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Summary report of the NEA EGOS Webinar on Radiation Protection in Underground Repositories

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NUCLEAR ENERGY AGENCY

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The mission of the NEA is:

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– to provide authoritative assessments and to forge common understandings on key issues, as input to government decisions on nuclear energy policy and to broader OECD policy analyses in areas such as energy and sustainable development.

Specific areas of competence of the NEA include the safety and regulation of nuclear activities, radioactive waste management and decommissioning, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information. The NEA Data Bank provides nuclear data and computer program services for participating countries.

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Foreword and acknowledgements

On 3 June 2024, the Nuclear Energy Agency (NEA) Expert Group on Operational Safety (EGOS) convened the Webinar on Radiation Protection in Underground Repositories to facilitate broad discussions on the challenge of applying radiological protection principles in the particular environment of an underground repository, where conventional and nuclear operations occur simultaneously.

The webinar discussed how design, regulatory and policy decisions can impact the implementation of the ALARA (as low as reasonably achievable) principle and the overall radiological protection programme underground. It was attended by 86 participants from 22 countries and international organisations such as the International Commission on Radiological Protection (ICRP), the International Atomic Energy Agency (IAEA) and the World Nuclear Association (WNA).

The NEA expresses its gratitude to the NEA EGOS members for the preparation of this webinar summary report.

The publication of the report was supported by the NEA Secretariat, Zhuoran Li (Radioactive Waste Management and Decommissioning Specialist) and Soufiane Mekki (Radioactive Waste Management Specialist).

This report was approved by the NEA Radioactive Waste Management Committee on 25 March 2025 by the written procedure.

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List of abbreviations and acronyms

ALARA	As low as reasonably achievable
ANDRA	Agence nationale pour la gestion des déchets Radioactifs (France)
DOE	Department of Energy (United States)
EGOS	Expert Group on Operational Safety
GEOSAF	International Project on harmonising the demonstration of safety of geological disposal facilities
HEPA	High-efficiency particulate air
HLW	High-level waste
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
LILW	Low- and intermediate-level waste
LTSA	Long-term safety assessment
NEA	Nuclear Energy Agency
NWMO	Nuclear Waste Management Organization (Canada)
NUMO	Nuclear Waste Management Organization of Japan
OECD	Organisation for Economic Co-operation and Development
ONDRAF/NIRAS	Organisme national des déchets radioactifs et des matières fissiles enrichies
OSA	Operational safety assessment
PURAM	Public limited company for radioactive waste management (Hungary)
SKB	Swedish Nuclear Fuel and Waste Management Company
STUK	Radiation and Nuclear Safety Authority (Finland)
WIPP	Waste Isolation Pilot Plant (United States)
WNA	World Nuclear Association

1. Introduction

1.1. Background

The system of radiological protection described by the International Commission on Radiological Protection (ICRP) in its Publication 103 (ICRP, 2007) is based on the application of the following fundamental principles:

- justification;
- optimisation of protection;
- application of dose limits.

A precise formulation of these principles of protection is an important component of the system of radiological protection in any nuclear installation.

While the ICRP Publication 122 recommends using these same principles for geological repository projects (ICRP, 2013), the underground environment in which nuclear operations take place poses significant challenges.

Geological repository projects are subjected to the requirements not only of the operational safety assessment (OSA), but also of the long-term safety assessment (LTSA), which can impose constraints in the application of the optimisation principle or challenge the justification of certain practices during the operational phase.

Policy decisions and the choice of site and host rock may also dictate requirements in terms of what can be implemented and the way in which operations can be conducted during the operational phase. All these elements play a role in the ALARA justification of the facility.

The application of engineering principles whose contribution to radiological protection is important, such as radiological zoning or the dynamic confinement function of the ventilation system, are not obvious in the confined environment of underground repositories, or in situations where disposal and construction operations may be happening simultaneously.

In its Publication 122, the ICRP explains how the system of radiological protection described in Publication 103 can be applied in the context of the geological disposal of long-lived solid radioactive waste. Publication 122 illustrates how the key protection principles of optimisation, justification and dose limitation should be interpreted, and how they apply over the different time frames of a geological disposal facility. In this publication, however, the ICRP elaborates mainly on the application of the protection principles during the post-operational phase and in what the commission calls “particular circumstances”, such as natural disruptive events and inadvertent human intrusion.

For what refers to protection in the operational phase, Publication 122 states in paragraph 49 that “waste emplacement activities are subject to the same principles of dose limitations and the requirement to optimise below constraints as those in any nuclear facilities” (ICRP, 2013). The commission does not, however, offer any specific recommendation on how to achieve those qualitative safety objectives.

Although some facilities have been already licensed and have a safety case approved by the competent authority, little operational experience exists in the performance of ALARA choices in underground repositories. When making decisions, extreme care must be taken to consider the socio-economic and long-term safety implications, as well as the consequences for operational nuclear safety and radiological protection.

The NEA EGOS webinar was organised to facilitate broad discussions on the challenge of applying radiological protection principles in the particular environment of an underground repository, where conventional and nuclear operations happen simultaneously.

Objectives

The objectives of the webinar were to:

- Learn from countries with more advanced programmes what the expectations of the nuclear regulators are on the applicability of the principles of justification, optimisation and dose limitation in an underground environment.
- Understand the choices made by different countries in the application of those principles and the reasons behind them.
- Identify lessons learnt on the applicability of standards that have an impact on radiological protection, e.g. ventilation standards, fire protection standards, radiological zoning.
- Discuss the decision-making process during the application of the ALARA principle in underground repositories.
- Better identify the role of radiological protection in policy decisions (e.g. co-activity or no co-activity).

1.2. Preparation

To develop the webinar programme, a Programme Committee was established consisting of the following experts: Kelly Liberda (NWMO, Canada), Zhuoran Li (NEA, Paris), Peter Buday (PURAM, Hungary), Satoru Suzuki (NUMO, Japan) and Dr Gustavo Rubio Antón (ONDRAF/NIRAS, Belgium). The Programme Committee held several meetings to discuss the workshop concept, topics for discussion, the preliminary questions for the discussion session, and the organisation of the technical session. During the workshop, the Programme Committee members led the technical session and subsequent discussions and compiled session outcomes. The Programme Committee also prepared presentations to introduce the technical subject, the reasons for organising the webinar, as well as the webinar's objectives. Following the workshop, the Programme Committee reviewed the findings of the workshop and prepared an outcome document and a flyer.

The workshop gathered 86 participants from 22 countries and international institutions. A detailed list of participants is presented in Appendix A.

1.3. Format

The Webinar on Radiation Protection in Underground Repositories took place on 3 June 2024. The event started with an update from the NEA on the mandate and activities of EGOS, followed by an introduction to the webinar presentation by the Programme Committee Chairman, Dr Gustavo Rubio Antón.

In the plenary session there were three types of presentations. First, international institutions such as the International Atomic Energy Agency (IAEA) and the ICRP provided their views on the application of radiological protection principles underground, and on the work that they are doing to provide international guidance on the subject. Next, countries with an operating repository presented their experience in radiological protection in an underground environment. Finally, countries with underground repository programmes that are advanced but not yet in operation discussed how they plan to implement the principles of radiological protection. They also shared information on the expectations from their respective regulatory bodies.

After the plenary session, there was a discussion session with all participants. During the discussion the focus was on the importance of the ALARA principle, radiological protection in general, and policy decisions such as allowing co-activity between emplacement and construction operations. The session evolved further into a discussion on the most challenging operations underground that the participants' organisations face in terms of radiological protection and how are they addressed.

2. Summary of the plenary session

Chair: Dr Gustavo Rubio Antón (ONDRAF/NIRAS, Belgium)

During the plenary session, six countries and two international institutions provided presentations.

Application of ICRP Recommendations for underground disposal of solid radioactive waste: Challenges for the operational and closure phases (Thierry Schneider, ICRP)

Thierry Schneider, the Chairman of the Committee 4 of the International Commission on Radiological Protection on the application of the commission's recommendations, gave a presentation on the work done by the ICRP on radiological protection in underground environments. Whereas radiological protection issues associated with waste disposal have been addressed by the ICRP in several publications (ICRP 5, ICRP 46, ICRP 77, ICRP 81, ICRP 122), the main focus on geological repositories has been the protection of future generations. He observed that potential radiological exposure situations will vary during the different phases of the facility (direct oversight, indirect oversight or no oversight), and radiological protection will rely on active controls, passive controls or a combination of both. The ICRP has not made any recommendations for the operational phase, but several issues that need to be addressed were identified, such as specific constraints due to the confined environment in underground repositories, the use of remotely controlled devices with possible human operation to deal with operational dysfunctions, or constraints that may be necessary during the operational phase to ensure the long-term confinement of radionuclides. Furthermore, the presentation elaborated on the application of the optimisation principle during the operational phase and the balance that needs to be achieved between what is reasonable and what is tolerable, as finding such a balance is key to ensuring the protection of present and future generations. Finally, Mr Schneider summarised some key challenges in the application of radiological protection principles underground. Among those were the need to establish an appropriate dialogue among the different stakeholders, clarifying the role of the dose constraints in the optimisation process at the design stage with limited feedback, addressing the different potential exposures, and dealing with conservatism in the safety assessment at early stages of the design process.

Radiation protection for geological disposal facilities: The IAEA guidance (Andrey Guskov, IAEA)

Andrey Guskov started his presentation by remarking that the safety principles in IAEA Safety Standards SF-1 (IAEA, 2006) are to be applied to all radioactive waste management activities. The presentation discussed IAEA publications containing relevant information and guidance on the areas of radiological protection and waste disposal, with special emphasis on the application of the optimisation, justification and dose limitation principles. The design of the facility should integrate the proposed operational activities with radiological protection practices considering operational safety (including both surface-based activities and underground activities), long-term safety, and also possibly mining and waste emplacement underground activities happening simultaneously. He stressed that the safety assessment of the facility, including normal operations and accidents, should confirm the absence of radiological consequences of any significance outside the facility. An operational radiological protection programme, a monitoring programme and emergency plans should be properly documented and maintained during the life of the facility. Mr Guskov referred specifically to the GEOSAF project launched by the IAEA in 2008 with the purpose of harmonising the demonstration of safety of geological facilities during and after their operation. Indeed, GEOSAF recognised the need to introduce statements into the IAEA safety standards for what refers to the duty holder's obligations to ensure radiological protection during the operational period, but also to ensure that radiological protection is an integral plan of any emergency preparedness and response plan.

Radiation protection requirements and implementation in deep geological repository for spent nuclear fuel in Finland (Mari Lahti, Posiva)

The presentation from Mari Lahti focused on the radiation safety of the personnel operating the Finnish geological repository. It started by listing the radiological protection regulations from STUK, the Finnish regulator, and explaining how they take into account recommendations from the ICRP and the IAEA. In the Finnish regulations it is mandatory to have an ALARA plan for the operational and long-term periods. The plan should detail the measures to limit doses for occupationally exposed workers. In the Finnish repository design, radiological zoning considers controlled, supervised and un-controlled areas. Controlled areas are defined on the basis of the possibility of receiving direct radiation. Surface or air contamination is limited to specific areas such as fuel handling cells or decontamination centres. There are some rooms with high dose rate (>30 mSv/h) where spent fuel or disposal canisters are handled in air without shielding. These rooms and the operations taking place in them are designed making use of labyrinth structures, locked doors, specifically selected shielding material, monitoring and remote-controlled processes. The handling of spent fuel in the encapsulation plant is done remotely. The containers with the spent fuel are brought down to the repository also remotely, using a shaft and without shielding. Underground, the canister is transported by a semi-autonomous vehicle operated remotely with some limited shielding. Once the container is placed in the deposition hole, the radiation levels in the surrounding area are very low. Contamination control in the encapsulation plant is very strict in order to keep the underground area clean, with packages being regularly sampled and decontaminated if necessary. Operational procedures are written to reduce the need to access high dose rate areas. When necessary, specific radiological protection measures are implemented.

Repository designs and considerations for pre-closure radiation protection in the NUMO safety case (Satoru Suzuki, NUMO)

Under Japanese law, the submission of a licence application for the disposal of radioactive waste requires, besides the type and amount of waste, also a description of the location, structures and equipment of the disposal facility, of the methods for disposal, and a construction plan for the facility. Since the regulatory requirements for geological disposal are in preparation, those for medium depth disposal are tentatively applied for consideration of the repository design in the NUMO safety case. The adoption of the ALARA concept in Japan shall take into account all necessary radiological protection measures such as shielding, the physical arrangement of equipment, remote operations, prevention of radionuclides releases and adequate ventilation. The on-site transport vessel for high-level waste (HLW) is designed for a dose rate of 100 μSv/h at 1 metre. The transport pathway is a radiation-controlled zone. The requirements for a radiation-controlled zone are defined on the basis of effective external doses and surface density of radionuclides. Under normal conditions, in the underground facilities radionuclides are confined in multiple containers, with radiological protection measurements implemented to ensure that ambient doses are kept as low as possible (e.g. remote waste transport operations). In addition, measures are put in place to completely segregate the construction and operation zones and to prevent construction workers from inadvertently entering the radiation-controlled areas. The workflow lines, evacuation pathways, and ventilation and drainage systems between the emplacement and construction zones are completely separated so that an accident involving the leakage of radionuclides does not affect the construction zone.

Principles of justification, optimisation and dose limitation in underground environments: Application to the French Cigéo DGR (Gaëtan Gerdolle, ANDRA)

Cigéo is designed to reduce the doses according to the ALARA principle. ANDRA defines dose limits for normal operations and design basis accidents. In normal situations and degraded modes, the dose to workers is limited to 5 mSv/y, with the objective of optimising it to less than 2 mSv/y for most workstations. Dose rate constraints are used in Cigéo for the separation of radiological zones through the use of air locks, walls and doors. Shielding needs are established on the basis of external dose rate calculations taking into account the position of the operators in relation to the source, the number of workers required to carry out the different operations and the type and duration of the activity, so that individual and collective doses (average and maximum) can be calculated during the operational phase and taken into account in the implementation of ALARA. Results show that workers in the control room receive doses as low as 1 μSv/y. In the surface buildings no worker receives more than 3 mSv/y and underground workers receive less than 1 mSv/y. All doses in Cigéo are considered to be from external exposure. The expectation is to not have any loose contamination underground, so there is not expected to be any dose from airborne contamination.

Radiation protection principles and general application at SKB (Patrik Berg, Daniel Tepic, SKB)

Swedish regulations establish a limit of 20 mSv/y for the total effective dose to any individual worker, with an optimisation target of 5 mSv/y. SKB does not evaluate dose to workers during accidents. Any area where individual workers can be exposed to a dose of more than 6 mSv/y is a controlled area. The Swedish radiation safety authority is, however, working on new regulations for non-reactor facilities and repositories that will include dose limits for workers in accident situations. The classification of the different areas where workers are expected to be present is based on conservative calculations during the design phase and in actual measurements during operation. During the design, the different areas of the facility are divided into radiation classes with respect to dose rate levels and risk of contamination. Radiological classification is done on the basis of the expected dose rate in a particular area but also taking into consideration the need for access (e.g. for loading or maintenance). In the Swedish repository there is no designation of zones based on contamination as no air or surface contamination is expected. A particular feature of the Swedish repository is that areas can be reclassified into a lower or higher dose radiation zone depending on the activities taking place. This eases the access of workers to specific places of the repository when no waste emplacement activities are taking place. Lessons learnt from the repository for short-lived radioactive waste show that during the design of the facility, conservative calculations tend to overestimate the actual operational dose. When the repository was constructed, the collective dose was calculated to be 25 mSvman/y, whereas the actual design is between 0 and 6 mSvman/y depending on the work being carried out. The reason for this can be that the amount of waste emplaced so far has been low and with a low dose rate.

Radiation protection challenges in a salt mine (Ed Garza, WIPP)

WIPP handles transuranic waste emitting mostly alpha radiation. The radiological control philosophy of the facility is "clean in, clean down". The waste is collected and packaged at WIPP's onsite facilities, mostly in plastic bags, then placed in metal containers. Bags are vented with specially fitted HEPA filters and metal containers are also vented with cylindrical filters screwed into ports integral to the containers. Any gas produced is allowed to escape while radionuclides are kept in. The waste is thoroughly inspected and monitored. When contamination is detected, work is stopped until the leaking package is found and sent back to origin. Radiological protection at DOE facilities in the United States is governed by 10 CFR 385 occupational radiological protection. This code establishes standards, limits and programme requirements for protecting individuals from ionising radiation resulting from the conduct of DOE activities. The workforce at WIPP is highly trained in radiological protection. Procedures are detailed and documented to ensure that any operational doses are reduced to a minimum. A salt mine poses numerous challenges for a nuclear operator. Salt dust has the ability to clog airborne samplers, impeding the ability of radiation monitoring equipment to detect certain forms of radiation. This can lead to delays in productivity since regulations specify that certain samplers must be operable for certain work activities. Another challenge is that naturally occurring radon can be attracted by the dust in the mine and into the detection equipment creating “false positives” in the monitoring equipment. Decontaminating a salt mine is virtually impossible since the surfaces are inherently dusty, porous and uneven. The amount and depth of contamination in the salt matrix is difficult to estimate unless core samples are taken and characterised. An important lesson learnt from WIPP is that it is well worth investing in training. Other lessons learnt included eliminating loose contamination underground, eliminating dust, which can impact monitoring equipment, and minimising naturally occurring radioactive material.

Radiation protection principles and examples in a L/ILW underground repository (Peter Buday, PURAM)

PURAM applies the principles of justification, optimisation and dose limitation in its radiological protection programme. As an example of the application of the principle of optimisation, packages for the IK-4 vault (which contains intermediate level waste, where higher dose rates are expected) were designed for internal shielding (a layer of concrete at the internal walls of the package), so that they could be emplaced manually by operators. The internal shielding meant an effective reduction of the useful volume for waste disposal. In order to avoid this problem and maximise the amount of waste being disposed of, the packages were optimised for the workplace dose rate conditions making use of external shielding. The packages were emplaced in the vault by means of an overhead crane. Steel shielding was added during transport to meet transportation requirements. The optimisation resulted in an overall reduction of doses to workers. The vaults in the Bátaapáti repository are backfilled with concrete. The backfilling operations are the reason for higher doses during operation. This activity is, however, justified because of its importance for long-term safety. Bátaapáti is operated with co-activity. Separated tunnels are, however, used for operation and excavation activities, and they are both undertaken at separate times. One empty vault is kept at all times as a safety buffer.

3. Summary of the discussion session

Chair: Kelly Liberda (NWMO, Canada)

During the discussion session, the participants commented on different operational aspects of their repository designs and how they influence their respective radiological protection programmes. Colleagues from Sweden explained that the radiological classification is fixed during the design process for the purposes of providing adequate shielding, but during operations certain areas may be reclassified to facilitate the efficiency of operations. The discussion touched on whether underground repositories can be claimed to be free from radiological contamination since, during the preparation of the disposal waste packages in the surface facilities, contamination on the surface of the packages can occur. Some countries receive the waste packaged from the nuclear sites and inspect the waste packages to ensure the absence of contamination.

A discussion was also held on the reasons why countries opt for or against co-activity, understood as the simultaneous execution of disposal operations and construction activities. An important argument is that the project time span will significantly increase if the start of operations has to wait until the complete repository has been built. However, activities are kept separated and construction work does not happen in areas where a disposal waste package is being transported to its final disposal position. Different time slots can also be allocated for different activities. Another reason for co-activity is to reduce the amount of time that the galleries are empty, thereby reducing the time that geological stresses occur on the galleries. In Finland, for example, there are not more than five deposition tunnels open at a time. Co-activity does not happen only between construction and emplacement. Emplacement activities will happen simultaneously with other activities such as testing, maintenance, repairs or inspections. It is important to take into account the doses to workers during these activities in controlled zones. In France, the separation between operational zones where waste is being emplaced and other work zones is carried out on the basis of processes and procedures. This was, however, challenged by the regulator on the basis of human factor considerations. The regulator asked to investigate the possibility of including a physical separation between emplacement zones and other work zones. This physical separation moves as construction activities progress and more vaults in the repository are filled with waste.

Participants discussed the most challenging operations planned in their repositories. Although this may be to some extent dependent on the type of waste being emplaced, there was some consensus that the backfilling, sealing and closing of galleries where waste has been emplaced is a challenging operation in terms of radiological protection. Different countries have different degrees of automatisation to perform these operations. The recovery of incidents/accidents is also a challenging area in terms of radiological protection. Some countries try to anticipate these situations and design robots to perform the necessary operations. In any case it became clear during the discussion that some countries, including where an operating licence had been granted, do not yet know exactly how they will recover from certain accidental situations underground. In Finland there is a regulatory obligation to calculate the consequences to the environment and the population living near the repository from radiological incidents underground. Since the ventilation system is equipped with filters, it is normally not difficult to meet the targets; the difficulty is to decontaminate the repository underground and restore normal operation conditions.

4. Key takeaways

During the webinar, the participants recognised the need for more guidance in the application of the principles of justification, optimisation and dose limitation in underground repositories. It was also highlighted that the reconciliation of practices from the mining and nuclear industries is not always evident.

During the presentations and the subsequent discussions several common themes were identified:

- There is a need to separate the underground facility into areas or zones based on dose rate, as well as a need to define operational procedures for access to those areas.
- Treating the underground facility as a clean area free of loose contamination offers many operational advantages. It does, however, require work to demonstrate that any package going underground is completely free of contamination.
- Remote handling is used in many facilities for operations in high dose rate areas or when handling unshielded containers, thus reducing workers' dose.
- If nuclear (emplacement) operations are occurring at the same time as construction activities, those zones must be physically separated and ventilated independently.

The participants agreed on the added value of the event in providing a forum for discussion for a sensitive topic in an area where little return of experience exists.

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APPENDIX A: List of participating countries and organisations

Country	Organisation
Argentina	CNEA - National Radioactive Waste Management Program /National Atomic Energy Commission
Austria	AGES - Austrian Agency for Health and Food Safety GmbH
Belgium	AFNC/FANC
	ONDRAF/NIRAS
Canada	Canadian Nuclear Safety Commission
	Nuclear Waste Management Organization
China	Beijing Research Institute of Uranium Geology, CNNC
	China Nuclear Power Engineering co., Ltd.
Czechia	SURAO
Finland	VTT
France	Andra
	ASN – Autorité de Sûreté Nucléaire
	CEPN - Centre d'étude sur l'Évaluation de la Protection dans le domaine Nucléaire
Germany	BGE - Bundesgesellschaft für Endlagerung mbH
	Bundesgesellschaft für Endlagerung mbH
Hungary	Hungarian Atomic Energy Authority
	PURAM
Korea	KORAD
	Korea Institute of Nuclear Safety
	Ministry of Climate and Environment
Spain	CSN - Nuclear Safety Council
	ENEL GROUP
	ENRESA - Empresa Nacional de Residuos Radiactivos, S.A.-
Switzerland	ENSI - Swiss Federal Nuclear Safety Inspectorate
	Nagra
Japan	Nagasaki University
	Nuclear Regulation Authority, Japan
	NUMO - Nuclear Waste Management Organisation
Norway	Norwegian radiation and nuclear safety authority
Romania	Nuclear and Radioactive Waste Agency
Slovak Republic	Nuclear Regulatory Authority of the Slovak Republic
Slovenia	SNSA - Slovenian Nuclear Safety Administration
Sweden	SKB
	Swedish Radiation Safety Authority
United Kingdom	ONR - Nuclear Waste Services
	Office for Nuclear Regulation
United States	CDC/NIOSH – Centers for Disease Control and Prevention/National Institute for Occupational Health and Safety

	Fermi Site Office
	Fringe Science LLC. (Fermilab)
	US Environmental Protection Agency
	US Nuclear Waste Technical Review Board
International Organisations	
	International Atomic Energy Agency
	International Commission on Radiological Protection
	Nuclear Energy Agency
	World Nuclear Association