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Guidelines for the operation and closure of deep geological repositories for the disposal of high level and alpha bearing wastes

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GUIDELINES FOR THE OPERATION AND CLOSURE OF
DEEP GEOLOGICAL REPOSITORIES FOR THE
DISPOSAL OF HIGH LEVEL AND ALPHA BEARING WASTES

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FOREWORD

This report is part of the IAEA's programme on radioactive waste management, relating to technologies for deep geological disposal of radioactive waste. The report may be of interest to administrative and technical authorities as well as to specialists planning for the safe operation and closure of geological repositories for the disposal of high level and alpha bearing wastes.

The siting, design and construction of a deep geological repository is a major long term project involving many disciplines. The operation and closure periods will likewise occur over decades and the post-closure period will extend to the distant future. During these periods, the prime consideration is that of safety and this is to be achieved by satisfying the safety objectives.

The fundamental safety objectives related to siting the repository and isolating the waste from the environment are addressed in IAEA-TECDOC-563, Siting, Design and Construction of a Deep Geological Repository for the Disposal of High Level and Alpha Bearing Wastes (1990). This document, however, addresses the fundamental safety objectives related to repository operations and closure. The operation period will require that waste received for emplacement is of the correct activity level, is adequately conditioned, is properly emplaced and that appropriate records of the operations are kept. In some cases, waste emplacement and further repository construction may occur concurrently and the necessary backfilling, safety and operational procedures will need to be defined. At repository closure, the necessary sealing and decommissioning will be required. After closure, the future use of the site should be considered. It is planned that the guidance contained in this technical document will be incorporated into a future Safety Guide in the Disposal Subject Area of the Radioactive Waste Safety Standards (RADWASS) series of documents.

A first draft of this document was prepared at a Consultants Meeting in May 1989 and was subsequently revised at an Advisory Group Meeting in June 1990.

CONTENTS

1. INTRODUCTION

1.1 Background

For about the last 100 years, radioactive substances have been known to exist in nature. Their generation and decay have been observed. Humans have learned to make use of them and to handle them safely. When the generation of electricity through use of nuclear fission became a practical reality, basic techniques for dealing with the unavoidable radioactive wastes were required, and investigations as to management of these wastes were initiated. The amounts of the high level and alpha bearing components of these wastes are small in volume, have concentrated radioactivity, and are of high toxicity and hence require isolation from the biosphere. All radioactive waste containing long-lived components in biologically significant concentrations is so far kept in interim storage under monitoring and surveillance.

Several options have been investigated or considered for long-term management of these wastes. Options such as shooting or rocketing these wastes into the sun or outer space, or transmutation into short-lived or inactive nuclides by neutron irradiation do not provide a satisfactorily safe or economic solution at this time. International consensus emerged that disposal in repositories constructed within selected deep geological formations should ensure the isolation of the radioactive waste from the biosphere to an acceptable degree, by providing barriers for as long as its radiotoxicity could cause damage to living organisms. Examples can be found in nature where stable geological formations have isolated radionuclides for many millions of years.

1.2 Objectives

The main objective of this document is to summarize the basic principles and approaches to the operation and closure of a deep geological repository for disposal of high level and alpha bearing radioactive wastes, as commonly agreed upon by Member States. This report is addressed to administrative and technical authorities as well as to specialists planning for the operation and closure of geological repositories for disposal of such wastes.

1.3 Scope

The various stages associated with a deep geological repository consist of the following: siting, design, construction, operation and closure. The first three stages are addressed in a previous report [1]. This document deals with the last two of these stages.

The operation stage is the period when waste is received and emplaced within the repository. During this stage, the waste is received at the repository, inspected, prepared for disposal, transferred to the underground facility, and emplaced in the various underground openings. During this period, underground excavation and construction may continue and backfilling and sealing may be initiated.

The closure stage is the period when the facilities are sealed and decommissioned. During this stage, the backfilling and sealing of the underground openings will be completed, the surface facilities will be decommissioned, and the site may be suitably marked.

Throughout the above stages, ongoing monitoring, testing and associated analyses of the repository system should be continued.

1.4 Structure

The document begins by dealing with those basic considerations that apply generally to the two stages of operation and closure of the repository, namely public and occupational health and safety, and the system of quality assurance that needs to be applied, including documentation (Chapter 2).

All those activities necessary for the safe handling and emplacement of waste are dealt with in Chapter 3.

In Chapter 4, those activities concerned with monitoring for radiation protection purposes are discussed, together with the testing and investigations that will produce the data to be used for repository performance confirmation.

A discussion is presented in Chapter 5 of these activities involved in closing the repository, leaving the underground area in a safe condition and the surface region in a state allowing future use of the site.

The report closes with a summary and conclusions (Chapter 6). The key item to note is the unique combination of nuclear operations in a deep underground location which will require careful planning by the operating organization.

2. BASIC CONSIDERATIONS

2.1 Radiation Protection Principles for Normal Operations

The aim of radiation protection is to prevent the occurrence of detrimental non-stochastic effects and to limit the probability of stochastic effects to levels deemed to be acceptable by national authorities. The basic principles for radiation protection are those recommended by the International Commission on Radiological Protection (ICRP) in its Publication No. 26 [2], which have been incorporated in the IAEA Basic Safety Standards, Safety Series No. 9 [3] and accepted by many national authorities[1/]. These principles can be summarized as follows:

(a) No practice shall be adopted unless its introduction produces a positive net benefit;

(b) All exposures shall be kept as low as reasonably achievable (ALARA), economic and social factors being taken into account; and

(c) The dose equivalent to individuals shall not exceed the appropriate dose limits.

As indicated in IAEA Recommendations, Safety Series Nos. 54 [4] and 60 [5], for radioactive waste management the positive net benefit is from the use of the radioactive materials from which the waste was derived. Thus, this principle is not applicable to waste management by itself; it must take into account the benefits derived from the activity by which the waste was generated.

1/ Since the final Advisory Group Meeting, the ICRP has revised its basic recommendations on radiation protection [ICRP Publication No. 60 (1991)]. Thus, while the parts of this document dealing with radiation protection remain consistent with the Agency's own Basic Safety Standards, which have yet to be revised, they are no longer fully consistent with the ICRP position.

The principle of ALARA, which the ICRP considers synonymous to "optimization of protection" [6], entails an evaluation of the viable alternative options for protection in relation to explicit or implicit preference criteria. A number of quantitative techniques are available to assist in the optimization process, one of which is cost/benefit analysis and there is considerable scope for the application of these optimization processes in waste management. It is most important that the radiation protection programme include an ALARA programme to reduce collective doses. This includes good planning of radiation work, training and use of mock-ups, feedback of experience, etc.

The dose limits for workers and members of the public in the ICRP dose limitation system relate to individuals of the critical group (i.e., those who would be expected to receive the greatest exposure) and are intended to include the effects from all sources of irradiation, excluding natural background and medical irradiation. (It should be noted that irradiation from the excavated rock brought to the surface should not be treated as background radiation, but rather as an additional radiation source resulting from repository operations.) For occupational exposure, ICRP 26 [2] recommends an annual effective dose equivalent limit of 50 mSv, with additional overriding limits on the doses incurred in, and committed to, individual organs and tissues. For public exposure, the principal limit is an annual effective dose equivalent of 1 mSv to the critical group. However, it is permissible to use a subsidiary dose limit of 5 mSv in a year for some years, provided that the average annual effective dose equivalent over a lifetime does not exceed the principal limit of 1 mSv. Additional overriding limits on organ and tissue doses for the public are also recommended by the ICRP [6].

The application of the individual dose limit to the dose distribution from normal releases involves two basic requirements. First, the critical group, must be identified. Second, the design and operation of the repository facility must provide assurance that the average dose in the critical group will not exceed the dose limits, taking into account possible exposures from global, regional, and other local sources. A dose upper bound that serves as the design constraint for the repository should therefore be established, and reserving a prudent fraction of the dose limit for potential future sources, e.g., future practices involving potential radiation exposure such as future uses of nuclear energy and other nuclear technologies.

A comprehensive radiation protection programme should include assessment programmes and the provisions for radiation monitoring as well as safe operating procedures. Additionally, precautionary procedures to cover aspects such as posting of caution signs, labeling of containers, and handling of waste packages and facility-generated waste should also be included. The primary aims of radiation monitoring are to ensure the radiation protection of workers and the public and to demonstrate compliance with the release limits authorized by the national authorities, and should be focused on clearly defined objectives: routine monitoring (associated with continuing normal operations), monitoring of an operation (applied to a particular operation), and special monitoring (in an actual or suspected abnormal situation). Monitoring programmes should include both personnel monitoring and monitoring of normal releases to the environment. The monitoring of releases may also contribute to the detection of abnormal situations. Monitoring of releases during an abnormal situation following, for example, an accident at the repository should have the principal objective of obtaining information necessary to assess the situation and to decide on the need for intervention.

2.2 Radiation Protection Principles for Accident Conditions

The IAEA Recommendations, Safety Series No. 60 [5] indicates that the repository shall be sited, designed, constructed, and operated in such a manner that the projected consequences of any radiological accident, taking into account the probability of its occurrence, are acceptable to the national authorities. Many countries have considerable experience in licensing nuclear facilities, and have consequently developed standards to address the radiation protection considerations for accident conditions. These standards are generally based on assessments of the probabilities of particular accident sequences in conjunction with assessments of the consequence, though not in a manner that is consistent in all countries. Because of its essentially passive nature, the radiological accident potential of a waste repository during operations is considered to be very low.

The objective of protecting individuals from the potential releases associated with accident conditions is best achieved by reverting to an individual risk limitation requirement. By dealing consistently in terms of risk, both the probability of an exposure and the magnitude of the exposure can be included. To take this into account, the ICRP recommends that a risk limit and risk upper bound be established in direct analogy to the dose limits and upper bounds established for normal releases. Such a risk limit should be consistent with the risk implied by the dose limits, such that the overall risk to an individual of the critical group remains below the level considered unacceptable. The restriction of doses over a lifetime to 1 mSv per year on average, as discussed in Section 2.1, implies a constraint of the average annual risk to a level less than one in one hundred thousand. Therefore, the ICRP has suggested that it seems reasonable to restrict the risk to an individual of the critical group resulting from accident conditions so that it is also less than one in one hundred thousand per year [6].

The evaluation of accident conditions that could occur during repository operations needs to be conducted during the repository design process, and should include events such as maximum credible natural phenomena, mechanistic failures associated with waste handling operations, and other man-caused events that could lead to the release of radioactive materials [7]. The design would have to include provisions for the prevention and/or mitigation of accidents through the use of engineered safety features.

While the design of the repository is focused on ensuring that operations can be conducted safely, from an operational standpoint, provisions still need to be available to cope with accidents, if one were to occur. In addressing worker safety during accident conditions, emphasis should be placed on the following areas:

- development of appropriate operating procedures to minimize the potential for operating accidents

- training of operating and support personnel

- monitoring of surface and subsurface environments to detect possible excessive radiation field and/or releases of radioactive material

- capability for on-site first aid treatment for repository-related incidents, coupled with comprehensive off-site medical services

- development of adequate emergency procedures for protection of repository personnel and for bringing the situation to a controlled state

While some of the items above also contribute to a degree to protection of the public, the following additional areas should be addressed as part of the radiation protection programme for the facility:

- controlling public access to areas of operational sensitivity

- monitoring of off-site environments to detect possible excessive radiation or releases of radioactive material

- informing the public on the general aspects of radiation hazards and repository operations

- development of appropriate emergency plans

Emergency planning is a critical element of the defense-in-depth approach that should be taken with respect to protection of the public against the potential consequences of an accident. This could include the use of a graded response approach depending on the level of action needed for a particular accidental release. Arrangements would need to be made for both on-site and off-site facilities so that shelter and medical services would be available, as needed. Emergency planning requires good coordination with local authorities and should also reflect any coordination needed with authorities of neighboring countries.

2.3 Industrial Health and Safety

In addition to the considerations discussed above related to radiation protection, surface and subsurface operations should also take into account those industrial and mining safety requirements that have been established by national authorities, as they relate to a repository facility. Potential conflicts between nuclear regulatory requirements and industrial or mining requirements should be evaluated. For example, the need to restrict and control access to and from controlled areas may potentially conflict with the need to have ready access for emergency egress. In developing the pertinent operating and emergency procedures, such differences need to be resolved.

As in radiation protection, in order to deal with potential industrial and mining accidents, the repository should incorporate facilities and procedures covering such matters as ground control, fire protection, ventilation control, and hazardous materials control. Well-trained emergency staff should be available to respond to such emergencies.

2.4 Quality Assurance

To meet the regulatory requirements of a particular country and to address public concerns, a quality assurance programme is needed to ensure safe operations and to provide adequate confidence that items which affect public and occupational health and safety during the pre- and post-closure phases of a repository, will perform satisfactorily [8]. The quality assurance programme should provide a disciplined approach to all activities affecting quality, including verification that each task has been satisfactorily performed, any corrective actions have been implemented, and that documentary evidence has been produced to demonstrate that the required quality has been achieved.

This programme will need to be developed to meet this objective at the onset of a repository project. This includes quality assurance requirements on vendors of items such as equipment, materials and services to the project. For example, some specific actions that should be taken during the operation phase are the checking of documentation provided by the waste producer, verification by varying degrees of waste form inspection and/or sampling, and auditing of supplier quality assurance programmes and documentation. Noncompliance on the part of suppliers can ultimately result in stoppages until the situation is rectified. Initially, some vendors of specialty items may not have formal quality assurance programmes to the level of quality required by the repository programme. Therefore, sufficient lead time to implement a programme and technical support to aid the vendor should be considered.

2.5 Documentation

A great deal of documentation will be provided as part of standard practices involved in operating any nuclear facility. There will, however, be certain additional requirements for a deep geological repository for high level and alpha bearing wastes. Chiefly, there is a need to provide a comprehensive record of the characteristics of the waste emplaced in the repository, and of the location of the waste packages in the repository geometry. Further information may be provided on the repository structure and the surrounding geology and hydrogeology. Also, information related to safeguards requirements will need to be recorded, where applicable.

3. OPERATION OF THE DEEP GEOLOGICAL REPOSITORY

3.1 Introduction

The main objective of the operation of a repository is to transfer waste packages from the surface and emplace them in an underground location in a safe and efficient manner.

This section of the report sets out those operations associated with ensuring that the waste is that which was dispatched from the point of origin and the operations to prepare it within its container to the standard required by the license for safe disposal.

In this section, a waste package is the waste form and any container as prepared for handling, transport, treatment, conditioning, storage and disposal. Should shielding or other protection be required to transport the waste packages to the site, or to transfer and/or to handle them on site, this will be provided by a cask, reusable or not, which is not considered as being part of the waste package itself.

As a general point, it is important to note that during the lengthy period of operation of the repository, there will be continuing improvements in technology, combined with on site experience which will lead to enhanced quality of structural design features such as construction of underground openings, and backfill and sealing techniques.

As another general point, throughout the repository operation stage, the underground openings will require a good standard of cleanliness because of the nuclear operations involved.

3.2 Receipt of the Waste

At the receipt point, the waste package can arrive in a form suitable for disposal or requiring further conditioning. It could also arrive as a single or composite package. The waste package for a repository may have a range of authorized designs of different shapes and sizes. The transportation cask used to provide shielding and containment and designed to dissipate heat and prevent criticality during surface transportation and handling will be either re-used or disposed of with its content.

The waste package could arrive at the repository site by a variety of shipment modes (i.e., by road, rail or sea). The transporter and the cask used to deliver the waste packages to the repository must be inspected at the point of origin to satisfy the existing transportation regulations. Additionally, it must be checked upon arrival at the repository for radioactive contamination and gamma radiation. Should radioactive contamination be detected, the transporter should be transferred to a clean-up station. The reason for the contamination should be determined and remedial action taken as needed. At the repository site, all the facilities that had been used for the acceptance of the contaminated package should be declared suspect until monitored and decontaminated, as necessary.

Emergency procedures and equipment should be provided at the repository site to deal with off-site transportation accidents to incoming packages in the general vicinity of the repository site. A team knowledgeable with not only the cleanup of and recovery from radioactive spillages but also with resources to deal with first aid and public concerns should be available.

The casks will be transferred from the transporter to a receipt building where the waste packages will be unloaded from the cask and receive the appropriate delivery and acceptance checks. Delivery and acceptance range from checking of the documentation upon delivery to the site to physical inspection of the waste package. Physical inspection of the packages may include determination of weight, radiation levels, verification of integrity and absence of contamination, checking the identification number, and verifying safeguards seals, where applicable.

From the receipt area, the waste package would be routed to the appropriate stage which typically would be one of the following:

- Buffer storage en route to disposal
- Preparation station for transfer underground
- Conditioning station
- Sampling station
- Refurbishment station for damaged packages.

3.3 Buffer Storage

The repository will be designed to accept the waste at an average rate with some allowance for variations from the average. The facilities to receive, check, transfer and emplace the waste will be capable of dealing with this rate of package delivery under normal circumstances. It will be prudent to provide a buffer storage at several stages of the repository system to accommodate the normal fluctuations of delivery rate of packages to the site and secondly, to cope with partial or complete interruptions of repository operations.

Buffer storage may be provided on surface and underground at various locations. For example, upon arrival of the transporter, the waste packages could be stored in their transportation cask. After being received and checked, the waste packages ready for disposal may be stored. Those requiring additional preparation could also be stored either before or after conditioning.

Waste buffer storage required to increase flexibility of repository operations does not include interim storage facilities for cooling high level waste before final disposal, that some Member States are considering to construct on the repository site.

3.4 Waste Package Preparation

Different possibilities for waste package preparation exist. In some cases, the waste packages will be delivered to the repository site in a non-reusable transportation cask designed to be disposed of along with the waste. Transfer of waste from surface to underground and emplacement of the waste will not require any further preparation of the waste package.

A common case consists of using two different casks, a transportation cask for delivery to the repository site and a transfer cask on site to handle, transfer and emplace the waste package at its final location. A reusable transfer cask will be returned to the surface after emplacement of the waste package. Another option is to dispose the transfer cask along with the waste package.

Conditioning or reconditioning of the waste for disposal may be required if the waste is delivered to the site in a form which is not suitable for disposal or if the waste package has been damaged during surface transport. Preparation of the waste for disposal could include packaging, repackaging, removal of overpack, overpacking, clean up of surface-contaminated packages, and refurbishing. Depending on the type of waste form, safeguards measures may be needed to prevent any possibility for nuclear material diversion.

3.5 Transfer of Waste from Surface to Underground

When the waste package is prepared for underground disposal, the next operation is to transfer the package via access shafts or ramps to the main underground accessway en route to the emplacement location.

The access to the underground repository may need to be multifunctional to limit the number of openings in order to minimize potential impacts to the waste isolation capability of the site. However, the transfer of the waste package should be done through a dedicated accessway. Other access functions, like those for personnel, emergency egress, construction and maintenance materials, excavated rock, backfill material, ventilation, and service systems, could be combined, as needed.

The various combinations of waste package emplacement activities and how they interface with other activities will necessitate careful forward planning. A key consideration, as mentioned above, is the need to segregate construction and waste emplacement operations, for example, by providing separate ventilation controls.

It is not possible to define exact operational sequences for the transfer of waste packages from the surface to the underground facility because there will be many different combinations depending on the various designs of the repository, sequences of construction and emplacement operations and types of waste packages. Nevertheless, several possible alternatives are being considered. For instance, the waste package could be transferred to the underground facility by lowering it down a shaft to a vehicle that would then transport the package to its emplacement location. If the repository has an access ramp, the waste package could also be transferred directly from the surface to the underground facility and to its emplacement location by using a transfer vehicle.

The operation of transferring the waste package must be done to defined procedures which limit the radiation exposure to personnel and ensure that the package handling equipment does not subject the package to conditions beyond those acceptable for the design. The contamination consequences resulting from an accidental spillage from a waste package should be restricted by ventilation air control and treatment. Thermal and criticality constraints should also be considered in the handling sequences.

The use of robust and reliable remote handling equipment is desirable to reduce doses to operators and to limit the number of operations required, again reducing the dose commitment.

3.6 Emplacement of Waste

There are quite a few options available for emplacement of wastes in underground openings. These range from emplacement of a single waste package in an individual emplacement borehole to stacking a number of waste containers in an orderly array in a disposal room. The alternative possibilities depend on the waste type and package, heat output, and criticality.

In all cases, the emplacement operation will require a crane and/or transfer vehicle to move the waste package to the emplacement location, to orient it for final emplacement in the borehole or in its emplacement position among other containers and where appropriate, to discharge it from its transfer cask and place closure shielding over the emplacement position.

The equipment to carry out the transfer and emplacement operations should be reliable and robust and it is desirable that as many operations as possible be remote to reduce the radiological impact to the operators. In most cases there is sufficient time to develop special purpose equipment for these operations. At all steps during the process, appropriate shielding should be provided to protect workers that may be present in order to satisfy applicable radiation protection standards. Also, where applicable, appropriate safeguards measures, including surveillance, should be applied, though there is no consensus on methods.

There can be many different combinations of equipment and transfer systems for the various containers and emplacement geometries. More detailed information on these concepts can be found in references [7,9,10,11,12,14,15].

The location of the emplaced package should be recorded as part of the waste inventory of the underground opening being used at that time. The location should be monitored for radiation and when the full inventory of the underground opening is in place, it can be prepared for backfilling and/or partial sealing. However, the timing of the backfilling and sealing operations will depend on national regulations or preference and also on the constraints dictated by the geological medium chosen for waste emplacement. The details associated with the backfilling and sealing activities are discussed in Chapter 5.

3.7 Partial Backfilling and Sealing

In some cases, the characteristics of the host rock may dictate backfilling of the underground openings shortly after waste emplacement. In other cases, the placement of a buffer material around the waste package followed almost immediately by backfilling is an integral part of the emplacement process. These operations can occur concurrently with continued construction in another section of the repository. This may allow excavated rock to be directly transferred from the construction area to the disposal area. Sealing structures, such as bulkheads, can then be constructed to isolate individual openings. Backfilling and sealing processes are presented in Section 5.3.

3.8 Support Facilities and Services

To support the mainstream operation of the preparation and emplacement of the waste, the repository will have facilities to service the disposal operation and to provide the normal administrative and domestic services. The normal support facilities and services for operations involving radioactive materials will be required, for example, treatment facilities for waste generated on site, health physics laboratory, decontamination facilities, hot cells, maintenance facilities, physical security and protection, and engineering, management and administrative services.

The main operation of the repository is high level radioactive waste disposal, but this process also creates radioactive waste of lower activity and there will be a need to have facilities to treat and package this waste. This waste could be disposed of on site or sent for off-site disposal to a facility licensed for that class of waste.

The unique situation of handling radioactive materials in an underground environment may require additional support service personnel trained to intervene in special emergency conditions such as a fire involving a waste transfer vehicle while underground. This combination of fire suppression, underground rescue and radiation protection capabilities will require special training requirements and facilities not normally available. In addition, the state-of-the-art technology employed at this specialized facility, particularly in geoscience and mining technology may require the upgrading of engineering and technical staff qualifications, including testing, beyond that required in the more normal aspects of these disciplines. Thus, facilities and services for training and qualification of staff should be provided at the facility.

4. ONGOING MONITORING AND TESTING

4.1 Introduction

Throughout the repository operation stage, there should be a programme of ongoing testing and monitoring, which would need to be properly coordinated with the other repository activities going on at the time (i.e., waste emplacement, underground excavation and construction, partial backfilling and sealing). Such a programme should include plans for radiation monitoring of the repository environment as well as a programme for continuing the testing and monitoring that were initiated during earlier repository stages for the purpose of confirming certain performance characteristics of the repository system. These operation stage monitoring and testing programmes should continue past the emplacement of the last waste package and up to the time of the closure stage.

The monitoring and testing programme would provide input to ongoing safety assessments. Preliminary performance criteria would have been established for individual components of the disposal system early in the development of the repository design. These criteria may need to be re-evaluated as additional information and analyses concerning the design and performance of the repository systems are developed during the operation stage of the repository. Safety assessment of the individual components of the disposal system is, therefore, an iterative process.

As part of the monitoring and testing programme, a control centre should be provided with links to the areas being monitored to provide, where possible, direct transmission of information on the state of the various facilities or components of the repository system.

The monitoring activities referred to above are concerned solely with radiation. In addition, other monitoring will be required for control of hazardous substances which may be present anywhere on site.

4.2 Radiation Monitoring

4.2.1 Monitoring during normal operations

The radiation monitoring programme to be conducted at the repository facility should monitor the repository environment, both surface and subsurface, and should be quite similar to the monitoring programmes normally conducted at other nuclear facilities. However, the following items of potential importance to a deep geological repository need special considerations.

4.2.1.1 Area monitoring

The total site will require the usual ground contamination radiation surveys. The large number of handling operations involving packages with highly radioactive material will require frequent monitoring of the routes and of the surrounds of the facilities that are used. Such monitoring could serve as a useful indicator of the performance of the containment function of the transfer casks and of the active cells. Area monitoring in the underground openings is particularly important as the airflows of the ventilation will complicate the location of the source of any leakage.

4.2.1.2 Air sampling

Air sampling should be applied to the site as a whole and each active facility should also be monitored. Again, underground air sampling will be important and a comprehensive system will be required to achieve a meaningful analysis as the ventilation airflow patterns are expected to be complex. The sampling frequency and response time of the monitoring equipment should also take account of the different air velocities in the various underground openings. This programme of air sampling should be coordinated with other sampling programmes for hazardous substances.

4.2.1.3 Water sampling

The site water drainage system will require sampling for radiation at appropriate collection points and treatment, if necessary, before release off site. Decontamination facilities for equipment are expected to make use of large quantities of water and thorough sampling and treatment will be required before any process water is returned to the drainage system.

Some of the original site confirmation boreholes could be retained as underground water monitoring stations during the operation stage. These may be both on site and off site.

4.2.2 Monitoring during abnormal or accident conditions

The routine radiation monitoring of the repository facility environment is expected to detect when an abnormal condition develops. During abnormal or accident events, it is important that routine monitoring continues and that it is augmented with additional surveys of the known or suspected area so that the appropriate safety precautions can be adopted and information is collected to understand and apply the necessary remedies.

4.3 Performance Confirmation

The performance confirmation programme conducted during the operation stage of the repository is intended to obtain the additional information needed to provide the sufficient level of confidence to close the repository. At each stage of the operation of the repository, from waste package emplacement to partial backfilling and sealing, sufficient instrumentation should be installed to allow an assessment of those parameters that contribute to the confirmation of performance. Measurements such as temperature, humidity, gas and water composition, and structural and hydraulic responses will provide useful information to ongoing repository performance assessments.

After waste emplacement operations have been completed, some national authorities may require that the repository operator continues its programme of performance confirmation testing and monitoring until such time as final repository closure begins. This period may vary from a very short time to as much as several decades. During this time, repository personnel would essentially be reduced to the number necessary for maintenance services, monitoring, and data analysis even though some other services such as physical security and protection and first aid would also be maintained [7].

Radiation protection coverage would need to be provided similar to those discussed earlier for normal and accident conditions. For example, the monitoring programme discussed in Section 4.2 would be continued with the exception of those aspects specifically associated with the actual movement of waste.

While some monitoring of the parameters related to facility safety is conducted, as noted above, the principal focus of this additional monitoring period is for purposes of performance confirmation, that is, to increase the confidence in predictions of the long-term performance of the repository system. This is basically a continuation of the programme conducted during repository operations, as discussed above.

In developing such a performance confirmation programme for this additional monitoring period, the following should be considered:

- the information obtained from the on-going monitoring conducted during earlier repository stages;
- the level of confidence that such a monitoring programme would add to predictions of long-term performance;
- the amount of underground access that would be needed to perform certain monitoring activities;
- primary and support services that would be needed;
- the extent to which the underground openings should be backfilled and sealed;
- the extent to which underground ventilation systems would be required to operate on a continuous basis or only as needed for particular activities; and

- the potential effect that conducting such a monitoring programme could have on the waste isolation characteristics of the site, particularly if the ventilation system is operated on an intermittent basis, leading to repository rock temperature cycling.

Some national authorities may require that until the time the performance confirmation programme is completed, the option to retrieve the emplaced waste be maintained. This retrievability consideration is intended to serve as a contingency plan in the event the performance confirmation programme results were to indicate that the repository site would not be able to provide the safe long-term isolation that had been expected. In the unlikely event that retrieval of the emplaced waste were necessary, such an operation is expected to take as long as it took to construct the repository and emplace the waste. Therefore, the radiation protection and industrial safety considerations discussed in Chapter 2 should be applied.

5. REPOSITORY CLOSURE

5.1 Introduction

As discussed earlier, the physical state of the repository prior to closure will differ, depending on the regulations and preference of the various Member States. For example, in some cases, no prior backfilling or sealing may have taken place and therefore all the repository openings would still be open. On the other hand, partial backfilling and sealing may have already been completed for emplacement areas. Regardless of these potential differences, the common consideration that must be satisfied is that the repository operator and other pertinent national authorities have a sufficient level of confidence that the repository system will satisfactorily perform its intended function of long-term isolation of the waste, and therefore final closure operations may begin.

5.2 Functions of Sealing and Backfilling Systems

Repository sealing systems are designed to limit the flow of fluids (groundwater, surface water, brine, gases) and transport of radionuclides along openings (shafts, ramps, boreholes) connecting the waste emplacement area of the repository to the biosphere [13]. A related function is to isolate sections of access openings which intersect major fracture zones forming pathways for rapid radionuclide transport to the biosphere. Another function is to divide the repository into several sections, so that if the geological containment is breached, e.g., by movement along a fault, the damage will be limited to one section and will not affect the entire repository.

In hard rock, seals will be required to maintain their performance over extremely long periods of time. On the other hand, in a plastic medium such as salt, seals may only be required to be effective for a short time until the backfill is sufficiently consolidated by creep to provide the long-term sealing function.

The simplest type of backfill is that formed by replacement of the excavated rock. The properties of such a material will depend on the particle sizes and the degree of compaction, but it will be inevitably more permeable and porous than the intact rock and may not act as a significant barrier to groundwater flow. Its primary function would then be to provide a long-term support to the surrounding rock and so minimize the extension of the disturbed zone. In plastic media such as salt or clay, progressive consolidation of the backfill will occur through creep and may become eventually an effective barrier to flow.

5.3 Backfilling and Sealing Process

Backfill and sealing materials could include excavated rock, cement, sand, clay, and bitumen-based materials. Sealing structures (e.g., bulkheads, dams, plugs, etc.) would be strategically placed to meet waste isolation needs. The selection of backfill and sealing materials and associated emplacement techniques will depend on the performance requirements. The entire backfilling and material sequence should be carefully planned with particular consideration given to changes that will occur in the work logistics and underground ventilation circuits.

Prior to initiating the backfilling and sealing of those underground openings that had not yet been previously backfilled or sealed, the removal of equipment, ground support systems, and miscellaneous items should be considered. The repository operator should check for potential contamination within the subsurface facility, and decontaminate, as needed. Deteriorated physical conditions that may adversely affect waste isolation should be corrected prior to the initiation of backfilling and sealing. Then, the backfill and sealing materials would be placed in each of the underground openings, as appropriate.

Once the underground openings have been backfilled and sealed, the shafts or ramps would then be similarly backfilled and sealed. As was done for the underground openings, equipment, ground support systems, and miscellaneous items not needed for sealing operations, should be removed, and correction of deteriorated conditions should be conducted.

As repository closure is being completed, consideration should be given to the desirability of placing subsurface marker systems to reduce the probability of inadvertent human intrusion. Another aspect of the closure programme that needs to be considered is the sealing of exploratory boreholes in accordance with the requirements of the appropriate authorities.

The activities related to closure of the repository are expected to take many years, depending on the extent of backfilling and sealing that had occurred in the operation stage. From a radiation protection and industrial safety perspective, the considerations discussed in Chapter 2 need to be addressed as well during this period. In addition, the monitoring programme discussed in Chapter 4 may be continued throughout the closure phase, to the extent required by national authorities.

5.4 Decommissioning of the Surface Facilities

The surface facilities will be required to be dismantled in a planned sequence to bring the site as closely as practicable to its original condition or to prepare it for the condition suited to a future use.

At this stage, the repository has been sealed and buildings, plant and equipment should be decontaminated, as needed, and then removed. The only component of the repository that may remain on the surface will be the spoil deposits of excavated rock.

During the construction and operation stages, the spoils may have been progressively placed in a planned location to blend with the local environment and topography. It is desirable to start partial landscaping and vegetation as an on-going process from the very beginning of construction. Use of excavated rock for on site construction (backfilling and sealing), road construction, etc. and when possible, off-site use will contribute to minimize the quantity of spoil material remaining on site at the decommissioning stage. Final landscaping and revegetation of residual spoils will be part of the decommissioning programme.

As part of the repository closure process, the necessary arrangements must be made for post-closure institutional control, to minimize the probability of inadvertent human intrusion, including the preservation of details of the facility and records of the type and location of waste. In addition, consideration should be given to the placement of surface markers or monuments to indicate that a repository exists at that location. The form or type of such records or markers would depend on national requirements or site conditions.

At each stage of the dismantling process, contamination monitoring must continue because even in the best controlled situation, at some point in time, active material could have been misplaced. The decommissioning programme is completed when the site is returned to an acceptable condition to meet the criteria established by national authorities.

5.5 Future Use of the Site

The total time cycle from initial site investigations to repository decommissioning will be in the order of one century. It would be premature for members of this generation to suggest possible future uses of the site. From the initiation of the disposal programme, the spoils and other alterations to the area may impact any future use. It would seem appropriate that the best overall planning strategy is to assume initially that the surface area should be restored as much as practicable to its original state and let indications of possible re-use to develop progressively. The presence of the underground repository should not be a significant limitation on future uses of the surface area.

6. SUMMARY AND CONCLUSIONS

The operation and closure of a deep geological repository for the disposal of high level and alpha bearing wastes is a long term project involving many disciplines. This unique combination of nuclear operations in a deep underground location will require careful planning by the operating organization.

The basic purpose of the operation stage of the deep repository is to ensure the safe disposal of the radioactive wastes. The purpose of the closure stage is to ensure that the wastes are safely isolated from the biosphere, and that the surface region can be returned to normal use.

During these two stages of operation and closure, it is essential that both workers and the public are safely protected from radiation hazards, and that workers are protected from the hazards of working underground.

For these periods of the repository, it is essential to carry out monitoring for purposes of radiological protection, and to continue testing and investigations to provide data for repository performance confirmation and for final safety assessment.

Over the lengthy stages of operation and closure, there will be substantial feedback of experience and generation of site data. These will lead both to improved quality of operation and a better understanding of the site characteristics, thereby enhancing the confidence in the ability of the repository system to isolate the waste and protect future generations.

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CONTRIBUTORS TO DRAFTING AND REVIEW

Consultants' Meeting, 8-12 May 1989, Vienna

M. Ginniff	UK Nirex Ltd., Curie Avenue, Harwell, Didcot Oxon OX11 0RH, UK
M. Lugo	Jacobs Engineering Group, Inc. Roy F. Weston 955 L'Enfant Plaza S.W., 8th Floor, North Bldg. Washington, D.C. 20024, USA
I. Vovk (Scientific Secretary)	International Atomic Energy Agency Division of Nuclear Fuel Cycle and Waste Management

Advisory Group Meeting, 18-22 June 1990, Vienna

P. Baumgartner	AECL - Whiteshell Nuclear Research Establishment Pinawa, Manitoba R0E 1L0, Canada
S. Blow	UK Nirex Ltd. Curie Avenue, Harwell, Didcot Oxon OX11 0RH, UK
M. Lugo	Jacobs Engineering Group, Inc. Roy F. Weston 955 L'Enfant Plaza S.W., 8th Floor, North Bldg. Washington, D.C. 20024, USA
J. Potier	ANDRA Route du Panorama Robert Schumann B.P. 38 92266 Fontenay-aux-roses Cedex, France
P. Verougstraete	ONDRAF/NIRAS Place Madou 1, B.P. 24/25 1030 Brussels, Belgium
M. Bell (Scientific Secretary)	International Atomic Energy Agency Division of Nuclear Fuel Cycle and Waste Management

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