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SAFETY GUIDES

safety series

Siting of Geological Disposal Facilities

A Safety Guide

A PUBLICATION
WITHIN THE RADWASS PROGRAMME

INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, 1994

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- The Safety Series number (111).
- Identification of the category of the document (F: Safety Fundamentals, S: Safety Standard, G: Safety Guide, P: Safety Practice).
- Identification of the subject area (1: Planning, 2: Predisposal, 3: Near surface disposal, 4: Geological disposal, 5: U/Th mining and milling, 6: Decommissioning/environmental restoration).
- Identification within a subject area by a serial number.

SITING OF GEOLOGICAL DISPOSAL FACILITIES

A Safety Guide

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A Safety Guide

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FOREWORD

Radioactive waste is generated from the production of nuclear energy and from the use of radioactive materials in industrial applications, research and medicine. The importance of 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 Radioactive Waste Safety Standards (RADWASS) programme is the IAEA's contribution to establishing and promoting, in a coherent and comprehensive manner, the basic safety philosophy for radioactive waste management and the steps necessary to ensure its implementation.

The RADWASS publications will (a) reflect the existing international consensus in the approaches and methodologies for safe radioactive waste management, including disposal, and provide mechanisms to establish consensus where it does not yet exist and (b) provide Member States with a comprehensive series of internationally agreed documents to assist in the derivation of and to complement national criteria, standards and practices.

In keeping with the IAEA's Safety Series structure, the RADWASS publications are organized in four hierarchical levels. The leading publication in this series is the Safety Fundamentals. This publication lays down the basic objectives and fundamental principles for the management of radioactive waste.

In addition to the Safety Fundamentals, six Safety Standards cover the following subjects:

— Planning
— Predisposal
— Near surface disposal
— Geological disposal
— Uranium/thorium mining and milling
— Decommissioning/environmental restoration.

As the programme develops, other subjects may be added to this list.

The Safety Standards are supplemented by a number of Safety Guides and Safety Practices.

This Safety Guide defines the process to be used and guidelines to be considered in selecting sites for deep geological disposal of radioactive wastes. It reflects the collective experience of eleven Member States having programmes to dispose of spent fuel, high level and long lived radioactive waste. In addition to the technical factors important to site performance, the Safety Guide also addresses the social, economic and environmental factors to be considered in site selection. Data needed to apply the guidelines are also specified. The Safety Guide has been prepared through two Consultants Meetings and a Technical Committee Meeting. The list of contributors to drafting and review of the the Safety Guide along with their affiliations is given at the end of the report. The IAEA wishes to acknowledge the contributions made by the experts in the preparation of the Safety Guide, especially D.E. Billington, who chaired the Technical Committee Meeting. Z. Dlouhy and M. Bell of the Division of Nuclear Fuel Cycle and Waste Management were the responsible officers of the IAEA.

EDITORIAL NOTE

CONTENTS

1. INTRODUCTION

BACKGROUND

101. The goal of radioactive waste disposal is passive isolation of waste so that it does not result in undue exposure to radiation of humans or the environment, now or in the future. This objective can be achieved by isolating radioactive materials in a disposal system which is located, designed, constructed, operated and closed such that any potential hazard to human health is kept acceptably low over required periods of time.

102. In the nuclear fuel cycle, a very important high level and long lived radioactive waste is spent nuclear reactor fuel, which may be disposed of directly to a repository or which may be reprocessed. Owing to the large amounts of radionuclides with long half-lives, such material requires isolation for a very long time. This implies that radiation protection of humans is needed for long time periods over which the radiation exposures should be maintained below the values set by national regulations or generally agreed international recommendations.

103. It is generally recognized that for spent fuel and highly radioactive waste the preferred concept is disposal into deep, stable geological formations. The safety of the concept does not rely on continuing institutional controls after closure of a repository, such as maintenance, monitoring and surveillance, thus minimizing the burden upon future generations.

104. A very important activity related to the disposal of high level waste and other long lived waste is the selection of an appropriate underground disposal site. Such a site should have favourable natural confinement characteristics for the waste types under consideration, and should be suitable for implementing all necessary engineered barriers to prevent or retard the potential movement of radionuclides from the disposal system to the accessible environment. Since the natural characteristics of the site play an important role in the disposal concept, site selection activities should be given major consideration in the overall development of an appropriate disposal system.

105. In assessing the acceptability of a given disposal system, the safety principles adopted by the regulatory authority are used as a basis for judgement. These safety principles should be complied with under all circumstances, when implementing a disposal system. General guidelines by which the acceptability of a site can be judged in relation to the proposed repository design and the waste types are also required. Subsidiary site selection criteria may also be established. In establishing these

criteria, the specific characteristics of the proposed repository design and the intended waste forms should be taken into account. An important role of the regulatory body is to set or approve the site selection criteria and to review the site related information to verify that the site is acceptable.

106. Safety assessment of disposal facilities should consider the radiological impacts of operation and post-closure. Potential radiological impacts following closure of the repository arise from gradual natural processes leading to the release of radionuclides to the biosphere and from discrete low probability events which may affect the repository, such as human intrusion. The suitability of a site will depend largely on its capacity to confine radioactive wastes and to limit rates of release of radionuclides, thereby limiting any potential adverse impact of the disposal system on humans and the environment for the required periods of time.

107. Quantitative definitions of acceptable activity levels and desired periods of time will largely depend on the overall performance of the disposal system, in which site characteristics play an important role. Therefore, these definitions should be developed by national regulatory authorities, taking into account existing national regulations as well as international recommendations.

OBJECTIVE

108. The objective of this publication is to provide guidance for identifying and selecting suitable geological disposal sites for radioactive waste. The information contained here should enable the personnel involved in siting of geological repositories to choose a proper site using a method that would best suit the specific conditions of the country, the waste type intended for disposal, and the performance requirements for a repository according to the disposal concept chosen. A description is provided of the stages of the siting process and information on the factors to be considered in this process. This publication may also be used by regulatory bodies for development of their more specific standards, criteria and specifications.

SCOPE

109. The disposal systems considered here are those consisting of mined cavities and deep boreholes in geological formations for accepting high level and alpha bearing waste in the solid and packaged forms. Spent nuclear fuel (if declared as a waste) falls into this category as well.

110. Wherever the term 'deep' is used in the text, it is intended to emphasize the distinction between the disposal facilities discussed here and those for near surface disposal, which are dealt with in a companion Safety Guide.

STRUCTURE

111. Guidelines contained here include basic safety considerations relevant to the geological disposal option (Section 2), followed by a description of the siting process (Section 3). Site selection guidelines are presented, together with an overview of data necessary for application of the guidelines in the siting process (Section 4). The document is supplemented by a bibliography, a glossary of terms used, and a list of drafting and reviewing bodies.

2. SAFETY APPROACH

201. Siting of radioactive waste disposal facilities is an important step in developing a waste disposal system that will best suit the needs for accommodation of waste from a national nuclear programme and, simultaneously, satisfy all safety, technical and environmental requirements set out in various national and international guidelines. When properly implemented, an underground disposal system is expected to provide the required isolation of radioactive waste from the environment over long time scales without relying on future generations to maintain the integrity of the disposal system. It is also expected to ensure the long term radiological protection of humans and the environment in accordance with current internationally agreed radiation protection principles (radiological safety). These basic principles are specified in the RADWASS Safety Fundamentals, 'Basic Principles of Radioactive Waste Management' [1]. Therefore, establishing comprehensive standards, development and issuance of regulations and guidance on the objectives of siting, and identification of factors to be applied in selecting suitable sites should be a major concern of responsible authorities. A Safety Standard 'Geological Disposal of Radioactive Waste', is being developed as part of the RADWASS series of documents [2]. In the interim, IAEA Safety Series No. 99 is the international consensus standard applicable to geological disposal of radioactive waste [3].

202. The purpose of siting is to locate a site which, along with a proper design and engineered barriers, will provide radiological protection to comply with requirements established by national regulatory bodies. The IAEA standards and existing international recommendations and guidance should be taken into account.

203. A suitable disposal site may be identified either by narrowing the field of candidates from a number of sites or by objectively evaluating one or more designated potential sites. For either method it is not essential to locate the best possible site, but to provide an overall disposal system of natural and engineered barriers which can be convincingly shown to comply with safety and environmental protection requirements. The approach to assessing the level of safety is similar regardless of the method of identifying the site for the repository.

204. It is generally recognized that there are several mechanisms by which radionuclides may become accessible either directly or indirectly to humans through various exposure pathways. A geological repository relies on both geological and engineered barriers to provide adequate protection from release by gradual processes which are expected to occur and by low probability events which may affect the repository. Because of the extended time periods involved it is not reasonable to rely on active monitoring, surveillance or other active institutional controls or remedial actions to ensure the long term safety of a geological repository.

3. THE SITING PROCESS

BASIC OBJECTIVE

301. The basic objective of the siting process is to select a suitable site for disposal and to demonstrate that this site, in conjunction with the repository design and waste package, has properties which provide adequate isolation of radionuclides from the accessible environment for desired periods of time. Site features should provide a natural barrier that assists in keeping the radiological impact to humans and the environment within acceptable levels as established by the regulatory body. It is generally recognized that the suitability of a site does not depend on geological characteristics alone and that engineered measures also contribute to overall safety. In order to keep potential releases within acceptable limits, the disposal system should be developed such that the design and engineering of the repository are compatible with the characteristics of the site and the surrounding geological media.

STAGES OF THE SITING PROCESS

302. Consideration should be given to the choice of an adequate approach or its possible variation in the course of general planning at the start of the siting process. If there are no pre-existing constraints, it may be possible to follow a systematic process of narrowing in from large regions to specific sites and to characterization and confirmation of these sites.It is also possible that specific possibilities for siting may exist at the outset. Specific sites may be designated for consideration by a local or national authority. Alternatively, only sites within public ownership might be considered. Existing nuclear sites or land adjoining existing nuclear facilities may be identified as worthy of special consideration because of the potential benefits of such co-location, particularly in relation to reducing waste transportation requirements.

Additionally, it might be possible to solicit volunteer sites from communities or land owners.For any method or for a combination of methods the objective is not to locate the 'best' site, but to provide a disposal system which can be convincingly shown to comply with established safety and environmental requirements.

303. In the siting process for a radioactive waste disposal facility, four stages may be recognized:

(a) conceptual and planning stage
(b) area survey stage
(c) site characterization stage
(d) site confirmation stage.

The transition from one stage to the next may be somewhat arbitrary because of the overlap of siting activities, and further phases of work within each stage may be considered. In each of these stages a set of procedures is implemented with the aim of selecting suitable areas or sites. The amount and precision of the data generally increases as the overall siting process progresses towards its goal of confirming a preferred site.

304. The process will involve integration of site investigative work from a number of disciplines. These include many branches of natural and earth sciences, engineering, safety analysis, health physics and social sciences. The overall siting process encompasses theoretical, laboratory and field activities carried out in a generally stepwise fashion but with significant interaction between individual steps. The process should start with an identified need for a disposal facility and conclude with selection of a site (or sites) that is confirmed as meeting all safety and other requirements by detailed studies.

305. During the conceptual and planning stage potentially important siting factors are identified, potential host rock(s) and possible siting area(s) are identified, and investigation objectives and investigation programmes are defined. In the area survey stage, a broad region is examined to identify one or more potential sites for further investigations. These sites are studied during the site characterization stage to identify the preferred site(s) for confirmation. Finally, during the site confirmation stage, the preferred site(s) should be characterized through detailed subsurface studies to determine acceptability from the safety point of view.

306. At each stage of the siting process, societal, ecological and legislative issues should be evaluated and addressed according to national policies. At relevant stages of the process, the regulatory body should be kept informed of and involved in decisions.

QUALITY ASSURANCE

307. Early in the siting process a quality assurance programme for all activities during siting should be established to ensure high data quality and traceability to demonstrate compliance with relevant standards and criteria. The extent to which the quality assurance programme will be applied may differ at different stages within the siting process. The quality assurance programme should contain provisions to ensure the identification of, and compliance with, requirements of appropriate regulations, standards, specifications and practices. It should also provide for production of documentary evidence to demonstrate that the required quality has been achieved.

308. Wherever possible throughout the siting process, data should be collected, presented, stored and archived in a suitably standardized fashion. Where standards and formats do not exist, they should be established early in the process and used throughout. Data should be compiled in a format that facilitates examination and comparison with the fullest possible usability. The organization of data should allow for prompt identification of information gaps.

CONCEPTUAL AND PLANNING STAGE

309. The purpose of the conceptual and planning stage is to develop an overall plan for the site selection process and identify, using available data, potential types of rocks and geological formations which can be used as a basis for the area survey stage.

310. The guiding principles of the siting process should be established by the operating organization early in the planning stage. The financial and human resources, materials, equipment, and time requirements should be estimated to the extent practicable, and responsibilities for the siting studies defined. The siting process should proceed according to a plan, which is likely to require periodic updating, and which should be developed in consultation with the regulatory authority. The plan should include:

(a) identification and description of general tasks to be performed
(b) sequence diagrams of various tasks
(c) any guidelines or criteria adopted for site characteristics
(d) an outline of procedures for applying these guidelines or criteria
(e) a comprehensive schedule
(f) cost estimates
(g) optimization for long term safety concerns.

311. At the start of the conceptual and planning stage, key decision points should be defined, based on the needs and timing for the repository. The types and quantities of waste to be emplaced in the repository should be defined and characterized. The projected waste volumes should be quantified. Using this information, the generic repository design concept should be developed.

312. The overall performance criteria for the repository should be developed by the operating organization, in conformity with national requirements, and, from these criteria, screening guidelines should be established for selecting suitable areas and potential host rocks, and later for selecting the preferred site(s).

313. As a part of this stage, a list of factors which influence the potential of the site to host a disposal facility are defined. These factors can be developed based on consideration of:

(a) long term safety
(b) technical feasibility
(c) socioeconomic, political and environmental considerations.

314. In general it is desirable to determine the potential suitability or acceptability of a site as quickly as possible with use of minimum resources. Thus, those factors or criteria which might result in the rejection of a site should be identified early in the planning stage and investigated early in the survey stage, even if investigations of such factors are not among the most easily conducted.

315. Available methodologies for safety and performance analyses should be reviewed and basic methods and models selected. Subsequently, a generic safety assessment should be performed with the aim of defining important parameters for further studies and as a basis for consultation with the regulatory body. This generic safety assessment could give confidence that the proposed repository concept is capable, in principle, of meeting the regulatory requirements.

316. Safety assessment is an iterative process that may suggest the need for additional data or to re-evaluate the conceptual design. Safety assessment incorporates both numerical analysis and expert judgement in arriving at decisions on the suitability of a disposal system. In these reviews, the opinions of independent experts in various fields (e.g. geology, seismicity, engineering, environmental protection) may be sought.

AREA SURVEY STAGE

317. The purpose of an area survey stage is to identify areas which may contain suitable sites, after the relevant siting factors that were identified in the previous stage

have been considered. This may be accomplished by the stepwise screening of a region of interest, which results in the selection of suitable small areas. If some small areas have already been designated as possible locations, studies can be conducted at this stage to gather the needed regional scale information.

318. The area survey stage generally involves two phases:

(a) area analysis (regional mapping phase) to identify areas with potentially suitable sites
(b) screening to select potential sites for further evaluation.

(a) Regional mapping phase

319. A typical stepwise screening approach starts with defining the region of interest. This may be, for example, the whole territory of a State, a region defined by natural or political boundaries, or lands adjacent to major waste producers in a country.

320. The choice of siting factors used for the regional mapping phase should be based on the type of intended disposal facility, the ability to apply simple guidelines, and the ready availability of the necessary data. Any specific regulatory requirement should also be considered. This analysis will rely mostly on available information (e.g. geological data from previous explorations, historical seismicity data, etc.).

321. In practice, the regional mapping should continue by considering large regions that contain land having favourable geological, hydrogeological and geographical features. Within such land, subsequent activities should focus on successively smaller and increasingly more suitable areas. The process should permit selection of one or more potential sites.

(b) Potential site screening phase

322. In the next phase, potential sites are identified within the suitable areas. The screening of potential sites may involve some factors not considered in the regional mapping phase. Some potential sites may be identified at an early stage, on the basis of those characteristics for which sufficient information can be readily obtained.

323. In the regional analysis and the subsequent screening of potential sites many national laws and regulations need to be considered (e.g. important groundwater resources, national parks, historical monuments). These are, as a rule, clearly defined and therefore no specific regulatory decisions are necessary.

SITE CHARACTERIZATION STAGE

324. The site characterization stage involves the study and investigation of one or several potential sites to demonstrate that they are acceptable in various respects, and in particular from the safety point of view. The information needed to develop a preliminary site related design should be obtained at this stage.

325. The site characterization stage requires site specific information to establish the characteristics and the ranges of parameters of a site with respect to the location of the intended disposal facility. This will require site reconnaissance and investigations to obtain evidence on actual geological, hydrogeological and environmental conditions on the site. This involves on-site surface and subsurface geological investigations supplemented by laboratory work. Other data relevant to site characterization, such as transport access, demography and social considerations, should also be gathered. The result of this stage is the identification of one or more preferred sites for further study.

326. To identify a site for further study, a preliminary safety assessment should indicate that the site is potentially suitable for a repository. The preliminary safety assessment should include the results of the site characterization and the description of the decision process used.

327. If several preferred sites are under consideration, a reasonable comparative evaluation may be made between sites on the basis of their ability to meet all safety requirements and of their acceptability for construction of the disposal facility.

328. At the conclusion of this site characterization stage, the preferred sites are identified. A report on the entire process is prepared, with documentation of all data and analytical work including the preliminary safety assessment. It is expected that the final site selection will also involve judgements based on socioeconomic, environmental and political considerations. It is also expected that the regulatory body will review the results and decide whether the preferred site(s) is (are) likely to be suitable for construction of a repository and whether the planned site confirmation studies are likely to result in a licence application.

SITE CONFIRMATION STAGE

329. The purpose of the site confirmation stage is to conduct detailed site investigations at the preferred site(s) to:

(a) support or confirm the selection of a preferred site(s)
(b) provide additional site specific information required for detailed design, safety analysis, environmental impact assessment and for licensing.

330. The site confirmation stage consists of detailed studies and investigation of the preferred site(s) prior to the start of full scale construction of the repository. Details of the site(s) and its (their) surroundings are defined through the use of additional field, laboratory and subsurface studies. These studies should allow radionuclide transport modelling based on site specific data. The results of this work are used to establish detailed engineering characteristics of the site and to evaluate costs.

331. An environmental assessment as specified by appropriate national authorities should be prepared at this stage. Depending on relevant national laws, the environmental assessment may be very broad and include an evaluation of the effects of the proposed disposal facility on public health and safety and the environment. It may also include a discussion on avoiding or mitigating these effects and other local or regional impacts of locating the disposal facility at the site.

332. Careful comparisons with all relevant criteria are made to confirm that the disposal system will perform as required. Upon confirmation of the suitability of the site, a proposal is submitted to the regulatory authorities with sufficient information to permit decisions to be made as regards approval for construction of the facility. This proposal will include a safety assessment based on the results obtained from the investigation, characterization and confirmation activities. Site confirmation studies are reviewed by the regulatory body, and after reviewing all the information, a decision on site suitability is made. If all necessary requirements are met, approval (licence, construction authorization, or other form of permission) to begin construction of the repository may be issued.

333. Even when siting of the repository has been completed, site confirmation may continue during design, construction, operation, shutdown, sealing and surveillance of the facility, as the activities may provide additional specific information that will allow upgrading of the previous safety studies. These may include larger scale studies that were initiated during site characterization and are continued throughout later stages of the repository life.

4. SITE SELECTION GUIDELINES AND DATA NEEDS

GENERAL

401. Owing to the predominance of factors and processes which may be highly site specific and interactive, only general guidelines can be identified that will govern the suitability of potential sites to host a repository. The relative position of these guidelines in this publication does not imply an order of priority, since their relevance to

the site selection process can vary in specific cases. It is necessary, therefore, that implementation of these guidelines and the development of any subsidiary criteria in a siting process be done in consideration of long term safety, technical feasibility and social, economic and environmental concerns. Criteria so developed should translate technical and institutional concerns into practical measures.

402. Guidelines can be helpful in the overall decision making process but they are not intended to be strict preconditions. To assess whether a disposal system meets its performance goals, the system of natural and engineered barriers has to be considered as a whole. Flexibility in the disposal system is important and the possibility to compensate for uncertainties in the performance of one component by placing more reliance on another should be retained.

403. The following text provides an example of the different siting factors that will have to be considered in a siting process. They are not meant to be a complete set of guidelines and their application will have to take into account the options available and the limitations within each country. Further, these guidelines should not be applied in isolation but will have to be used in an integrated fashion for an overall optimization of site selection.

GEOLOGICAL SETTING

404. Guideline:

> The geological setting of a repository should be amenable to overall characterization and have geometrical, physical and chemical characteristics that combine to inhibit the movement of radionuclides from the repository to the environment during the time periods of concern.

405. The depth and dimensions of the host rock should be sufficient for hosting the repository and provide sufficient distance from geological discontinuities that could provide a rapid pathway for radionuclide transport, such as brecciated fault zones or the flanks of a salt dome. Uniform rock formations in comparatively simple geological settings are preferred because they are likely to be more easily characterized and their properties more predictable. Similarly, formations with few major structural features or potential transport pathways whose impact on performance can be readily assessed are also preferred.

406. The mechanical properties of the host rock should be favourable for the safe construction, operation and closure of the disposal facility and for ensuring the long term stability of the geological barrier surrounding the disposal facility. For heat-generating waste, the thermal and thermomechanical properties of the host rock also

need to be considered. Depending on the potential for gas generation by the disposal system, the gas transport properties of the geological barrier should also be considered in assessing its suitability for disposal.

407. Data needs:

Regional and local structural and stratigraphic data of the rocks, sediments and soils, and their chemical and physical properties, including mechanical and, where appropriate, thermal properties.

FUTURE NATURAL CHANGES

408. Guideline:

The host rock should not be liable to be affected by future geodynamic phenomena (climatic changes, neotectonics, seismicity, volcanism, diapirism) to such an extent that these could unacceptably impair the isolation capability of the overall disposal system.

409. Future climatic evolution (external geodynamic) represented by interglacial and glacial cycles may result in fundamental changes in the Earth's hydrosphere, such as sea level fluctuations, changes in erosion/sedimentation processes, transitions in glacial or periglacial conditions, and variations in the surface and subsurface hydrological balance. Internal geodynamic activities such as ground motion associated with earthquakes, land subsidence and uplift, volcanism and diapirism may also induce changes in the Earth's crust conditions and processes. Both types of events, which can be in some cases interrelated, may affect the overall disposal system through disturbances in the site integrity or modifications of groundwater fluxes and pathways. A preliminary assessment of the predictability and effects of these phenomena should be made for the required periods of time at an early stage of the siting process. The site should be located in a geological and geographical setting where these geodynamic processes or events will not be likely to lead to unacceptable radionuclide release.

410. Data needs:

(a) climatic history (local and regional) and expected future trends at regional and more global scales;
(b) tectonic history and framework of the geological setting at a local and regional scale and its historical seismicity;
(c) evidence of active (Quaternary and possibly late Tertiary) neotectonic processes, such as uplift, subsidence, tilting, folding, faulting;

(d) any presence of faults in the geological setting, their location, length, depth and information on the age of latest movement;
(e) the in situ regional stress field;
(f) estimate of the characteristics of the maximum earthquake physically possible at the site on the basis of its seismotectonic context;
(g) estimate of the geothermal gradient and evidence of thermal springs;
(h) evidence of active (Quaternary and possibly late Tertiary) volcanism;
(i) evidence of diapirism.

411. The above information is not likely to be available at the area survey stage. However, it should be collected as a result of the site characterization and confirmation programmes.

HYDROGEOLOGY

412. Guideline:

The hydrogeological characteristics and setting of the geological environment should tend to restrict groundwater flow within the repository and should support safe waste isolation for the required times.

413. An evaluation of the mechanisms of groundwater movement, as well as an analysis of the direction and rate of flow will be an important input to the safety assessment of any site because the most likely mode of radionuclide release is by groundwater flow. Irrespective of the nature of the waste or the disposal option, a geological environment capable of restricting flow to, through and from the repository will contribute to preventing unacceptable radionuclide releases. Natural features such as aquifers or fracture zones are potential release pathways for radionuclides. Such paths should be limited in the repository host rock so that the protective functions of the geological and engineered barrier system remain compatible. The dilution capacity of the hydrogeological system may also be important and should be evaluated. Siting should be optimized in such a way as to favour long and slow moving groundwater pathways from the repository to the environment.

414. Possible consequences for the hydrogeology resulting from processes caused by the disposal of radioactive waste (e.g. thermal and radiation effects, increased hydraulic conductivity due to mining, etc.) should be taken into account.

415. Data needs:

(a) hydrogeological evaluation of local and regional geological units; characterization and identification of aquifers and aquicludes in sufficient detail;

(b) identification and characterization of important hydrogeological units in the region (e.g. location, extent, interrelationship);
(c) recharge and discharge of the major local and regional hydrogeological units (location and water budget);
(d) hydrogeological characteristics of the host rock (distribution of porosity, hydraulic conductivity and hydraulic head gradients);
(e) groundwater flow (average flow rates and prevailing directions) of all aquifers in the geological environment;
(f) physical and chemical characteristics of the groundwater and host rock in the geological environment.

GEOCHEMISTRY

416. Guideline:

The physicochemical and geochemical characteristics of the geological and hydrogeological environment should tend to limit the release of radionuclides from the disposal facility to the accessible environment.

417. The choice of a host rock and of a surrounding geological environment that has suitable geochemical characteristics and good retardation properties for long lived radionuclides is particularly important in the disposal of long lived waste. In a formation where groundwater movement through fissures and pores occurs, retardation by minerals both within the rock matrix and on the rock surfaces could be important to ensure satisfactory long term performance of the repository system. The retention or retardation processes which govern the consequent rate and quantity of radionuclide migration include processes such as dispersion, diffusion, precipitation, sorption, ion exchange and chemical interaction. The ability of groundwater to transport radioactive colloids may be important and should also be taken into account.

418. Data needs:

Information necessary to estimate the potential for migration of radionuclides to the accessible environment should encompass the description of geochemical and hydrochemical conditions of the host rock, the surrounding geological and hydrogeological units, and their flow systems. This information should include:

(a) mineralogical and petrographical composition of the geological media and their geochemical properties;
(b) groundwater chemistry.

419. The range of chemical and physicochemical interactions between the waste form, the canister and backfill material and the repository environment should be evaluated. To assess migration of radionuclides to the accessible environment resulting from rock-water-canister interactions followed by corrosion of the canister and leaching of radionuclides from the waste, information should be collected on

(a) chemical, radiochemical and mineralogical composition of the rocks (including the fracture infilling materials);
(b) sorption capacities of the minerals and rocks for ionic species of important radionuclides;
(c) radionuclide content and chemical composition of the groundwater, including pH and Eh;
(d) effects of radiation and decay heat on the rock and the groundwater chemistry;
(e) effects of organic, colloidal and microbiological materials;
(f) pore structure and mineral surface characteristics of the rock (including cracks);
(g) effective diffusion rate of nuclides in the rock units;
(h) solubility and speciation of radionuclides.

EVENTS RESULTING FROM HUMAN ACTIVITIES

420. Guideline:

> The siting of a disposal facility should be made with consideration of actual and potential human activities at or near the site. The likelihood that such activities could affect the isolation capability of the disposal system and cause unacceptable consequences should be minimized.

421. In the assessment of a host rock for a repository, valuable or potentially valuable alternative uses of the host rock, such as for storage cavities, should be considered. For example the potential presence of gas/oil deposits, valuable minerals and of geothermal energy should be taken into account to minimize the potential for human intrusion into the geological disposal system. Preference should be given to sites located in areas which minimize the likelihood that the host rock would be exploited for these uses.

422. Pre-existing boreholes and excavations in the host rock and surrounding rocks exhibiting actual or potential hydraulic continuity should be identified. All such boreholes and other structures which could represent potential migration pathways for radionuclides should be plugged and sealed effectively.

423. Surface characteristics that could lead to flooding of the disposal facility as a result of failure of existing or projected surface water impoundments should be carefully considered and evaluated. In the regional analysis, potential sites can be selected on the basis of the severity of effects of flooding.

424. Data needs:

(a) records of past and present drilling and mining operations in the vicinity of the site;
(b) information about occurrences of energy and mineral resources in the area around the site;
(c) evaluation of actual and potential future use of the surface and groundwater at the site;
(d) location of existing and planned surface water bodies.

CONSTRUCTION AND ENGINEERING CONDITIONS

425. Guideline:

The surface and underground characteristics of the site should permit application of an optimized plan of surface facilities and underground workings and the construction of all excavations in compliance with appropriate mining rules.

426. Overall mining or excavation strategies should be prepared and applied to the development of underground workings to ensure that they comply with national mining regulations and that the excavation and waste emplacement do not interfere with one another. The excavation works should be carried out in such a way that they do not create changes in the surrounding rock that would represent unacceptable preferential pathways from the repository to the environment. Rock spoil generated by sinking shafts, driving tunnels and excavating rooms may be evaluated, for example, with a view to its use as backfill in the proposed disposal system. Where this is not possible, appropriate surface dumps could be provided to integrate the spoil into the natural environment. Proximity to appropriate sources of aggregate or water for construction activities may also be a consideration.

427. The disposal system should be deep enough so that only minimum restrictions on, or surveillance of, surface or near surface activities would be needed. However, some restrictions may have to be imposed for the land surface above the repository on activities that can adversely affect the safety of the disposal system, such as drilling, blasting, impoundment of liquid waste, etc. Surface characteristics that could adversely affect the design and construction of surface and underground facilities, such as potential for landslides and floods, should be avoided.

428. Data needs:

(a) detailed geological and hydrogeological data on the host rock and its overburden;
(b) topography of the site and the surrounding area;
(c) flood history of the area;
(d) definition of areas of landslides, potentially unstable slopes or materials of low bearing strength or of high liquefaction potential;
(e) potentially adverse conditions during the mining works (high rock temperature, high gas concentration);
(f) historical seismicity of the region.

TRANSPORTATION OF WASTE

429. Guideline:

The site should be located such that radiation exposures of the public and the environmental impacts of transporting the waste to the site are within acceptable limits.

430. Transportation of radioactive waste to a geological repository involves exposures of the public to ionizing radiation, consumes fuel and adds combustion products to the atmosphere. These impacts will increase with increasing distance of the waste to be transported. Transportation of waste to the repository could also be a significant factor in obtaining public acceptance of a repository location.

431. In some instances new access routes will need to be constructed or existing ones improved. Access routes are more difficult and expensive to construct where unsuitable terrain conditions, such as steep grades and natural obstacles, exist. For these reasons, preference may be given to sites requiring shorter transportation distances, a limited amount of additional construction, and where access routes are not required to traverse difficult terrain.

PROTECTION OF THE ENVIRONMENT

432. Guideline:

The site should be located such that the quality of the environment will be adequately protected and the potentially adverse impacts can be mitigated to an acceptable degree, taking into account technical, economic, social and environmental factors.

433. Geological disposal facilities, like any other major industrial facility, have to comply with the requirements of protection and conservation of the environment and other relevant regulations of non-radiological concern. Among possible adverse effects a geological disposal system may have on the environment, the following may be mentioned:

(a) degradation of the environment due to mining, excavations, and other industrial operations in the area of interest;
(b) impact on areas of significant public value;
(c) degradation of public water supplies;
(d) impact on plant and animal life, particularly endangered species.

434. Data needs:

To estimate potential impacts on environmental quality, the types of information should include:

(a) location of national parks, wildlife areas and historical areas;
(b) existing surface water and groundwater resources;
(c) existing terrestrial and aquatic vegetation and wildlife.

LAND USE

435. Guideline:

In the selection of suitable sites, land use and ownership of land should be considered in connection with possible future development and regional planning in the area of interest.

436. The jurisdiction over the land, or ownership, will in most countries be a significant factor with respect to economics and public acceptance. Existing ownership of the land by the implementor or the government could simplify the site planning and evaluation efforts, and reduce the problems associated with the withdrawal of land from other uses.

437. Data needs:

(a) existing land resources and uses and their jurisdiction;
(b) land use plans for the area of interest.

SOCIAL IMPACTS

438. Guideline:

The site should be located so that the overall societal impact of implementing a repository system at the site is acceptable. Beneficial effects of the siting of a repository in a region or area should be enhanced whenever feasible and any negative societal impacts should be minimized.

439. Areas that have favourable infrastructure or social features for hosting a repository or areas that would particularly benefit from the economic and industrial activities created in conjunction with repository construction and operation might be preferred.

440. The construction and above ground operations such as receiving and handling the waste containers, decontamination and repackaging as required, like any large industrial activity, should avoid densely populated areas. On the other hand, the site should be located in an area capable of absorbing the project related population fluctuations and demands for necessary services, such as construction labour and operating staff, housing, hostels and restaurants, supporting service industry and established civic and cultural organizations. In general, preference should be given to sites away from highly populated areas, but capable of absorbing expected changes in the infrastructure and having a workforce available.

441. Data needs:

To estimate the impacts that might result from the development of a disposal system at a site, the types of information should include data on:

(a) population composition, density, distribution and trends;
(b) employment distribution and trends in the economic sector;
(c) community services and infrastructure;
(d) housing supply and demands;
(e) economic base and expectations in the region.

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[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety Principles and Technical Criteria for the Underground Disposal of High Level Radioactive Wastes, Safety Series No. 99, IAEA, Vienna (1989).

GLOSSARY

The IAEA published a Radioactive Waste Management Glossary as TECDOC-264 (1982) and a second edition as TECDOC-447 (1988). Over the years, continuing developments in the field of radioactive waste management made it necessary to update or revise individual terms. New terms also needed to be defined or added to the Glossary. The IAEA recently published the third version of the Radioactive Waste Management Glossary, incorporating such updates, revisions and amendments. The Radioactive Waste Management Glossary serves as a source for the terms included in this Glossary.

analysis, safety. The evaluation of the potential hazards associated with the implementation of a proposed activity.

area survey. (See survey, area.)

assessment, safety. An analysis to predict the performance of an overall system and its impact, where the performance measure is radiological impact or some other global measure of impact on safety.

barrier. A physical obstruction that prevents or delays the movement (e.g. migration) of radionuclides or other material between components in a system, e.g. a waste repository. In general, a barrier can be an engineered barrier which is constructed or a natural barrier which is inherent to the environment of the repository.

criteria. Conditions on which a decision or judgement can be based. They may be qualitative or quantitative and should result from established principles and standards. In radioactive waste management, criteria and requirements are set by a regulatory body and may result from specific application of a more general principle.

disposal. The emplacement of waste in an approved, specified facility (e.g. near surface or geological repository) without the intention of retrieval. Disposal may also include the approved direct discharge of effluents (e.g. liquid and gaseous wastes) into the environment with subsequent dispersion.

disposal facility. (See repository.)

engineered barrier. (See barrier.)

geological repository. (See repository, geological.)

host medium/host rock. (See rock, host.)

institutional control. Control of a waste site (e.g. disposal site, decommissioning site, etc.) by an authority or institution designated under the laws of a country or state. This control may be active (monitoring, surveillance, remedial work) or passive (land use control) and may be a factor in the design of a nuclear facility (e.g. near surface disposal facility).

long lived waste. (See waste, long lived.)

potential site. Site(s) selected for further investigation following area survey. (See siting.)

preferred site. Site(s) selected for further investigation following site characterization. (See siting.)

repository. A nuclear facility (i.e. geological repository) where waste is emplaced for disposal. Future retrieval of waste from the repository is not intended. (See also **disposal**.)

repository, geological. A nuclear facility for waste disposal located underground (usually more than several hundred metres below the surface) in a stable geological formation to provide long term isolation of radionuclides from the biosphere. Usually such a repository would be used for long lived and/or high level wastes.

rock, host. The stable geological formation in which a repository is located.

safety analysis. (See analysis, safety.)

safety assessment. (See assessment, safety.)

site. The area containing, or under investigation for its suitability to construct, a nuclear facility (e.g. a repository). It is defined by a boundary and is under effective control of the operating organization.

site characterization. Detailed surface and subsurface investigations and activities at candidate disposal sites to obtain information to determine the suitability of and to evaluate long term performance of a waste disposal facility at the site.

site confirmation. The final stage of the site selection process for a nuclear facility (e.g. a repository). Site confirmation is based on detailed investigations on the preferred site which provide site specific information needed for safety assessment. This stage includes the finalization of the repository design and the preparation and submissions of a licence application to the regulatory body.

siting. The process of selecting a suitable disposal site. The process comprises the following stages: (1) concept and planning; (2) area survey; (3) site characterization; and (4) site confirmation.

survey, area (siting process). One of the stages of siting a waste repository, during which a broad region is examined to eliminate unsuitable areas and to identify other areas which may contain suitable sites. (See also **siting**.)

waste, long lived. Radioactive waste containing long lived radionuclides having sufficient radiotoxicity in quantities and/or concentrations requiring long term isolation from the biosphere. The term 'long lived radionuclide' refers to half-lives usually greater than 30 years.

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