. tolerant to uncertainties. The results of the assessment, including identification of uncertainties, should be compared with the design goals and regulatory criteria, with account taken of other lines of reasoning and considerations contributing to the acceptability of the repository.

2.15. Characterization of the system and description of the pathways require the acquisition of appropriate data through field or laboratory experiments. Scenario analysis requires the identification and definition of phenomena that could initiate or enhance the release of radionuclides from the repository and result in exposure to humans. Throughout the iterative process of safety assessment, additional data collection may be required that is focused on the parameters identified as important for the safety of the repository.

Safety assessment process

2.16. The first step of the process should consist in performing screening calculations in order to evaluate the proposed conceptual model and to focus on the relevant radionuclides, pathways and release mechanisms on which further knowledge is required. Screening calculations need only limited data on waste package characteristics as well as identification of the major pathways. These data can be obtained, for example, through literature searches, material specifications, laboratory studies and studies of natural analogues, pre-operational monitoring in the surrounding area, and preliminary investigations on the site and characterization of the waste. The process should continue by the acquisition of additional data, for example, by field and laboratory investigations and appropriate modelling, as the design is developed, until a basis for reasonable confidence in the ability of the repository to meet the assigned safety requirement is achieved and the repository is accepted or until the studied concept is finally determined to be unacceptable.

2.17. During this process, relevant scenarios should be identified [9, 10]. Determining the relevance of each scenario to the evaluation of the repository and site may need supporting studies and additional data collection, and require further iterations of the safety assessment process. Such studies and analyses may also be useful in reducing uncertainties when attempting to quantify the events and phenomena that lead to the release and transfer of radionuclides. Even if safety assessments are robust, i.e. rely, for example, on clearly identified conservative assumptions, and are approved as such by the regulatory body, greater uncertainty is inevitably attached to longer term predictions. Consequently, there may be a need to allow a period of comparison of field monitoring results with parameter values used in the analyses. Extending monitoring into the period of active controls (or part of it) is therefore generally considered useful and is often a regulatory requirement. In such a case, the post-closure monitoring programme should meet the needs identified in the safety assessment process.

3. GUIDELINES FOR SAFETY ASSESSMENT

GENERAL

3.1. Safety assessment requires the development of both qualitative and quantitative arguments depending on site characterization results, waste characteristics, design data and mathematical modelling. Results from assessments, in their turn, provide necessary input for decisions throughout the development of disposal systems. The assumptions and judgements on which the safety assessment is based need to be robust and readily communicable to a wide range of interested parties in order to achieve confidence in safety assessment results.

3.2. In safety assessment, the validity of outputs of mathematical models should be considered with respect to uncertainties in input data for models, assumptions within the different parts of the models, assumptions about the interfaces between the individual parts of the overall model and uncertainties related to the long term evolution of the disposal systems. All of these uncertainties should be investigated by sensitivity and uncertainty analyses supplemented by other means of building confidence (see Section 4) and, where appropriate, by expert judgements.

3.3. The involvement of expert opinion and other safety assessment activities in developing the basis for a reasonable assurance that the regulatory standards have been met by the near surface disposal system should be started at the earliest stages of development of the repository (see para. 2.8).

3.4. Section 3 provides general guidance enabling the operator and the regulator to develop the necessary framework for safety assessment and to elaborate specific guidelines for the various activities comprising safety assessment of near surface repositories in accordance with international recommendations and national regulatory requirements.

DEFINING OBJECTIVES

3.5. Safety assessment plays a central role, and may be used for multiple purposes, in the development of a near surface repository (see Section 2). Since these various uses may require different levels of detail of analysis and imply different data needs, or presentation of results to different interested parties such as technical specialists and lay people, the objective of the safety assessment should be clearly defined in accordance with the particular application.

3.6. One output of assessments consists of numerical results used to compare projected system performance with established criteria. This requires a proper identification and, on the basis of relevant data, a thorough examination of all significant features, events and processes. Understanding the behaviour of a disposal system and its interaction with the natural and human environment is aided by the development of a set of models. The quantitative evaluation of effects requires mathematical modelling supported by the use of computer codes. Models are simplified to a certain extent, depending on the purpose for which the model was developed. The necessary complexity of a model should be carefully considered, in view of the fact that the most complex and detailed model is not necessarily the best one for a particular purpose.

DATA REQUIREMENTS

Types of data

3.7. The amount and quality of data required will depend on the purpose of the assessment. Preliminary assessment will probably require only simple models using data that are readily available. The results will normally only be used as a guide to future studies [9]. In this case, only a limited appreciation of the uncertainties associated with the results is needed. While finalizing the design and licensing certain stages of the repository, the operator should support the application with an assessment based on sufficient, probably large quantities of quality assured data describing the site, the design and the waste characteristics. Although a quality assurance programme and procedures should be established (and followed) as early as possible in the process, it is recognized that a similar quantity and quality of data may not be necessary at an early stage in the design and scoping stages of the repository. The operator should plan the data acquisition programme carefully to ensure that the objectives are achieved in a cost effective way.

3.8. Data will be needed from several sources, with levels of detail and uncertainty values that depend on the objective of the particular safety assessment. Data on the following are typically required:

(a) waste characteristics (radionuclide composition as a function of time, total inventory, physical and chemical characteristics, including gas generation rates, mass transfer parameters under disposal conditions);
(b) container characteristics (mechanical and chemical performance under disposal conditions);
(c) repository characteristics (dimensions, backfill/buffer material, structural material, engineered features);

(d) site characteristics (geology, hydrogeology, geochemical properties, climatic conditions);
(e) biosphere characteristics (natural habitat, atmospheric conditions, aquatic conditions); and
(f) demographic and socioeconomic characteristics (land use, food habits, population distribution).

Collection and collation of available data

3.9. Early scoping and screening data needs are normally met through literature search, collection of material specifications and very limited site or design specific investigations. These data may be used to make preliminary analyses and to develop preliminary designs. The basic conceptual model of the near surface disposal system will be developed on the basis of these data. A preliminary safety assessment, at this stage, may be carried out as a check on the potential of the system to perform adequately. Since only few data of limited detail are usually available at this stage of the safety assessment, simple models are appropriate.

Data acquisition programme

3.10. Data collection activities should be targeted to defined data needs on the basis of the conceptual design, the current knowledge of the site and the results of the preliminary safety assessment of the near surface disposal system. On the basis of the preliminary design, information available on site characteristics and the preliminary assessment, it should be possible to start to determine the amount of detail required to provide a basis for assurance of safety in compliance with regulatory requirements. Direct links between safety assessment and collection of site characterization data should be established in a data acquisition programme. For example, if fractures play a role in groundwater transport predictions, appropriate detail of the fracture system such as transmissivity, connectivity and orientation will be required. If the preliminary safety assessment indicates that, for the expected radionuclide inventory, retention by geological media plays a minor role in reducing contaminant concentrations at the receptor, little effort should be expended in its further consideration. If long term stability of the facility depends on the mechanical properties of the waste package, on the loadbearing strength of the host medium or on seismic activity, data collection activities should place emphasis on obtaining this information.

3.11. The results of the safety assessment may indicate additional needs. Sensitivity and uncertainty analyses may indicate that the results of the safety assessment are particularly sensitive to one parameter. This could identify a need for additional studies that might provide more precise and accurate determination of that parameter or changes in design or models. Collection of further data may continue, for example, in order to provide additional confidence in the assessment results.

Pre-operational monitoring data

3.12. Ambient conditions should be defined for a near surface repository as a baseline to measure performance during operations and for the post-closure monitoring period. Background measurements are normally carried out for radionuclides and for certain other 'indicator' parameters. These may include data relating to surface hydrology, local climate or groundwater chemistry. Pre-operational monitoring may also gather important data for the safety assessment and may provide a benchmark against which testing of models can be done.

3.13. Site parameters that are expected to vary with time, such as those used to calibrate hydrological flow models or atmospheric transport models used for safety assessment, should be measured with a regularity that allows estimation of their variability. For some parameters, it may be important to determine the extremes of the range of variation. This could entail a protracted period of measurement. Also, since there is often a delay between collection of the site data, analysis of the data and preparation of the licensing documentation and review by the regulatory body, plans should be made to continue measurements of time varying parameters, throughout this period where appropriate, to increase the reliability of the available information.

Operational and post-closure monitoring data

3.14. Operational monitoring data may indicate differences from predicted conditions. In this case, changes in operational procedures or other corrective actions should be considered. The reasons for these differences should be identified and used to improve the understanding of the system. The monitoring system should then be reviewed. Where significant deviations from predicted conditions are observed, a new safety assessment might be required to confirm that the design objectives remain valid.

3.15. Post-closure monitoring should be used to verify the absence of unacceptable radiological impact [2] and to provide confirmation of some other aspects of system performance. For example, infiltration through engineered covers may be monitored and compared with projected values to assist in the validation of the models used. However, national programmes do not commonly plan to use post-closure monitoring data to provide confirmation of estimated doses. This is because estimated consequences are generally small and are projected to occur far in the future.

SYSTEM DEFINITION

3.16. Safety assessment of a near surface disposal system is based on a multidisciplinary approach to system definition and on systematic analysis of possible sets of events and processes that may affect the performance of the disposal system [11]. The description of the near surface disposal system requires information on waste characteristics, repository design and site properties, and constitutes the basis for the development of a conceptual model of the waste disposal system, scenarios of its possible behaviour and assessment of potential radionuclide migration pathways.

Development of the conceptual model

3.17. The ultimate goal of the development of the conceptual model is to provide a framework that will permit judgements to be made about the behaviour of the total disposal system. If possible, the model should have enough detail that mathematical models can be developed to describe the behaviour of the system and its components so as to provide an estimate of the performance of the system over time. Different levels of detail will be required at different stages as the iterative safety assessment is conducted and eventually a licensing decision is made. The model should be as simple as possible but should include enough detail to represent the system's behaviour adequately for the purpose of ensuring compliance with safety requirements.

3.18. Development of a conceptual model should include the following steps:

(a) Identification and characterization of the waste in terms of inventory, waste form and package. This information should be sufficiently detailed to allow adequate modelling of radionuclide releases, i.e. the source term. As a minimum, information should be provided as a basis for the justification of a simple release model, such as by assuming that the release rate is constant or that a fixed proportion is released each year. The conceptual model of the source term may be refined by iteration as more information on the waste and the disposal system is obtained.

(b) Characterization of the disposal site by the necessary parameters, including geology, hydrogeology, geochemistry, tectonics and seismicity, surface processes, meteorology, ecology and distribution of local populations and their social and economic practices. This site information is needed to define pathways and receptors and thus to develop a conceptual physical, chemical and biological model of the site.

(c) Specification of facility design. Before the assessment starts, the design should be specified in terms of the material used and the components of the system.

TABLE I. PHENOMENA RELEVANT TO SAFETY ASSESSMENT OF NEAR SURFACE REPOSITORIES[a] (modified from Ref. [8])

NATURAL PROCESSES AND EVENTS

Biological intrusion

- Animals
- Plants

Faulting/seismicity

Meteorological processes and climate changes

Fluid interactions

- Erosion
- Flooding
- Fluctuations in the water table
- Groundwater flow
- Seepage water

Weathering

- Deterioration with time
- Freezing/thawing
- Wetting/drying

FEATURES AND PROCESSES OF THE WASTE AND THE REPOSITORY

- Obstruction of the drainage system
- Improper waste emplacement
- Failure of the top cover
- Presence/generation of chemical compounds that may disturb barrier performance, for example, complexing agents
- Gas generation
- Waste and soil compaction
- Waste/soil interaction

HUMAN ACTIVITIES

- Construction activities
- Farming
- Groundwater exploitation
- Habitation
- Salvage
- Reuse of disposed material
- Archaeology
- Other industrial activities

[a] This list is for illustrative purposes and should not be considered complete (see para. 3.21).

Changes in the design, either on the basis of the safety assessment or otherwise, may require the safety assessment to be updated.

(d) Increased knowledge of the site might suggest that one or more feasible alternative conceptual models exist and need to be considered. Where alternative models have been considered and discounted, the reasons should be clearly documented and, where appropriate, identified in the safety assessment.

Development of the mathematical model

3.19. Developing the mathematical model from the conceptual model is an important step in which the conceptual model is expressed quantitatively through mathematical equations in a calculational model. The general procedures used to develop such models are well accepted, and predictive mathematical models, varying in both level of detail and complexity, have been developed in key areas. They should be used to describe individual processes, subsystems and overall system performance. In the transition from conceptual models to mathematical models, and finally to implementation using calculation techniques, errors may be introduced owing to the simplifications, approximations, modelling assumptions or mathematical approaches used. Therefore, models used in performance assessment should be tested and updated not only on the basis of comparisons of their outputs with empirical data (Section 4), but also in the process of their development on the basis of peer review, inter-code comparisons, comparisons with other performance assessments, results of experiments carried out to test specific aspects of conceptual and numerical models, and comparisons with cases for which analytical solutions exist.

Analyses of features, events and processes (FEPs)

3.20. Systematic examination of potential features, events and processes (FEPs) should be used to identify the factors that might influence the long term safety of a repository and thus aid development of an appropriate safety assessment model. The safety assessment model can be built either through scenario analysis or by some alternative technique such as sampling parameter space.

3.21. The first step in identifying which of the many phenomena are relevant to the safety assessment should be to establish a checklist such as that presented in Table I. More recently, information on the FEPs has been assembled at the international level by working groups of the OECD Nuclear Energy Agency. In developing a suitable list of scenarios the following headings should be considered:

(1) processes and events of natural origin;

(2) processes attributable to the waste itself or to features of the near surface repository; and
(3) human activities.

Scenario analysis

3.22. Scenarios depend on characteristics of the environment and of the repository system, and on events and processes that could either cause initial release of radionuclides from waste or influence their fate and transport to humans and to the environment. The choice of appropriate scenarios and associated conceptual models should be a subject of special attention of both operator and regulator as this may strongly influence subsequent analysis of the waste disposal system. In some countries scenarios are specified by the regulators, although the operator may also choose to consider others. In other countries the operator may select the scenarios and be required to justify the selection to the regulator.

3.23. Normal evolution scenarios are usually based on extrapolation of existing conditions into the future and incorporate changes expected to occur with the passage of time. Since there may be a range of possible evolutions, a set of normal evolution scenarios should be developed to provide a reasonable assurance that the actual evolution will be within this range. Events that are less likely to occur may introduce significant perturbations to the system and require the development of alternative scenarios. Some of these scenarios can be handled by using the same models but with revised parameters. Other scenarios may require new models. The intended design will probably be based on the normal evolution scenario but may need to be modified to account for the results of the assessment based on other scenarios.

3.24. A wide range of scenarios should be considered and documented so as to develop as complete as possible an understanding of the system. However, where there are options, those scenarios should be selected for detailed assessment that are most likely to occur or that are relatively unlikely but could have major consequences. The selection of scenarios for detailed assessment should be clearly justified in the safety assessment documentation and, where appropriate, supporting evidence should be provided. This selection is to ensure the effective use of extensive assessment efforts and to ensure that the design of the repository is developed in a way that best protects human health and the environment.

3.25. Scenario development should lead to a systematic focusing of the safety assessment on the important conditions and phenomena related to performance of the disposal system. The scenario should be developed so as to cover the post-closure safety aspects of the near surface repository adequately. Expert judgement, fault and event tree analysis [8] and other techniques can be used to focus on the important scenarios. The process, the judgements made and the factors considered should be recorded.

Identification of pathways

3.26. The important pathways for radioactive materials released from the repository to the environment for both undisturbed (normal) conditions and disturbed (non-normal) conditions should be identified from a comprehensive set of potential pathways by screening. Experience shows that only a few pathways are likely to be important for the undisturbed performance of a near surface disposal facility. They include groundwater, soil, land plants, land animals, surface waters, aquatic animals and gaseous pathways. For the disturbed performance, the major addition to this list is suspended radioactive material and direct exposure.

CONSEQUENCE ANALYSIS

Model calculations

3.27. Once all relevant scenarios and pathways to humans have been identified, the next stage in the safety assessment process is consequence analysis. This involves the development and application of transport and exposure models to evaluate the potential impact of releases from the repository, or of disturbance of the repository, on humans and the environment.

3.28. It may be very helpful to use a modular systems approach to model the potential release and transport of radionuclides via selected environmental pathways to humans. This will ensure that individual submodels can be made available for inspection to assist in understanding how estimated doses were determined. The model will usually consist of the following discrete submodels: infiltration and leaching, gas generation, near field transport within and near disposal units, gas and groundwater transport, surface water transport, atmospheric transport, uptake by plants and animals, and dose to humans. A modular approach also allows flexibility and the concentration of effort on those parts of the system that need sophisticated modelling in order to ensure that the results are technically acceptable. The benefits of this approach can be significant when sophisticated models are used to provide added assurance that the disposal site and the repository will perform in an acceptable manner.

3.29. The source term used in the models should be representative of potential releases of radionuclides from various waste forms under the identified range of environmental conditions, and degradation of engineered barriers, such as cover systems and concrete structures, should be considered. Early models are likely to be simple, but as understanding of the system develops it may become necessary to employ more detailed models to ensure that the system is adequately represented. However, the models should be simple enough to be compatible and commensurate with available data; otherwise, the result could be greater uncertainty rather than improved accuracy. Expert judgement should be used here to ensure a proper balance between using simple models and existing data and more detailed models that may need some data not readily available. This does not preclude the use of more complex models of parts of the system to improve the understanding of the phenomena involved. Examples of such sophisticated models might be the use of finite element groundwater codes to assess hydrological boundary conditions and temporal variability of water levels if physical characteristics or groundwater monitoring suggest the need to understand changes in the system at a more sophisticated level.

3.30. Reasonable conservatism that can withstand scientific scrutiny should be built into the safety assessment modelling from the beginning. A simple modelling approach is likely to be more efficient, easily understandable and justified. Assumptions should be formulated on the basis of available data and knowledge of the system or similar systems, and selected so that they are not likely to underestimate the release and transport of radionuclides or, if required, the exposure of an inadvertent intruder. Since acceptance of the results can be the most difficult aspect of an assessment, any approach to make that acceptance easier will be a long term benefit. An approach which balances simplicity, conservatism and realism is likely to be the best starting point for assessments.

3.31. The chosen model should be consistent with the assessment objective, easy to use (considering the complexity of the system), and the one for which the data can be obtained. The model should be appropriate for the application, the accuracy of the algorithms should be demonstrable, the assumptions should be reasonable and the input data should be representative.

3.32. The modelling approach selected should be fully and clearly documented together with the matters considered as it is developed. The documentation should provide a traceable record of all the assumptions and decisions made during development and application of the modelling approach. This should include the reasons for disregarding any alternative models considered in the process of developing the modelling approach.

Uncertainty

General

3.33. Uncertainty is inherent in any safety assessment. Sensitivity and uncertainty analyses have the important goal of extending understanding and reducing, where possible, the uncertainty in some of the results of the safety assessment by directing attention to a better definition of those parameters that most affect the results and their uncertainty. The analyses of sensitivity and uncertainty are closely related. Sensitivity analysis should be used to identify those parameters, system components or processes that produce significant effects on the predicted disposal system performance. Identification of sensitive conceptual model components and important scenarios is usually done through application of systematic parameter variation. Each scenario may require its own distribution of parameters. Often bounding values for the expected case are used to investigate system behaviour under uncertainty. Statistical techniques may also be employed to explore the whole range of expected parameter variation [8, 9].

3.34. Broadly, two main sources of uncertainty should be considered in safety assessment for near surface disposal. One is the degree to which the model represents the real system. This uncertainty is associated with the model inputs, being inherent in the description of the disposal system, the site characteristics, the engineered features of the repository and their interaction with the environment, and the modelling itself. The other source of uncertainty is related to the unpredictability of future human actions and the evolution of the facility and its environment over long periods of time.

3.35. The first source of uncertainty should be reduced by improving the quality of site characterization and waste data, details of the design of the facility, the conceptual model and the scenario selection. The goal should be to estimate and reduce this uncertainty to a level either deemed acceptable or shown to be unimportant in the context of the performance of the near surface repository. The second source of uncertainty should be examined so that its likely effects in the future can be seen. The results of such an examination may provide a reasonable assurance that the disposal system will be safe even though model outcomes may be uncertain. Thus, the primary importance of the sensitivity and uncertainty analyses for regulatory decisions is in using them as a tool for assessing compliance with safety requirements in the face of uncertainty. It stands to reason that, if compliance with the safety standards can be shown by some other means, for example, by using a demonstrably conservative model, the uncertainty analysis may not be required.

3.36. A major source of uncertainty in scenario development stems from the potential for missing an important scenario. Peer review of the scenarios chosen can help and should be used to reduce such uncertainty.

3.37. Similarly, uncertainty in development of the conceptual and numerical models of the site should be evaluated by peer review. The general trend is to use simple models for ease of explanation and for computational efficiency. The uncertainty associated with the simplification existing in building the conceptual and numerical models can often be determined by additional modelling studies and data collection. Again, the modular approach and careful analysis of intermediate computational results can lead to a more detailed understanding of the system. This in turn can lead to an overall reduction in model uncertainty. However, an over-complex model demands greater quantities of data, and these data may be uncertain and may lead to greater uncertainty in the results or may not be obtainable at all.

3.38. Inherent uncertainty arises from attempting to project future events. Some of these uncertainties can be disregarded following careful examination of extreme or bounding scenarios or from the results of probabilistic assessments, but only if they have little effect on the performance of the repository system. Other uncertainties, particularly those associated with human actions dictated by future socioeconomic conditions or major changes in climatic conditions, may have a significant effect on the exposure of humans in the future yet are not amenable to quantified projections. Although in such circumstances only qualitative deductions can be made, it may still be possible to point to the multiple factors providing assurance of safety and, for each factor, to comment on the growing uncertainty over time as to whether it would continue to be effective. Safety assessment is based on a conceptual model whose prime purpose is to provide a framework to allow analysis to proceed. Where suitable mathematical models can be derived and the data exist, the assessment can be quantitative. If this is not the case then qualitative assessment should be made. This does not invalidate the assessment process but renders it more dependent on qualitative judgements of the experts, supported where possible by calculation. Within this framework, however, the basis for the judgements should be carefully documented for examination as part of the safety assessment. Care should also be taken with respect to the reliability of the available information that is reflected in the level of calculational detail provided in the assessment and in the interpretation of results, which should therefore change according to the length of time into the future being considered (see paras 2.9 and 3.45).

Sensitivity analysis

3.39. The system should be analysed to determine how and to what degree the predicted behaviour of the near surface disposal facility depends on the conceptual model used, the scenarios that are applicable to the model and the variation in the parameters used to describe the system as input to the model. If the results are sensitive to initial and boundary conditions, then more extensive data, including revised measurements from the site, may have to be generated. The process should look at the model's sensitivity to different scenarios and exposure pathways to be reasonably expected. If it is determined that the assessment is sensitive to these parameters, consideration should be given to their further evaluation.

3.40. Single parameter variation or variation of combinations of a few parameters should be considered as a starting point of sensitivity analysis for safety assessment of near surface repositories. Consideration should be given to extreme but reasonable variation of some parameters because this may change the relative importance of different pathways and make the model no longer applicable.

3.41. Different methods for varying parameter values can be used for this task, but the analysis should be structured with care to ensure that the combinations that are chosen by the computer code are not impossible, or physically unrealistic. In addition, the output from the exercise should be structured to preserve the information needed to determine the sensitive combinations and to identify sensitive parameters.

3.42. Sensitivity analysis should guide the iterative process used for improvement of the model formulation, scenario development and gathering of additional data. Sensitivity analysis results should be used to indicate where design features should be effectively improved to yield better performance.

Uncertainty analysis

3.43. Parameter uncertainty is the type of uncertainty that should be addressed by uncertainty analysis. This should be done by concentrating on those parameters that are shown by sensitivity analysis to be important for defining the result of the safety assessment. Methods commonly used are related to the sensitivity analysis techniques of single variable or multivariable variation with the goal of developing bounds for the predicted performance of the near surface repository. Simple bounding analyses should generally produce fully adequate information on the range of performance but it should be noted that, since the systems are so complex, extreme values on a parameter-by-parameter basis may not always yield the bounding behaviour of the system. Monte Carlo analysis can also provide distributions of expected results based on statistical analysis of estimates of input parameter variation. When developing the input distributions for the Monte Carlo analysis and correlation between the parameters, access to expert judgement will be needed, which should be elicited in a formal and recorded manner, when necessary.

PRESENTATION OF RESULTS OF THE SAFETY ASSESSMENT

General

3.44. The presentation of the safety assessment results as a body of all relevant information (see para. 3.46) is important for understanding and acceptance. These results will be used for various purposes. In the decision making process they are used principally for comparison with the regulatory standards applicable to the near surface repository. The need to build a consensus that the repository is a safe disposal option for the designated waste for a long time in the future adds an important dimension to safety assessment and presentation of its results.

3.45. Since safety assessment results normally provide the basis for establishing requirements on waste acceptance and repository design, it is important to provide information on the performance of system components, particularly to the system designers and ultimately to the regulatory body, in order to illustrate the levels of protection provided by the various parts of the repository system. Outputs of the models used in safety assessments are in fact indicators of what might happen under certain conditions that may prevail in the future, not actual predictions. Conveying this and the complexity of a near surface disposal system composed of both natural and engineered parts, as reflected in near surface repository models, to different interested parties is very important; therefore, presentation of results should be carefully prepared.

Comparison with regulatory standards

3.46. The most common use of safety assessment results is to show evidence of compliance with regulatory requirements (see Section 2). For this purpose, to substantiate the outcome of the safety assessment the following items are required:

- — a clear description of the site, the selected design and the waste inventory for disposal;
- — a thorough discussion of the conceptual model and the physical basis for the model;
- — a discussion of alternative models considered and the reasons for disregarding such models;
- — the basis for selecting or developing scenarios and pathways;
- — documentation of assumptions and justifications of simplifications used;
- — a summary of the inputs to the models and codes;
- — the actual data used, their source and justification; and
- — the interpretation of results.

The documentation of the results of the safety assessment should include information on uncertainty and the conclusions of any sensitivity and uncertainty analyses.

Performance of system components

3.47. The results of a safety assessment should be presented in a way that provides a demonstration of the performance of individual system components. This is a worthwhile exercise which is done easily if a modular approach to modelling is taken. Showing the expected behaviour of each component and the iterative improvement in component design or knowledge of the component's expected behaviour, to ensure its effective performance, increases the level of confidence in the performance of the whole system.

Future radiological impacts

3.48. The results of a safety assessment should be presented in a way that allows consideration of variations in projected impacts with time. This approach can be particularly useful since the projections are only indications of performance of the near surface repository, and showing the evolution of the repository generated impacts over time can contribute to the credibility of the safety assessment results. In any case, it may be useful to show how the effect of radioactive decay generally leads to decreasing impact with time. Such an approach should also be followed when long term radiological impacts are compared with natural radiation levels, for example, to demonstrate in a relative way the effect of disposing of long lived radionuclides in the near surface repository.

Level of presentation

3.49. In order to represent the complexities of the near surface disposal system, complex models are sometimes necessary. Presenting and explaining these models may be difficult, particularly when dealing with the general public. In addition, the licensing of near surface repositories may form the basis of legal action. Since discussing the results of complex modelling in a judicial context may be very difficult, efforts should be made to supplement the sophisticated modelling approach with a less complex model for explanatory purposes.

3.50. While simplification may cause loss of detail, demonstration of equivalence of simple and complex methods may be possible if it can be shown that simplification has actually focused the safety assessment on the critical factors related to system safety. This is often referred to as robust modelling of the system. Robust assessments should be demonstrated to provide good estimates of system behaviour using simple models and a minimum of data. They also should be demonstrated to bound the system behaviour. Satisfactory simplification generally requires very good understanding of the near surface repository system and its performance. Provided that this understanding can be demonstrated, simple robust models and safety assessment methods using qualitative data are easier to explain to the public than complex models requiring large amounts of data.

4. CONFIDENCE BUILDING

INTRODUCTION

4.1. Safety assessments provide a basis for rational and technically sound decisions in the process of establishing waste repositories. As discussed in the preceding sections, safety assessments play a role in different stages of the process. Preliminary assessments can be used in site selection. Safety assessments should provide inputs to repository design and allow the definition of waste acceptance requirements on a repository specific basis. Finally, licensing of a repository should, at least in part, be based on the outcome of a safety assessment.

4.2. Scientists, regulators, decision makers and other interested parties should all have confidence in the information, insights and results provided by safety assessments. This section discusses what can be done to ensure that the results of safety assessments command a high degree of confidence. Activities contributing to confidence building include: (1) verification, calibration and, if possible, validation of models; (2) investigation of relevant natural analogues; (3) quality assurance; and (4) peer review.

VERIFICATION, CALIBRATION AND VALIDATION OF MODELS

4.3. Safety assessments are based on models of the repository and of its natural surroundings. These models are used to simulate the evolution of the system and to provide an indication of the consequences of a number of scenarios. The modelling effort comprises the development of conceptual models and mathematical models and the corresponding computer codes or other methods of calculation. Confidence in the modelling results depends on two questions. First, does the method of calculation solve accurately the mathematical equations that constitute the model? The process of verification is used to answer this question. Second, does the model reproduce sufficiently accurately field and/or experimental results? Calibration and validation using different data sets are used to answer this question.

Verification

4.4. Verification of the method of calculation is achieved by solving test problems designed to show that the equations in the mathematical model are solved satisfactorily. Through the use of test problems and feedback from diversified use of the method, it is possible to reach a high level of confidence in the correctness of the mathematics and that the equations are correctly encoded and solved. Comparison of the results of different methods solving the same problem and using the same input parameters is also an effective approach. Therefore, verification of the methods of calculation is feasible and should be used for confidence building in safety assessments. International intercomparisons and peer reviews (see paras 4.9, 4.10 and 4.11) are important aids to obtaining public acceptance.

Calibration

4.5. Calibration aims to reduce uncertainty in conceptual and numerical models and parameters and is performed by comparing model or submodel predictions with field observations and experimental measurements. Calibration is, therefore, a site specific procedure, whereby a set of site specific input data is used to compare predictions and observations at that site. In practice, if a model can be calibrated successfully for a variety of site specific conditions, an increased level of confidence can be placed in the model's ability to represent those aspects of system behaviour and therefore to estimate their effects in situations in which they cannot be measured. However, one difficulty that is often encountered in the calibration process is that different conceptual models and their associated sets of input data produce results which show equally good agreement with the observed data. This limits the reduction in uncertainty that can be achieved.

Validation

4.6. As far as possible, modelling output should be shown to be valid, that is, to correspond to empirical data obtained in an actual situation. In contrast to calibration, which is a more site specific model adjustment process, validation has more to do with producing credible results at a variety of different sites or under a wide range of conditions. Although the validation of models for the long term evolution of a specific site is not possible over the relevant time-scales, limited validation may be possible through use of data from natural analogue studies or climate analogues. It may also be useful to compare modelling outputs with observations concerning the behaviour of certain components of the repository system, for example, data sets obtained with in situ experiments, or with measurements performed during site characterization and during the repository's operational phase.

NATURAL ANALOGUES

4.7. Natural analogues have been studied so that the results of observations in nature may be compared with the performance of repository components or processes expected to take place in a disposal system [12]. The analogy between natural analogues and a waste repository is not perfect since in most cases only the end results of the naturally occurring processes can be observed, and there is significant uncertainty about initial conditions and their evolution over time.

4.8. To date, it has proven difficult to use natural analogue studies in a quantitative way to calibrate/validate models or to provide values for the parameters used in these models. However, some relevant processes such as weathering of package materials, wind resuspension, radionuclide transport by groundwater or transfer of elements from soil to biota could be investigated in appropriate natural analogues with an adequate level of detail and with sufficient control of boundary conditions to allow some model testing. Therefore, despite some reservations, natural analogues should be used in building confidence in various processes and materials used for the disposal system. The use of information derived from natural analogue studies could be particularly useful for increasing the decision makers' and the public's confidence in the assessment. Information of this type should be used to provide confidence that near surface disposal is safe.

QUALITY ASSURANCE

4.9. Quality assurance is a planned and systematic set of procedures to document the various steps in a process and to provide confidence that the results of the process are of good quality. Quality assurance and quality control (QA/QC) procedures have been or are being introduced into many areas of radioactive waste management [13]. The need to generate confidence in the results of safety assessments requires that a quality assurance procedure be applied to the various elements of the assessment, and in particular to data acquisition, design activities, development of models and methods of calculation, from the earliest stage. The quality assurance approach should provide a framework in which safety assessment activities are performed and recorded, attesting to compliance with the procedure. In this way it can be shown that reliable and traceable sources of information have been used. As a result, confidence in the results of the safety assessment will be enhanced.

PEER REVIEW OF SAFETY ASSESSMENTS

4.10. In scientific activities, confidence in the validity of results depends to a great extent on the outcome of the peer review process. Scientific work and results relevant to safety assessment should be published in the open literature, so that they become available for detailed scrutiny by other experts active in the same field as well as by anyone interested in the subject.

4.11. The peer review process for work that constitutes the basis for safety assessments should include forms other than the typical peer review of scientific publications and programme results. National radioactive waste management programmes should have provisions for the technical review of important activities. The regulatory body should develop an independent capability for reviewing safety assessments. In some cases the operator of the repository organizes, or the competent authorities organize, critical reviews by independent bodies. Such reviews can additionally make use of the expertise of natural and social scientists and can be effective in raising the level of confidence in the assessment.

ADDITIONAL CONSIDERATIONS

4.12. Since safety assessment of near surface repositories involves hypothetical future events and their consequences, there is no expectation that particular projections will become reality. The only realistic objective is a reasonable degree of assurance of safety, based on evaluating all appropriate evidence, including professional judgements and mathematical modelling, that the repository will perform within acceptable bounds.

4.13. It should be borne in mind that implementing a near surface repository programme depends on scientists, regulators and decision makers being confident of its safety, and also depends on public acceptance. For the purpose of obtaining the confidence of the public, the process of developing a waste repository should incorporate a number of features aimed at providing openness, public involvement and effective and widespread information. A well designed safety assessment using simple, robust performance assessment techniques applied to an adequately grounded conceptual model may help foster public understanding and acceptance of the near surface repository.

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, The Principles of Radioactive Waste Management, Safety Series No. 111-F, IAEA, Vienna (1995).

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Near Surface Disposal of Radioactive Waste, Safety Standards Series No. WS-R-1, IAEA, Vienna (1999).

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Classification of Radioactive Waste, Safety Series No. 111-G-1.1, IAEA, Vienna (1994).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Siting of Near Surface Disposal Facilities, Safety Series No. 111-G-3.1, IAEA, Vienna (1994).

[5] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Radiological Protection Policy for the Disposal of Radioactive Waste, Publication No. 77, Elsevier, Oxford (1997).

[6] FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR ORGANISATION, OECD NUCLEAR ENERGY AGENCY, PAN AMERICAN HEALTH ORGANIZATION, WORLD HEALTH ORGANIZATION, International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources, Safety Series No. 115, IAEA, Vienna (1996).

[7] OECD NUCLEAR ENERGY AGENCY, Shallow Land Disposal of Radioactive Waste: Reference Levels for the Acceptance of Long-lived Radionuclides, OECD, Paris (1987).

[8] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety Analysis Methodologies for Radioactive Waste Repositories in Shallow Ground, Safety Series No. 64, IAEA, Vienna (1984).

[9] INTERNATIONAL ATOMIC ENERGY AGENCY, Performance Assessment for Underground Radioactive Waste Disposal Systems, Safety Series No. 68, IAEA, Vienna (1985).

[10] OECD NUCLEAR ENERGY AGENCY, Systematic Approaches to Scenario Development, OECD, Paris (1992).

[11] OECD NUCLEAR ENERGY AGENCY, Review of Safety Assessment Methods, OECD, Paris (1991).

[12] INTERNATIONAL ATOMIC ENERGY AGENCY, Natural Analogues in Performance Assessments for the Disposal of Long Lived Radioactive Wastes, Technical Reports Series No. 304, IAEA, Vienna (1989).

[13] INTERNATIONAL ATOMIC ENERGY AGENCY, Quality Assurance for Radioactive Waste Packages, Technical Reports Series No. 376, IAEA, Vienna (1995).

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