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Technological Implications of International Safeguards for Geological Disposal of Spent Fuel and Radioactive Waste

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TECHNOLOGICAL IMPLICATIONS
OF INTERNATIONAL SAFEGUARDS
FOR GEOLOGICAL DISPOSAL OF
SPENT FUEL AND RADIOACTIVE WASTE

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IAEA NUCLEAR ENERGY SERIES No. NW-T-1.21

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FOREWORD

A number of questions arise in considering the implications of safeguarding spent fuel in its disposal phase. Since safeguards must be continued for nuclear material still considered to represent a potential target of diversion for undeclared and non-peaceful uses, the need to continue safeguards must be in harmony with plans to ensure that spent fuel is managed and disposed of in a way that ensures long term safety. A major concern from the waste management point of view is thus that the arrangements made to ensure the long term safety of spent fuel in a geological repository are harmonized with safeguards.

Interface issues between nuclear safeguards and radioactive waste management were already addressed by an IAEA Working Group on Principles and Criteria for Radioactive Waste Disposal, and published in 1996 in as IAEA-TECDOC-909. Beginning in 1988, the IAEA held a series of meetings to develop a safeguards policy with respect to the disposal of spent fuel in geological repositories. In addition, the IAEA Programme for the Development of Safeguards for the Final Disposal of Spent Fuel in Geological Repositories (SAGOR) was active from 1994 to 1998 and developed a generic comprehensive safeguards approach based on the provisions of INFCIRC/153 (i.e. traditional safeguards measures that were not yet integrated with the provisions of the additional protocol, INFCIRC/540) for geological repositories. Recognizing the progress made by some countries in the development of geological repository programmes, the IAEA continued sponsoring Experts Group Meetings of SAGOR-II from 1998 to 2005 to evaluate potential measures for implementing the traditional safeguards approach. This resulted in a number of publications in the Safeguards Technical Reports Series. Since 2005, a new Experts Group,, known as the Application of Safeguards to Repositories (ASTOR), has been convened to support the application of a safeguards approach to geological repositories and to address implementation issues for specific repositories.

Building on previous work this report focuses on the technological implications of international safeguards at a generic geological repository containing spent fuel and radioactive waste during its design, construction, operation and post-operational phases. It addresses the potential technological implications for a repository operator to satisfy postulated traditional IAEA obligations (INFCIRC/153) with respect to safeguarded spent fuel, and possibly other nuclear material waste on which safeguards has not been terminated, that will be transferred to a geological repository. These implications are based on the status of knowledge, both on waste management and safeguards issues, which was available during the preparation of this report by two consultants meetings and Member State representatives of a Technical Meeting held in Vienna from 19 to 23 April 2004.

A model safeguards approach that seeks the optimal combination of traditional safeguards with State level assurances provided by the evaluation of all information available to the IAEA regarding nuclear fuel cycle activities in the State and complementary accesses to locations in the State (i.e. integrated safeguards under INFCIRC/540) are currently being developed by the IAEA. The geological repository integrated safeguards approach would become part of an approach for a specific State that takes into consideration State level and facility level factors to enhance the effectiveness and efficiency of IAEA safeguards. Any identified technical implication of the traditional safeguards approach for geological repositories used as the model for this evaluation is likely to cover the potential implications of an integrated approach for a repository.

The IAEA would like to express its thanks to all participants involved in the drafting of this report. Special thanks are due to B. Moran (USA) for his leading role in discussions during the consultants and Technical Meetings, and to I. Upshall (United Kingdom) for his contribution in finalizing this report.

The IAEA officers responsible for this report were S. Hossain and B. Neerdael of the Division of Nuclear Fuel Cycle and Waste Technology.

EDITORIAL NOTE

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1. INTRODUCTION

1.1. BACKGROUND

The IAEA has been involved in the development of geological disposal concepts for nuclear material, with a particular emphasis in the areas of safety, technology and safeguards. The issue concerning the interface between nuclear safeguards and radioactive waste management was discussed in the 1990s at meetings of a Working Group of the International Waste Management Advisory Committee (INWAC) [1]. Discussions at those meetings indicated that there may be significant implications with regard to the application of IAEA safeguards in geological repositories by the waste management community.

The IAEA has been working on various aspects of safeguards for geological repositories for about 20 years. Beginning in 1988, a series of Advisory Group and consultants meetings were held to develop a safeguards policy with respect to geological repositories [2]. At the same time, the IAEA and Germany established the first task on the development of a safeguards approach for a geological repository in a salt dome [3, 4]. In addition, the IAEA Programme for the Development of Safeguards for the Final Disposal of Spent Fuel in Geological Repositories (SAGOR), comprising eight Member State Support Programmes, the European Commission, and the IAEA, was active from 1994 to 1998 [5]. A generic safeguards approach based on the provisions of INFCIRC/153 (i.e. traditional safeguards that were not yet integrated with the provisions of the additional protocol, INFCIRC/540) developed by SAGOR was recommended to the IAEA at the 1997 Advisory Group Meeting [6]. When not otherwise specified, the safeguards measures evaluated in this report are based on measures identified for possible use within this traditional safeguards approach.

Recognizing the progress made by some countries in the development of geological repository programmes, the IAEA shifted its focus from generic approaches to site specific facilities. From 1998 to 2005, IAEA Experts Group meetings of SAGOR-II evaluated potential measures for implementing the traditional safeguards approach. This resulted in the issuance of a number of publications in the Safeguards Technical Reports Series. Since 2005, a new Experts Group, named Application of Safeguards to Repositories (ASTOR), has been meeting to support the application of safeguards to geological repositories and to address implementation issues for specific repositories.

A model safeguards approach that seeks the optimal combination of traditional safeguards with the State level assurances provided by the evaluation of all information available to the IAEA regarding nuclear fuel cycle activities in the State and complementary accesses to locations in the State (i.e. integrated safeguards under INFCIRC/540) are currently being developed by the IAEA. The geological repository integrated safeguards approach would become a part of the State level approach for a specific State that takes into consideration State level and facility level factors to enhance the effectiveness and efficiency of IAEA safeguards. As the safeguards measures contained in a facility specific traditional safeguards approach are likely to be more intensively implemented than the measures required under an integrated safeguards approach, any identified technological implications of the generic traditional safeguards approach for geological repositories will cover the potential implications of an integrated approach on a repository.

The IAEA has published, under its Safety Standards Series, Safety Requirements that could be used by countries in the development of their own geological disposal programmes [7]. To be licensed, constructed and operated, a geological repository will require that a safety case[1] and supporting safety assessments be prepared and regularly updated by the operator. As the facility evolves, the safety case will be updated as a continuous process and will be sufficiently detailed and comprehensive to provide sufficient technical input to regulatory and other decisions. According to the Safety Requirements, it is expected that a geological repository will be licensed by a country's regulatory authority only after a satisfactory safety case has been accepted by the relevant national authorities.

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[1] A safety case is a collection of arguments, at a given stage of repository development, in support of the long term safety of the repository. A safety case comprises the findings of a safety assessment and a statement of confidence in these findings. It should acknowledge the existence of any unresolved issues and provide guidance for work to resolve these issues in future development stages. (See OECD NUCLEAR ENERGY AGENCY, Radioactive Waste Management, Confidence in the Long-term Safety of Deep Geological Repositories, its Development and Communication, OECD, Paris (1999).)

A geological repository that would accept safeguarded nuclear material could be managed under an appropriate safeguards regime as long as a safeguards agreement exists between the State/regional safeguards authority and the IAEA. Since this safeguards agreement is likely to remain in force for a long period of time, the impacts of meeting facility specific obligations have received significant attention from the safeguards community, which also recognizes the need to minimize the burden on future generations while maintaining the long term safety of the repository.

It is generally accepted that safe evolution of a geological repository must not be reliant on continuing, active, institutional control even after its closure. However, the requirement to apply IAEA safeguards could, as long as the IAEA's safeguards agreement with the State/regional authority remains in force, necessitate a long term inspection regime which might call for specific measures, as far as feasible and agreed.

1.2. OBJECTIVE

The objective of this report is to contribute towards preliminary clarification of potential technological implications of implementing international safeguards measures at a generic geological repository containing spent nuclear fuel, unirradiated nuclear material waste, and other radiological waste during the design, construction, operation and post-operational phases.

1.3. SCOPE

This report addresses the potential technological implications to a repository operator of the expected IAEA obligations with respect to safeguarded spent fuel and other nuclear material that will be transferred to a geological repository. These implications are based on the status of knowledge, both on waste management and safeguards issues, which were available to the experts during the preparation of this report. All phases of the repository lifetime are considered, from conception and design through to post-operational oversight.

A generic geological repository is designed for the disposal of high level waste (HLW), spent fuel for which no further use is foreseen, and other long lived radioactive waste material including unirradiated uranium, thorium and plutonium bearing material. Out of this material, only spent nuclear fuel and unirradiated uranium, thorium and plutonium bearing materials are subject to safeguards (see Section 4.3). The rest of the waste material in the repository, e.g. vitrified HLW and other long lived low and intermediate level waste (LILW), as mentioned in Section 4.3, will not be subject to safeguards verification but could affect safeguards implementation.

The potential impact of the applied technical measures on the safe operation of the facility is especially considered. Domestic requirements for the physical security of the geological repository and for nuclear material control and accountability are not considered here as they may be different from those demanded by the application of IAEA safeguards.

1.4. STRUCTURE

Following this introduction, specific aspects of the technological implications of safeguards considerations in the different phases of the life cycle of a generic geological repository are discussed. Section 2 summarizes the basic principles of both repository safety, and IAEA safeguards. In Section 3, the design of the generic geological repository is described, with a focus on the features likely to be relevant when meeting safeguards obligations. Section 4 describes the safeguards considerations and associated measures that are expected to be relevant during the lifetime of a repository. Section 5 highlights the technological implications expected to result in applying safeguards to the disposal facilities. Finally, in Section 6 some concluding remarks are presented. The conclusions indicate to the waste management community at large how safeguards considerations could be met effectively within the constraints of safety and acceptable performance.

2. REQUIREMENTS FOR REPOSITORY SAFETY AND IAEA SAFEGUARDS

A generally accepted principle relating to the long term safety of radioactive waste/spent fuel present in a geological repository is that the isolation systems should be passive in nature and that an active monitoring programme should be unnecessary. This has been interpreted "as (p)ost-closure safety…(being) provided by means of engineered and geological barriers,…. (not relying) on monitoring or institutional controls after the facility has been closed" [7]. This principle has been recognized and accepted within the nuclear safety and safeguards community with regard to the disposal of spent nuclear fuel. In accordance with the legal basis of the application of IAEA safeguards for repositories containing spent fuel and other nuclear material bearing waste on which safeguards have not been terminated, there remains an obligation to establish and implement a safeguards regime that is capable of detecting the possible diversion of nuclear material for use in nuclear weapons production.

2.1. REPOSITORY SAFETY

The national obligation to control and manage radioactive waste/spent fuel safely is clearly recognized and formalized in the terms of the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management [8]. The IAEA has been independently developing safety requirements for geological repositories to ensure that people and the environment are protected from the effects of exposure to ionizing radiation, both now and in the future [7]. The requirements for the disposal of radioactive waste/spent fuel in a geological repository cover both operational and post-closure safety and are based on nine basic principles. These are stated in the IAEA publication Principles of Radioactive Waste Management [9] and are consistent with the International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radioactive Sources [10].

The safety requirements for the disposal of radioactive waste/spent fuel in a geological repository are concerned with safeguards only from the point of view of the impacts that safeguards specific measures could have upon overall repository safety — both during the operational and post-operational phases. Requirements with respect to nuclear safeguards state:

> "Nuclear safeguards requirements shall be considered in the design and operation of a geological disposal facility to which nuclear safeguards apply, and shall be implemented in such a way as not to compromise the safety of a geological disposal facility." [7]

The safety functions, and in turn the safety case for a geological repository, do not rely upon safeguards measures. However, the latter may occasionally contribute to safety in some aspects of repository performance. In view of the very long time frames involved, international consensus is that safety must be provided by a combination of passive natural and engineered barriers. Any aspects featured in the design or operation of the repository necessary to provide safeguards assurance must be considered in this assessment process.

Geological repositories are likely to be developed over a period of several decades. Before the start of construction, the repository design and operations must be sufficiently understood to support a safety case that is capable of satisfying the applicable national regulatory requirements. The development of the safety case will require the operator to clearly define the characteristics of the waste/spent fuel that is to be managed within the repository. These so called 'waste acceptance criteria' (WAC) are considered part of the repository assessment and licensing process and will generally specify radionuclide or radioactivity limits, heat output, waste matrix, conditioning, encapsulation requirements and waste container properties. Additional criteria might be required for specific reasons; for example, in case of nuclear material subject to safeguards, specifications concerning the identification of waste/spent fuel packages and means for detecting undeclared opening of packages (e.g. safeguards seals).

2.2. IAEA SAFEGUARDS

The Treaty on the Non-Proliferation of Nuclear Weapons [11] prescribes that signatory States declare the quantities and location of *source or special fissionable material*[2] in all peaceful nuclear activities within their territory, under their jurisdiction or carried out under their control anywhere. In addition, the signatory State must allow the IAEA to verify the correctness and completeness of these declarations. The State is to make declarations on all nuclear material (except for those whose quantity is such that they have been exempted from safeguards or for those for which safeguards has been terminated). Safeguards inspections are conducted at locations in a State where nuclear material is declared to be present. It follows, therefore, that the IAEA will implement safeguards measures where nuclear material is placed in a geological repository.

The statutory obligation for the IAEA to conduct safeguards inspections at facilities in non-nuclear weapon States possessing or using thorium, uranium, or plutonium bearing nuclear materials is established by the INFCIRC/153 type safeguards agreement [12] concluded between the IAEA and the signatory State or regional safeguards authority pursuant to the NPT. Articles 1 and 4 of INFCIRC/153 state, respectively:

> "The Agreement should contain…an undertaking by the State to accept safeguards…on all source or special fissionable material in all peaceful nuclear activities within its territory…for the exclusive purpose of verifying that such material is not diverted to nuclear weapons or other nuclear explosive devices."

and

> "The agreement shall be implemented in a manner designed:
>
> (a) To avoid hampering the economic and technological development…of peaceful nuclear activities….
> (b) To avoid undue interference in the State's peaceful nuclear activities, and in particular the operation of facilities;
> (c) To be consistent with prudent management practices required for the economical and safe conduct of nuclear activities."

Countries, from 1997 onwards, began concluding a protocol additional to their safeguards agreements with the IAEA (i.e. additional protocol) that follows the provisions of the Model Additional Protocol (given in INFCIRC/540) [13]. The additional protocol gives the IAEA the means to provide credible assurance to the international community of the absence of undeclared nuclear material, facilities, or activities in the signatory State. Under the additional protocol, a signatory State provides additional information about its nuclear programme and related activities and also provides the IAEA with access to locations involved in these activities. The term 'relevant information' can include descriptions of buildings on sites with nuclear facilities and locations of high and intermediate level waste on which safeguards have been terminated. As mentioned in the Introduction, facility specific approaches integrating traditional safeguards and information analysis, and complementary accesses to locations have yet to be developed. However, because a facility specific integrated safeguards approach is likely to be less intensive than a traditional safeguards approach, this evaluation considered only the measures that have been identified for possible use in a traditional safeguards approach.

In summary, the more general objectives of integrated IAEA safeguards [14] are:

> "…to verify a State's compliance with its undertaking to accept safeguards on all nuclear material in all its peaceful nuclear activities and to verify that such material is not diverted to nuclear weapons or other nuclear explosive devices…the detection of undeclared nuclear material and activities in a State."

An IAEA Safeguards Policy Series publication provides guidance for the planning of safeguards measures where it is intended to dispose of spent fuel in geological repositories.

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[2] Thorium, uranium, or plutonium bearing nuclear material.

The Advisory Group Meeting on Safeguards Related to Final Disposal of Nuclear Material in Waste and Spent Fuel (AGM-660), held in September 1988 [2], recommended the adoption of the following policy statement:

> "Spent fuel disposed in geological repositories is subject to safeguards in accordance with the applicable safeguards agreement. Safeguards for such material are maintained after the repository has been back-filled and sealed, and for as long as the safeguards agreement remains in force. The safeguards applied should provide a credible assurance of non-diversion."

While it has accumulated significant experience in the implementation of traditional safeguards on existing types of nuclear facilities, the IAEA has no direct experience relating to the implementation of safeguards in geological repositories.

3. REPOSITORY CONCEPTS AND PHASES

3.1. TYPES OF WASTE AND SPENT FUEL

The types of waste/spent fuel requiring long term isolation from the biosphere, and therefore destined for eventual emplacement in geological repositories, are:

- **High level waste is defined by the IAEA [15, 16] as:** The radioactive liquid containing most of the fission products and actinides present in spent fuel — which forms the residue from the first solvent extraction cycle in reprocessing — and some of the associated waste streams; this material following solidification; spent fuel (if declared as waste); or any other waste with similar radiological characteristics. Typical characteristics of HLW are thermal power above about 2 kW/m^3 and long lived radionuclide concentrations exceeding the limitations for short lived waste.
- **Long lived, LILW is defined [15, 16] as:** Radioactive waste with radiological characteristics between those of exempt waste and HLW. Typical characteristics of LILW are activity levels above clearance levels and thermal power below about 2 kW/m^3.

In addition the content of long lived radionuclides must be above the level established on the basis of the waste acceptance criteria for near surface disposal.

According to the indications in the IAEA classification of radioactive waste [16] and to the strategy adopted by a large number of countries, the use of the geological repository concept is the preferred disposal option for high activity and/or 'long lived' radioactive waste, including spent fuel. ('Long lived' is used where the waste contains sufficient quantities of radioactive materials with half-lives of such a period that they will not become sufficiently harmless within the established period of institutional controls.) Wastes containing radioactive materials decaying to sufficiently low levels of activity within the institutional control period are considered as 'short lived' and are generally taken to be acceptable for near surface disposal. However, some countries have decided to use a more conservative approach by not making this distinction and are thus planning to place all types of radioactive waste in geological repositories.

Depending on the nuclear material content of the waste/spent fuel, IAEA safeguards could be applied to both short and long lived materials including spent nuclear fuel.

3.2. WASTE/SPENT FUEL PACKAGES

The design and operating philosophy of the repository will be dictated, to a certain extent, by the waste/spent fuel packaging arrangements. In broad terms, the package will typically comprise three components: the waste/spent fuel itself, the encapsulation media, and the container. Consideration will be given to the WAC when establishing the design and subsequent production of the package. The following paragraphs describe some of the important features of each of the three components of the package.

The waste/spent fuel may also be mixed with a suitable conditioning material and its characteristics will be wide ranging. In a State with the full range of nuclear fuel cycle activities these could include radioisotope sources, contaminated materials, manufacturing and processing waste, decommissioning waste, spent fuel reprocessing waste and unreprocessed spent fuel. The waste may be in either solid or liquid form prior to its conditioning for disposal and are also likely to contain non-radioactive toxic substances. Some waste materials may be excluded, however, if they cannot be shown to be safe in the environment of the disposal facility (for example, organic materials and pressurized containers).

Normally, the WAC will require that the ‘raw’ waste is immobilized to delay the transfer of any long lived radionuclides to the surrounding environment, when the primary containment of the waste package eventually fails (either through unforeseen events or through natural degradation). Most countries have opted for the use of either a cement or bitumen based immobilization matrix for LILW, while liquid HLW generally will be vitrified. The raw waste may comprise finely divided particulates (for example, plutonium contaminated material — PCM — or discrete items such as fuel assemblies).

Container types will vary according to the physical, chemical and radiological characteristics of the waste/spent fuel. For HLW and spent fuel, the container is generally constructed from a combination of metals.[3] For LILW, the container may be manufactured from stainless steel or concrete (sometimes with a steel liner). The dimensions of the container and the quantity of materials used will be dictated by physical limitations such as the weight that can be safely transported and handled.

It is expected that the radionuclide content of the raw material would be determined prior to the preparation of their package for disposal. Each waste/spent fuel package will be uniquely identified in order to record its location and movement.

3.3. REPOSITORY CONCEPTS

For the purpose of this report, it is assumed that the geological repository in which safeguards will be applied is a purpose built facility and is based on the reference repository design described in this section.

Many repository concept designs are possible and, in fact, different options have been considered by various countries. The majority of geological repositories currently planned are based on a series of deep excavated vaults at depths of several hundreds of metres. Alternative geological disposal systems have been considered by some countries, for example, repositories consisting of a matrix of deep boreholes drilled either from the surface or from an underground facility. However, the concept of a repository involving deep borehole emplacement of waste from the surface has not been developed in comparable detail as with the concept of a more conventional deep geological repository comprising a series of excavated vaults, or disposal galleries, access tunnels to the vaults, access and ventilation shafts, access ramps or drifts and surface facilities. As a consequence, the application of safeguards to other concepts such as deep borehole facilities is not considered further here.

The development of the actual design for a deep repository shall be based on established procedures and on a comprehensive set of site specific data. There is agreement in current programmes that geological disposal facilities will be developed in a series of steps, each supported, as necessary, by iterative evaluation of site characteristics, design options, management procedures and the safety case, on the basis of progressively updated performance and safety assessments.

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[3] In some national disposal programmes, spent fuel containers are expected to be made out of cast iron or stainless steel and, additionally, may have either copper or titanium cladding.

3.3.1. The generic repository design

General description

For the purpose of describing the safeguards application, it is helpful to briefly describe the layout and key features of the generic repository that is capable of accepting HLW, spent fuel, and LILW, as described in Ref. [17]. The work that led to the design of this generic repository was commissioned by EURATOM and undertaken by a consortium of European waste management agencies with support from various licensing authorities. In practice, however, the repository design will vary according to the particular site constraints, preferences of the State, material inventory, heat output, etc.

The generic repository comprises surface facilities for receiving, handling and temporary storage of packages, as well as those necessary for ongoing construction. The underground facilities comprise the transfer infrastructure, emplacement areas for the waste/spent fuel packages and openings for disposal of LILW. The design basis assumes that the facility will accommodate HLW, spent uranium oxide and mixed oxide fuel, and/or LILW.

The surface facilities are connected to the underground disposal area by means of four access routes: the waste/spent fuel access ramp, the service shaft and two ventilation shafts.

The general layout of a typical repository is shown in Fig. 1 (taken from Ref. [17]). The remainder of this section briefly describes features of the repository that are likely to be of relevance when discussing the application of safeguards.

Surface facilities

The surface facilities of the repository site have been designed to receive spent fuel, vitrified HLW and LILW. The surface facilities comprise all above ground installations necessary for receiving, treating and handling the different waste streams as well as the equipment required to operate the underground repository. The waste/spent fuel will be shipped to the repository site in transport casks either by road, boat or rail or a combination thereof. The HLW canisters and spent fuel assemblies are unloaded from transport casks, transferred to an encapsulation plant and placed in a package and loaded into shielding overpacks, which are subsequently transferred to the emplacement area via a sloping ramp. LILW in drums is received on-site in transport containers that are unloaded in the reception building and placed into overpacks prior to transfer to LILW disposal areas.

Access to underground facilities

The generic repository design considers two types of connections between the surface and the underground facility: access ramp or shafts. The access ramp and the service shaft are located close to each other inside the surface facilities and at some distance from the emplacement areas. The final location of the ventilation shafts will depend on the layout of the emplacement area.

The access ramp is constructed in such a way as to permit the safe transfer of the packages from the surface to the emplacement level.

The service shaft provides access for personnel and materials and serves as an air intake for the underground areas. It is equipped with two hoisting systems, one for transportation of workers and heavy materials and a smaller cage for emergency purposes and shaft maintenance activities. The service shaft contains the main ventilation ducts as well as other supply systems that could include electrical distribution, monitoring and drainage systems.

The ventilation shafts are located at the far end of the emplacement area. Within the generic design, these shafts could be located some distance away from the surface facilities and therefore require special protection and surveillance. The shafts are not equipped with any form of hoist equipment, except for an auxiliary personnel cage for emergency escape. A rescue chamber is provided near each ventilation shaft at the emplacement level.

Underground facilities

The underground facilities comprise the central area, main galleries and emplacement areas.

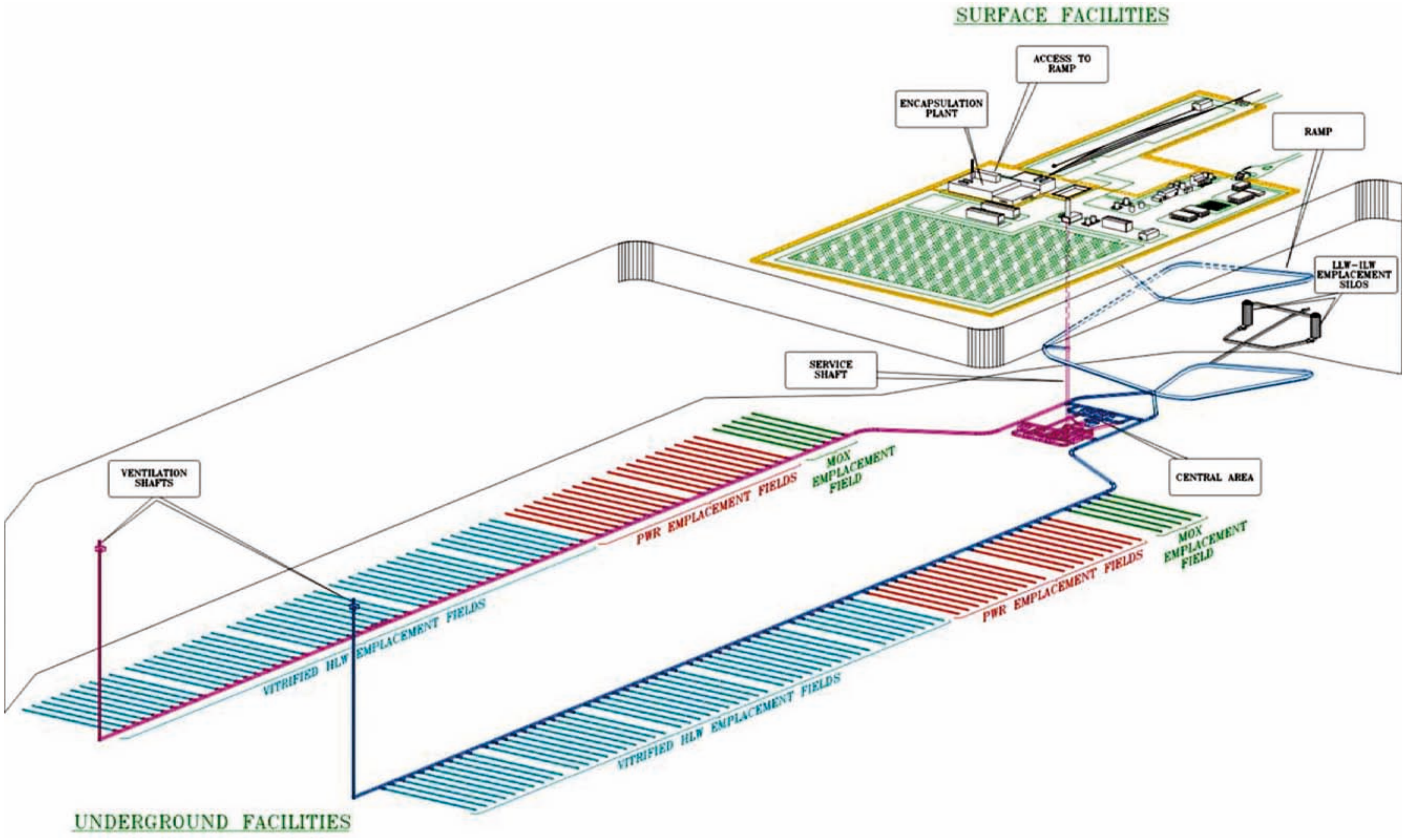

FIG. 1. General layout of a geological repository.

The central area is large enough to accommodate installations and equipment for performing conventional underground construction activities and for the receipt and transfer of the packages.

The central area is connected with the disposal areas by means of two access drifts (main galleries). These are designed to allow for two traffic lanes and give ample space for underground construction and emplacement devices.

The emplacement area consists of one area for HLW and spent fuel and another for LILW. These two areas are physically separated to avoid any undesirable interaction between them but are both accessed from the main galleries. The LILW area consists of two drum silos located near the sloping ramp. The area for HLW and spent fuel comprises two emplacement panels with emplacement fields and drifts.

Emplacement process for packages

Two different emplacement methods are foreseen:

- HLW and spent fuel disposed of in packages centrally emplaced in the emplacement drifts and surrounded by compacted bentonite blocks;
- Drummed LILW disposed of in cylindrical openings (silos).

The generic design proposes that the packages containing HLW or spent fuel be transported from the surface to the underground through a sloping ramp by means of an underground transport vehicle. At the entrance to the emplacement drift the packages are removed from the transport vehicle to a track-bound transport system equipped with equipment for transfer of the package to its final emplacement location.

The overpacked LILW is unloaded from the transport vehicle by means of an overhead crane and moved to an inlet cell where the overpack is opened. The drummed waste is unloaded and transferred to the disposal silo. The empty overpack is returned to the surface.

3.4. REPOSITORY PHASES

A number of steps for the development of a geological repository can be identified. From a safeguards perspective, these steps have been grouped to form three basic phases:

- Pre-operational phase;
- Operational phase;
- Post-closure phase.

3.4.1. Pre-operational phase

During the pre-operational phase, the following main activities in the repository development are carried out:

- Site characterization;
- Underground exploration and access construction;
- Construction of the repository.

It should be noted that in most countries, generic site characterization activities (including underground exploration) take place before selection of a specific candidate site for the repository. At these sites, licensing activities may be limited to the performance of preliminary site investigations. After selection of a specific site for construction of the repository, a new site license will be required and the beginning of the pre-operational phase may be assumed to take place.

Site characterization from the surface is used both to distinguish between different potential sites and to characterize, in detail, the candidate repository site. The objectives of this work are to establish the baseline information for the site, to provide a comprehensive understanding of the nature and properties of the geological and surface environments and to support the safety case and the basic repository system design. Site characterization work, at least for sites seriously considered as potential candidates, will include drilling of exploratory boreholes. Some of the in situ monitoring techniques may be useful for safeguards purposes. Therefore, the synergy of various monitoring programmes should be considered.

Construction of a geological repository (or in some countries, of an exploratory facility) starts with the excavation of access shafts or ramps and the preliminary layout of access galleries. Reconnaissance and investigation work at this stage will supplement site characterization information acquired during the surface exploration.

In some programmes, it is envisaged that construction of the main repository might be preceded by a pilot stage during which demonstrations of technology can be made to enhance confidence in the concept. Construction may be carried out as part of a single construction campaign, or be a progressive programme, with waste/spent fuel packages being emplaced before some regions of the repository are constructed.

3.4.2. Operational phase

The operational phase starts with the commissioning of the repository system and/or receipt of the first package. Activities undertaken during this phase may vary according to the country's policy and licensing procedures. However, for the purpose of this report the activities carried out during the operational phase might include:

- Construction of additional drifts;
- Receipt of packages;
- Emplacement of packages and installation of engineered barriers;
- Backfilling of disposal drifts and vaults;
- Repository backfilling and sealing (repository closure).

The main activity in the operational phase is the emplacement of the waste/spent fuel packages within their surrounding engineered barriers. There are different options for the time at which these various barriers may be put in place, depending on waste and rock characteristics. National requirements for spent fuel retrievability may have a significant influence on the methodology and timing of the activities foreseen by the disposal options chosen. Construction of the repository may proceed in some cases in parallel with waste/spent fuel emplacement.

The time of backfilling of emplacement drifts where disposal has been completed will depend not only on decisions on retrievability, but also on constraints dictated by the properties of the host rock. Backfilling could occur concurrently with continued construction or disposal activities in other drifts. This may allow disposal drifts, after package emplacement, to be directly backfilled, when appropriate, to isolate individual emplacement drifts or vaults.

Backfilling and sealing of all remaining underground areas, including all access routes, are the final actions of the operational phase of a repository. The decision to close the repository will depend on a number of factors including national policy, technical considerations, societal choices and the impact on safety of keeping the repository open.

3.4.3. Post-closure phase

The post-closure phase will begin when the repository access ways have been sealed. Some countries may choose to begin the post-closure phase with a period of institutional control. It is a principle of geological disposal that the long term safety of the repository does not require post-closure monitoring or other institutional control. It is, however, possible, and in some countries required, that some form of institutional control be maintained for an undefined period of time for societal or other reasons. It is obvious that the need to meet safeguards obligations may be one of these reasons.

3.5. RETRIEVABILITY

The disposal programmes of some countries require that the repository design and operational regime provide the ability to monitor the evolution of the facility including waste/spent fuel packages and, if necessary, to retrieve packages from the facility. Retrievability might be provided to allow the possibility of adopting different waste management options in the future such as different disposal routes or recovery of certain materials from the spent fuel. In this case monitoring could play a role in deciding whether and how the packages might be retrieved [18–20].

Detection of unforeseen repository behaviour at an early stage might require prompt remedial action (up to and including retrieval) before radioactive material can migrate to the geosphere and, eventually, the accessible environment.

In some States, the capability to retrieve may need to be demonstrated by suitable demonstration activities. To confirm that packages will be accessible and be able to be handled, retrieval related equipment may have to be developed, installed, and maintained in operational conditions. Such requirements might form part of the maintenance schedule of the facility that would be agreed with the regulators. Inspection of the waste/spent fuel emplacement and retrieval systems would provide ongoing confirmation that reversal of the emplacement of these packages and other near field barriers remains an option. Such inspection would only be meaningful while the repository remained open.

The ability of the facility to reverse the package emplacement system and more specifically to recover waste or spent fuel packages can potentially raise additional issues from the perspective of safety and safeguards. Retrievability can be provided in different ways, such as:

- After emplacement of the packages in the disposal locations, all foreseen engineered barriers are emplaced; however they are designed and built with feasibility of removal as a required feature.
- After emplacement of the packages, only part of the engineered barriers are emplaced. For example, the disposal rooms might be backfilled and sealed, while the access tunnels and connections of the underground openings with the surface could be left open.
- After emplacement of the packages, no engineered barriers, with the exception of the near field buffer, are emplaced until such time when the decision to close the repository is taken.

Regardless of the reasons to include retrievability with a partially or totally open repository in the disposal strategy, comprehensive evaluations of the potential implications of such decision on short and long term safety and on safeguards would appear to be required.

4. SAFEGUARDS MEASURES FOR GEOLOGICAL DISPOSAL

The starting point for the development of a safeguards approach for a specific facility is the identification of the credible means for diverting the nuclear material from its declared location or use. In terms of IAEA safeguards, ‘diversion’ relates to the undeclared transfer of nuclear materials for the possible production of nuclear weapons or other nuclear explosive devices.

The safeguards applied should provide a credible assurance of non-diversion and of the absence of undeclared safeguards relevant activities [12]. In the countries where the measures of the additional protocol [13] are implemented, the safeguards should also enhance the possibility of detecting related undeclared nuclear material and activities in the State.

The design of a geological repository should take into account, among other things:

- The risk from natural processes acting over long periods of time. The design has to limit the release of radioactive material resulting from those processes under the limits prescribed by the safety standards.
- Safeguards requirements. Those requirements are based on diversion scenarios.

4.1. DIVERSION SCENARIOS

The objective of the diversion of nuclear material, as defined by the IAEA, is to obtain sufficient nuclear material to construct at least one nuclear explosive device. Taking into consideration the conversion processes involved, the quantity of nuclear material required is taken to be 8 kg of plutonium or ^{233}U, 25 kg of ^{235}U contained in high enriched uranium (HEU) (20% enriched or more in ^{235}U), 75 kg of ^{235}U contained in low enriched uranium (LEU) (less than 20% enriched in ^{235}U), 10 t of natural uranium, or 20 t of depleted uranium or thorium. The credible diversion paths for a geological repository will be determined by its specific design. Generic diversion paths for geological repositories were documented by the IAEA Programme for the Development of Safeguards for the Final Disposal of Spent Fuel in Geological Repositories (SAGOR) [5]. These diversion paths include direct substitution of an empty disposal container at the surface, retrieval of a spent fuel package from underground, opening of spent fuel packages underground followed by removal of spent fuel assemblies or pins and their transport to the surface, and removal of spent fuel from the spent fuel packages for reprocessing underground. These pathways include removal of the nuclear material through the service shaft or ramp, through vent shafts, or any other openings extending from the repository to the surface. The diversion paths also include clandestine tunnels excavated into the repository or out from the repository to the surface or to a nearby tunnel system. If waste containing non-irradiated material of safeguards interest is also disposed of in the geological repository, similar diversion paths would be relevant.

4.2. SAFEGUARDS APPROACH

The primary objective of IAEA safeguards is to detect the diversion of nuclear material from the time the spent fuel and/or any other type of safeguarded nuclear material is shipped to the repository. To ensure that the site specific safeguards approach is effective, the IAEA needs to begin consultations with the repository developer and with the national or regional authorities in advance of the start of construction of the repository. These consultations will include design information examination and may establish knowledge of baseline environmental and geological parameters associated with the undisturbed repository site. From this information, safeguards measures and equipment types will be determined.

During construction, design information verification (DIV) would be used to verify the declared design of the repository. To accomplish this, the IAEA may undertake inspection and monitoring activities to assure itself of the absence of undeclared chambers or tunnels, and to identify undeclared equipment (for example, hot cells for opening spent fuel packages or equipment for reprocessing of spent fuel). DIV in this instance might employ a range of techniques to verify declared and detect undeclared excavation activities. Geophysical techniques and satellite imagery, in so far as these techniques are technically feasible and effective, could be implemented during the repository pre-operational and operational phase to verify declared excavation activities.

When the repository enters the operational phase, the spent fuel will arrive on-site in packages that may be ‘safeguards sealed’, to maintain continuity of knowledge, by the IAEA with mechanical, optical or electronic devices, and/or by the use of controlled welds to indicate access to the nuclear material in the spent fuel packages. Knowledge of the contents of each package will be maintained through the use of material accounting techniques (for example, verification of the number of packages and their identification numbers or information on nuclear material content) supported by a reliable and comprehensive containment and surveillance (C/S) system above ground to verify the continued integrity and movements of the spent fuel packages and to maintain continuity of knowledge on them. The C/S measures may include visual observation, camera surveillance, safeguards seals, radiation (neutron and gamma ray) monitors and motion detectors. A system of radiation monitors and surveillance cameras is expected to be used to verify declared transfers of spent fuel casks from the surface buildings to the underground facility. These monitors and cameras would likely be located at the entrance to the transport shaft or ramp.

Once nuclear material is underground, all openings that could potentially be used for the undeclared removal of nuclear material from the underground facility should be monitored. For operational reasons, frequent movements of personnel, equipment, transport vehicles, and excavation spoils from the repository will occur. At openings, where containment structures exist (for example, fan housings), seals could be used to provide assurance that nuclear materials could not be removed undetected through the opening. At openings having no safeguards seal and where radioactive material should not be present, radiation detectors and surveillance might be used. At the transport shaft or tunnel, the radiation monitors could be designed to determine the direction of movement of the nuclear material. The design of the monitoring equipment will be location specific to ensure effectiveness and to minimize impacts on repository operations.

Design information verification will be the primary safeguards measure for the underground space of the operating repository facility. DIV will also continue to be used to verify the declared design of the surface buildings. The ‘as built’ information and declared operations in the above ground and underground areas of the repository will be subject to safeguards inspections. In addition, environmental sampling [4] and air monitoring could be applied to detect fission products or other radioactive isotopes released during opening of spent fuel packages or reprocessing of spent fuel.

After backfilling of all drifts, tunnels, shafts, and boreholes and removal of the surface facilities, the safeguards measures will be reduced to those measures that give assurance that no intrusion to the repository occurs that could result in the retrieval of nuclear material. The application of geophysical (for example, passive seismic) methods and satellite imagery techniques may continue.

It should be noted that to be successful, the safeguards approach will have to be site specific. Liaison between the operator, State (and/or regional safeguards authority) and the IAEA will be a prerequisite in order to implement an effective safeguards system that also meets the safety goals of the repository. The safeguards measures applied will change throughout the lifetime of the repository (construction, operation, and post-closure) because of changes in safeguards relevant activities and evolving safeguards technologies.

4.3. SAFEGUARDS VARIATIONS

The safeguards approach will need to address site specific design and operating factors or variations. Most of these variations will not affect the basic safeguards approach concepts but could affect the design and installation of the safeguards equipment. Where it is not possible for the IAEA to detect the removal of nuclear material at the surface openings of a repository, it may be necessary to implement additional monitoring activities underground. An example of such a removal may be the repeated removal of small quantities of non-irradiated safeguarded material through an access ramp opening.

For safeguards design purposes, waste/spent fuel types have been categorized as safeguarded and non-safeguarded. Safeguarded includes:

- Power reactor and research reactor (including zero power reactor spent fuel) spent fuel for which no further use is foreseen;
- Wastes containing unirradiated uranium, thorium, plutonium, and other materials of safeguards concern.

Non-safeguarded includes:

- Vitrified HLW on which safeguards was terminated;
- Irradiated reactor and fuel components;
- Other highly radioactive or long lived radioactive wastes (not containing nuclear material).

The waste/spent fuel types identified as safeguarded will be received at the repository under IAEA safeguards. The remaining waste types are either not subject to safeguards or will have had IAEA safeguards terminated at the generating facility. Table 1 presents a summary of the issues associated with each waste/spent fuel type.

Although the last three waste types are not subject to safeguards, they are of concern to the safeguards design because their radiation emissions could be similar to those from the safeguarded material. As these wastes will be identified by the radiation detectors at the waste transfer shaft or tunnel entrance, special procedures will be required to differentiate between those packages subject and not subject to safeguards and to ensure that packages not subject to safeguards are not used to camouflage the diversion of safeguarded material. The

TABLE 1. RADIOACTIVE WASTE/SPENT FUEL SUBJECT TO GEOLOGICAL DISPOSAL

Waste/spent fuel type	Characteristics	Radiation level	Safeguards applicability	Comments
Power reactor spent fuel (irradiated LEU and MOX).	Irradiated LEU fuel pellets contained in Zr cladding assembled into assemblies or consolidated into spent fuel packages.	High gamma and neutron emissions.	Not subject to termination of safeguards after emplacement.	Safeguards measures defined by generic IAEA safeguards approach.
Research reactor spent fuel (irradiated HEU and LEU).	Cores from research reactors and critical assemblies in various forms and configurations.	Low to high gamma emissions.	Not subject to termination of safeguards after emplacement.	Safeguards measures defined by generic IAEA safeguards approach.
Unirradiated U, Th and Pu bearing waste.	Various process wastes and scrap from nuclear fuel cycle manufacturing activities.	Low gamma and neutron emissions.	Subject to termination of safeguards only in very low concentrations and quantities.	Safeguards measures derived from generic IAEA safeguards approach for spent fuel.
Vitrified high level waste.	Fission products and transuranic activation products resulting from reprocessing activities.	High gamma and neutron emissions.	Termination of safeguards expected at reprocessing facility before shipment to repository.	Radiation levels similar to those of power reactor spent fuel.
Irradiated reactor and fuel components.	Fuel assembly skeletons and end caps, control rods and guide tubes, leached hulls, internal reactor components.	Low to high gamma emissions.	Not subject to safeguards.	Radiation levels may be similar to those of power and research reactor spent fuel.
Other highly radioactive or long lived radioactive waste (non-U, Th or Pu bearing).	Various wastes from industrial and medical uses of radioactive materials.	Variable gamma and neutron emissions.	Not subject to safeguards.	Radiation levels may be similar to those of power and research reactor spent fuel.

repository operator, the national or regional authority, and the IAEA will need to consult to develop appropriate procedures.

The wastes containing separated plutonium will be subject to safeguards and will be subject to more intensive verification procedures than spent fuel. However, the radiation level emitted by plutonium may be too low for effective detection by radiation sensors at the openings. From the viewpoint of safeguards implementation, these materials would likely need to be segregated within particular sections of the facility and be subjected to similar IAEA safeguards measures as were applied to it above ground, until the drift in which it is emplaced is backfilled and sealed.

It is conceivable that on rare occasions waste/spent fuel packages might need to be returned to the surface from the underground facility. The operator or the national or regional authority would be required to inform the IAEA in advance of any activity to remove a radioactive package from the underground facility.

This notification should be made sufficiently in advance of the removal to permit the IAEA to be present and to verify the removal of the item.

4.4. GENERAL IMPLEMENTATION OF IAEA SAFEGUARDS

IAEA activities during the pre-operational phase establish the bases on which safeguards will be conducted during the operational phase. Thus, a high level of cooperation and sharing of information among the IAEA, the facility operator, and the national or regional authority is required to ensure that the subsequent IAEA safeguards activities and measures will be effective, will minimize impacts on the facility, and will be acceptable to both the IAEA and the national or regional authority. The IAEA's site specific safeguards approach will be based on the design information and the as-built information declared by the national or regional authority. The site specific safeguards approach should be documented and a facility attachment to the subsidiary agreements to the safeguards agreement with the IAEA needs to be negotiated between the IAEA and the national or regional authority.

The installation of the safeguards equipment is of necessity a joint undertaking. While the IAEA generally provides the equipment, in some cases, the IAEA can take advantage of facility equipment. In this case, the IAEA authenticates that falsified data produced by the facility's equipment is detected. The location of the equipment is mutually agreed by the IAEA, the State/regional authority and the facility operator. For safety reasons, the IAEA does not install its equipment, but rather observes installation of the equipment by facility personnel, verifies its satisfactory location, installation and operation, and secures the equipment against tampering. During the pre-operational period, the IAEA might wish to use installed equipment (for example, passive seismic monitors) to independently verify design information and to establish baseline values against which subsequent values would be compared.

When the operational phase begins, the facility will have a zero nuclear material inventory and comply with the design information submitted during the pre-operational phase. When the facility starts receiving packages, IAEA activities will verify declarations by the State or regional authority on changes to the nuclear material inventory and will continue to verify the design of the facility. These activities will include reviewing records, downloading data from IAEA equipment, observing facility operations, verifying nuclear material items in interim storage, and maintaining IAEA equipment. As necessary, IAEA equipment will be replaced and reinstalled.

The post-closure phase will begin when the repository access ways have been backfilled, permanently closed and sealed[4]. Some national programmes may choose to begin the post-closure phase with a period of institutional control. With or without such a period, safeguards monitoring and surveillance are expected to be maintained for as long as the safeguards agreement is in force and future generations consider it beneficial. The IAEA, in consultation with the State or regional authority, may conduct site visits during the post-closure period to supplement its knowledge gained from other monitoring activities or to address anomalies identified by satellite or geophysical monitoring techniques.

5. TECHNOLOGICAL IMPLICATIONS OF SAFEGUARDS REQUIREMENTS

The following discussion is based on the reference repository concept briefly described in Section 3 and the safeguards measures expected to be implemented at a geological repository described in Section 4. The potential impacts of these measures on geological repository operations and safety and design changes that could reduce the impacts are outlined in Table 2. This table describes the impacts and technological implications of the safeguards requirements during each specific repository activity. It identifies the safeguards measures proposed in the generic safeguards approach and potential measures that the IAEA would need to implement if the implementation of those measures was not successful (for example, the failure of an IAEA instrument) and the potential operational impacts of both. The generic safeguards measures were developed in coordination with the repository developers, and the implementation of the site specific measures would be performed in coordination with and with the approval of the repository operator.

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[4] The term 'sealed' in this context refers to the final closure of the repository and does not suggest that the repository openings will have 'safeguards seals' applied.

TABLE 2. TECHNOLOGICAL IMPLICATIONS OF APPLYING SAFEGUARDS MEASURES TO ACTIVITIES IN A GEOLOGICAL REPOSITORY

Repository activity	Safeguards measures	Impact of applying safeguards measures	Remedial safeguards measures, if primary was not successful	Impact of applying remedial safeguards measures
Site characterization and repository design.	Review site characterization information and repository design for developing specific safeguards activities for monitoring waste/spent fuel transfer, storage and emplacement.	Prepare, review, submit and discuss documents. Alter design to facilitate safeguards implementation.	Review additional site characterization and repository design information.	Prepare additional documents. Potential delays of future operations.
Repository construction.	Verify that the as-built facility is in agreement with declared repository design information. Install and calibrate IAEA safeguards equipment (including geophysical monitors) above ground.	Support IAEA activities (e.g. escorting, sealing, or maintaining or using IAEA equipment). Review safety of and, if acceptable, install IAEA equipment mountings and cabling.	Use alternative safeguards measures and resolve inconsistencies.	Support additional IAEA activities. Potential delays of future operations.
Waste/spent fuel receipt.	Verify that continuity of knowledge on the quantity of nuclear material in the package is maintained by safeguards seals and container integrity verification.	Support IAEA activities (e.g. escorting, sealing, or maintaining or using IAEA equipment). Interrupt operations during IAEA presence, if necessary.	Re-establish continuity of knowledge by, e.g. gamma ray and/or neutron measurement.	Support additional IAEA activities. Potential interruption of operations.
Temporary storage of waste/spent fuel packages.	Maintain continuity of knowledge of the quantity of nuclear material in the package through cameras, safeguards seals, container integrity verification and radiation monitors.	Support IAEA activities (e.g. escorting, sealing, or maintaining or using IAEA equipment). Interrupt operations during IAEA presence, if necessary.	Re-establish continuity of knowledge by, for example, gamma ray and/or neutron measurement.	Support additional IAEA activities. Potential delay of operations.

TABLE 2. TECHNOLOGICAL IMPLICATIONS OF APPLYING SAFEGUARDS MEASURES TO ACTIVITIES IN A GEOLOGICAL REPOSITORY (cont.)

Repository activity	Safeguards measures	Impact of applying safeguards measures	Remedial safeguards measures, if primary was not successful	Impact of applying remedial safeguards measures
Waste/spent fuel transfer to underground.	Verify transfer of the package through cameras, safeguards seals, container integrity verification, and radiation monitors. Verify that no nuclear materials are removed by interfaced radiation monitoring and cameras.	Support IAEA activities (e.g. escorting, sealing, or maintaining or using IAEA equipment).	Use alternative safeguards measures and resolve inconsistencies.	Support additional IAEA activities. Potential interruption of operations until verification capability reestablished.
Underground operations.	Verify that operations are consistent with declarations by observation and location specific environmental sampling.	Prepare, review, submit, and discuss documents. Support IAEA activities (e.g. escorting, sealing, or maintaining or using IAEA equipment).	Use alternative safeguards measures and resolve inconsistencies.	Support additional IAEA activities. Potential interruption of operations until verification capability reestablished.
Material/personnel transport to underground.	Verify that no nuclear material is removed by interfacing radiation monitoring and cameras.	Support IAEA activities (e.g. escorting, sealing, or maintaining or using IAEA equipment).	Use alternative safeguards measures and resolve inconsistencies.	Support additional IAEA activities. Potential interruption of operations until verification capability is reestablished.
Ventilation through shaft.	Verify that no nuclear material is removed through the shaft by seals on the vent housing, or, if necessary, by interfaced radiation monitoring and cameras. Verify absence of underground reprocessing by continuous air monitoring.	Support IAEA activities (e.g. escorting, sealing, or maintaining or using IAEA equipment). Interrupt operations while awaiting IAEA presence, if necessary.	Use alternative safeguards measures and resolve inconsistencies.	Support additional IAEA activities. Potential interruption of operations until verification capability reestablished.
Backfilling and sealing.	Verify, by observation, that status is consistent with declarations.	Prepare, review, submit, and discuss documents. Support IAEA activities (e.g. escorting, sealing, or maintaining or using IAEA equipment).	Use alternative safeguards measures and resolve inconsistencies.	Prepare additional documents. Support additional IAEA activities.

TABLE 2. TECHNOLOGICAL IMPLICATIONS OF APPLYING SAFEGUARDS MEASURES TO ACTIVITIES IN A GEOLOGICAL REPOSITORY (cont.)

Repository activity	Safeguards measures	Impact of applying safeguards measures	Remedial safeguards measures, if primary was not successful	Impact of applying remedial safeguards measures
Waste/spent fuel package retrieval.	Maintain continuity of knowledge by applying safeguards seals until the package contents can be re-verified.	Prepare, review, submit, and discuss documents. Support IAEA activities (e.g. escorting, sealing, or maintaining or using IAEA equipment).	Reestablish continuity of knowledge by re-verifying package contents .	Support IAEA activities (e.g. escorting, sealing, or maintaining or using IAEA equipment).
Repository closure.	Verify that closure is consistent with declarations.	Prepare, review, submit, and discuss documents. Support IAEA activities (e.g. escorting, sealing, or maintaining or using IAEA equipment).	Use alternative safeguards measures and resolve inconsistencies.	Prepare additional documents. Support additional IAEA activities.
Post-closure site controls.	Remote surveillance and geophysical monitoring.	No facility operator; State or regional authority would support IAEA activities (e.g. escorting, sealing, or maintaining or using IAEA equipment). Long term management of repository knowledge.		

In September 2002, an Expert Group Meeting was held to identify and correlate the potential monitoring activities that would be carried out in relation to geological repositories [21]. The focus was to identify the monitoring activities, foreseen by the repository operator and the Member State that could also be utilized for IAEA safeguards purposes. The evaluation identified many parameters that could be monitored for safeguards reasons and would probably also be monitored by the operator or the Member State for other purposes (for example, operational safety, performance confirmation, quality assurance, physical protection, and material control and accounting). Many monitoring needs were identified by different organizations in both pre-operational and operational phases of the repository. However, for the post-closure phase, the monitoring needs were primarily those of IAEA safeguards.

There is general agreement within the international nuclear safety community that geological repositories should not need active institutional control (monitoring) to provide adequate safety in the post-closure phase. Annex 1 details information provided in Table 2, based on the discussion and output of the Expert Group Meeting and underlies the implication for the repository operator.

5.1. PRE-OPERATIONAL PHASE

Many of the technological implications relevant to a geological repository during the pre-operational phase are similar to those for other nuclear facilities. These include the exchange of information and its examination, verification of design information through discussions and facility visits, satellite imagery, discussion of the proposed site specific safeguards approach, and installation of safeguards equipment, including geophysical monitoring devices. The safeguards measures for a geological repository differ from those implemented at conventional surface facilities. The impacts on the facility operator result from the requirement to compile and provide information and documents to the IAEA. In addition, the operator needs to examine information provided by the IAEA to facilitate the installation of IAEA equipment, provide access to safeguards relevant facility areas, and provide logistical and technical support. These actions are conducted by the operator through discussions, in cooperation with the State or regional authorities and the IAEA.

5.2. OPERATIONAL PHASE

Regarding the surface activities connected to the geological repository, the situation is quite similar to the pre-operational phase in terms of technological implications. Because underground safeguards measures under the generic safeguards approach are limited to DIV (e.g. visual observation and transportable geophysical monitoring techniques), the technological implications in the underground part of a geological repository are substantially less than those for the above ground part or for other nuclear facilities. The safeguards measures for the surface package handling facilities are nuclear material accountancy measures and C/S (e.g. item identification, safeguards seals, package integrity verification, cameras, radiation monitors, and neutron and gamma ray measurements). Other surface applied safeguards measures are those to verify that nuclear material us not removed from the repository (e.g. safeguards seals on vent shaft housing, radiation monitoring and surveillance of materials/personnel transport shafts and ramps, geophysical monitoring, and continuous air monitoring of exhaust air).

The impacts on the facility operator with respect to surface material handling activities result from the requirement to record and report on package receipts, storage, transport, and other safeguards relevant operations; provide access (and necessary escorts) to the package storage and handling areas, shafts and ramps; and provide logistical and technical support related to operation and maintenance of IAEA equipment.

The impacts on the facility operator with respect to emplacement activities result from requirements to provide access (and necessary escorts) to the emplacement area and provide logistical and technical support related to the operation of IAEA equipment.

The impacts on the facility operator with respect to the option of retrieving waste/spent fuel packages result from the requirements to record and report on package removals, storage, transport and other safeguards relevant operations. The operator should provide logistical and technical support to facilitate the application of appropriate C/S measures and the timely re-verification of the package. The impacts on the facility operator with respect to backfilling and closure activities result from requirements to provide access (and necessary escorts) to the relevant underground areas, shafts, and ramps.

5.3. POST-CLOSURE PHASE

During the post-closure phase, there will be no facility operator and the country is expected to assume responsibility for the repository site. Therefore, any technological implications arising during this phase will be referred to the State, or its representative.

6. SUMMARY AND CONCLUSIONS

The possible technological implications of IAEA safeguards on the various phases of the life cycle of a generic geological repository containing spent nuclear fuel and nuclear material waste subject to IAEA safeguards have been considered. During design and construction of the repository, the safeguards approach calls for design information verification of the surface buildings and of the as-built information of the excavated subsurface areas to ensure the absence of any safeguards relevant undeclared activities. The safeguards approach recognizes that the repository design is likely to be modified as site characterization progresses and that construction may also be undertaken in parallel to the package emplacement operations. The synergy of various monitoring programmes used in the design and operation of the geological repository should be considered for safeguards. Repository safeguards measures should be part of the repository planning and design from the outset of a project to facilitate installation of IAEA equipment and to ensure that safeguards measures do not unduly disturb facility operations.

Based on the considerations of this report, it was concluded that, with appropriate advance planning, the operational and safety impacts of applying routine traditional IAEA safeguards in a geological repository is no greater or more technically challenging than those affecting other types of nuclear facility. In addition, no impacts were identified that would require changes in design or would compromise safety. The safeguards approach was developed with significant input from repository designers and safety experts. These interactions demonstrated the value of early and close cooperation between the disciplines. Minimizing the risk of loss of continuity of knowledge is a must, should it be only from the technological viewpoint. Therefore, the robustness of a safeguards approach developed and implemented site specifically must be ensured. The reliability of the techniques and procedures should be proven in site specific situations.

A prerequisite for ensuring that all stakeholders are aware of both safety and safeguards requirements, can plan their activities accordingly, and can avoid conflicts, is the early establishment of appropriate and effective communication channels. All stakeholders (these may include the construction company, future operator, State/regional authorities, and the IAEA) should be encouraged to develop an integrated plan that identifies both complementary and, if any, conflicting activities. The experience of some countries engaged in the preliminary design of geological repositories confirms the value in establishing baseline knowledge and using this as a means for coordinating the wide range of activities.

It is recommended that where appropriate, the country, operator and safeguards authorities establish a framework that promotes a culture of information exchange from the earliest stage of the repository lifetime.

Safeguards approaches that integrate the traditional safeguards measures with information analysis and complementary access to related safeguards relevant locations in the State are currently being developed by the IAEA. The integration of the measures seeks to enhance the effectiveness and efficiency of IAEA safeguards implementation. Any identified technological implications of the generic traditional safeguards approach for geological repositories will likely cover the potential implications of an integrated approach on a repository. However, if the integrated safeguards approach for geological repositories should include measures not discussed in this report, the technological implications would have to be adjusted accordingly and an updated report issued.

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Annex I

TECHNOLOGICAL IMPLICATIONS OF APPLYING SAFEGUARDS MEASURES IN A GEOLOGICAL REPOSITORY BASED ON SAFEGUARDS ACTIVITIES

Safeguards related activity	Safeguards reasons	IAEA ‘tools’ deployed	Activity location	Technological implication for repository operator
Pre-operational phase				
Review activities aimed at site characterization and definition of baseline conditions. Review the repository design, planned operating procedures, installed equipment, construction materials and activities.	Facilitate the design of site specific safeguards approach.	Open source information; Document reviews; Inspection.	IAEA HQ/on-site; IAEA HQ/on-site; On-site.	Provide design and construction documentation. Revise documents and plans as necessary to facilitate application of safeguards measures.
	Identification of inconsistencies in declarations that may indicate the intention to divert safeguarded material.	Document reviews; Satellite imagery; Aerial photography; Inspection; Geophysical measures.	IAEA HQ/on-site; Space; Aerial; On-site; Subsurface/surface	Provide support services, where necessary, to enable IAEA to undertake inspection of as-built facility. This may include office accommodation, equipment maintenance areas and utilities.
Confirm the absence of undeclared neighbouring underground constructions, cavities or features.	Detection of pre-existing structures or activities that potentially could facilitate undeclared access to repository.	Satellite imagery; Aerial photography; Inspection; Geophysical measures; Open source information.	Sace; Aerial; On-site; Surface/subsurface; IAEA HQ/on-site.	Provide support services, where necessary, to enable IAEA to undertake inspection of facility. This may include office accommodation, equipment maintenance areas and utilities.
Install safeguards equipment.	Prepare for safeguards monitoring activities.	Joint use operator/IAEA instrumentation; IAEA instrumentation.	On-site surface facilities; On-site surface facilities.	Provide support services during installation of cabling and data communications systems. Provision of power supplies.
Monitor all excavation activities.	Detection of the construction of additional access routes into or within repository and to verify the as-built design.	Satellite imagery; Aerial photography; Inspection; Geophysical monitoring.	Space; Aerial; On-site; Surface/subsurface.	Provide support to IAEA inspections of the facility. This may include provision of office accommodation, equipment maintenance areas and utilities.

Safeguards related activity	Safeguards reasons	IAEA ‘tools’ deployed	Activity location	Technological implication for repository operator
Monitor the effectiveness of installed instrumentation.	Ensure the effective performance of operator and IAEA instrumentation.	Instrument/signal authentication; Calibration checks; Trend analysis.	On-site; On-site; IAEA HQ.	IAEA may employ operator’s instrumentation to support safeguards activities. Separate signal cables may be required. Provision of instrument calibration and maintenance logs.
Operational phase				
Review the repository design, planned operating procedures, installed equipment, construction materials and activities.	Identification of inconsistencies in declarations that may indicate the intention to divert safeguarded material.	Document reviews; Satellite imagery; Aerial photography; Inspection; Geophysical measures.	IAEA HQ/on-site; Space; Aerial; On-site; Subsurface/surface.	Provide support services, where necessary, to enable the IAEA to undertake inspection of the as-built facility. This may include office accommodation, equipment maintenance areas and utilities.
	Detection of activities that potentially could support the diversion of safeguarded material through comparison of surveillance with operating records.	Local camera surveillance; Open source information; Inspection.	Surface on-site; IAEA HQ/on-site; On-site.	IAEA camera equipment may require artificial lighting. Provision of power supplies.
	Identification of facilities and equipment that could support reprocessing activities.	Inspection; Camera surveillance; Location specific environmental sampling; Open source information.	On-site; Surface on-site/subsurface; Surface/subsurface; IAEA HQ.	IAEA camera equipment may require artificial lighting. Provision of power supplies.
Monitor all excavation activities.	Detection of the construction of additional access routes into or within repository and to verify the as-built design.	Satellite imagery; Aerial photography; Inspection; Geophysical monitoring.	Space; Aerial; On-site; Surface/subsurface.	Provide support to IAEA inspections of the facility. This may include provision of office accommodation, equipment maintenance areas and utilities.
Monitor all subsurface radiological events.	Detection of the undeclared opening of a package for the removal of safeguarded material and undeclared reprocessing activities.	Environmental sampling; Air sampling; Inspection.	On-site; Ventilation shafts; On-site.	Provision of power supply. Ventilation equipment design to accommodate air sampling equipment.

Safeguards related activity	Safeguards reasons	IAEA ‘tools’ deployed	Activity location	Technological implication for repository operator
Confirm waste/spent fuel package management activities.	Detection of the undeclared exchange of a waste package containing spent fuel with a waste package containing items of lesser or no safeguards significance.	Item identification; Seal identification and verification; Local camera surveillance; Package weighing; Radiation monitoring.	Receiving area; IAEA HQ/ receiving area; On-site; Receiving area weighing equipment; Unloading station	Provide support for confirmation of package identity. Design of the package receiving station may be adapted to accommodate readers, recorders and associated power supplies. Weighing equipment and recorders may be required too.
Confirm the absence of activities and equipment that may relate to the undeclared removal of spent fuel from a package.	Detection of the undeclared removal of spent fuel during shipment, partially loaded container or inaccurate declaration.	Records review; Seal identification/verification; Cask integrity checks; Non-destructive assay; Radiation ‘fingerprint’.	Receiving area.	Receiving area to be equipped with shielded inspection area. Provision of power supply.
	Detection of the undeclared removal of spent fuel from a package in buffer store.	Records review; Seal identification/verification; Camera surveillance; Cask integrity checks; Environmental sampling.	Buffer store.	Provision of power supply.
	Detection of the undeclared removal of spent fuel from underground areas through personnel and materials, shafts/ramps and ventilation shafts.	Camera surveillance; Radiation monitoring; Seal identification/verification.	Transfer ramp; Ventilation shaft; On-site.	IAEA camera equipment may require artificial lighting. Provision of power supply. Service shaft design to accommodate radiation detector and camera locations.
Monitor the effectiveness of installed instrumentation.	Ensure the effective performance of the operator and IAEA instrumentation.	Instrument/signal authentication; Calibration checks; Trend analysis.	On-site; On-site; IAEA HQ.	IAEA may employ operator’s instrumentation to support safeguards activities. Separate signal cables may be required. Provision of instrument calibration and maintenance logs.
Post-closure phase				
Monitor all activities that may relate to undeclared activities.	Detection of the construction of new access routes into repository.	Satellite imagery; Aerial surveillance; Inspection; Geophysical monitoring; Open source information.	Space; Aerial; On-site; Surface/subsurface; IAEA HQ.	IAEA safeguards continue: No operator–State responsibility.

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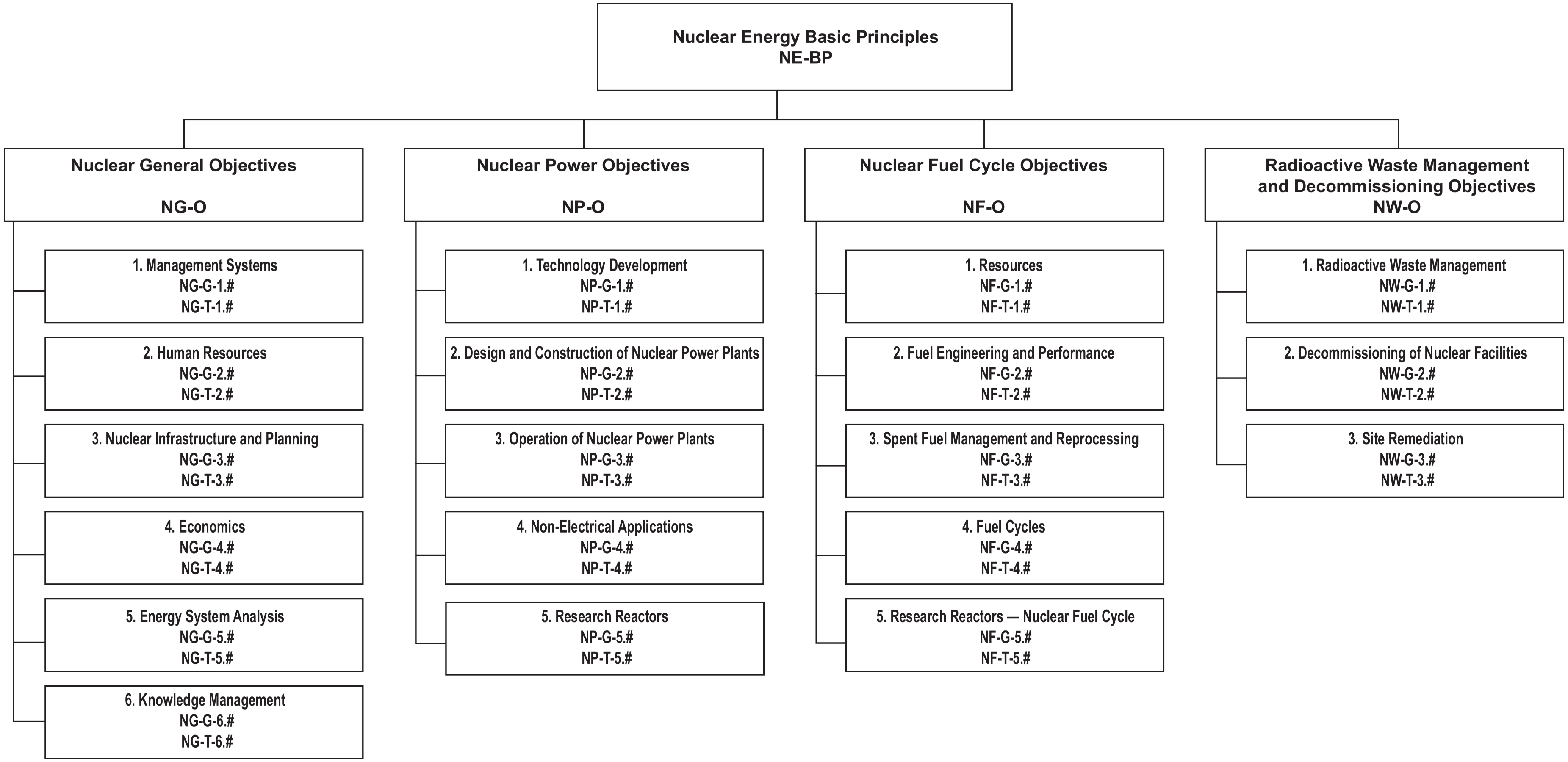

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