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Optimisation of Geological Disposal of Radioactive Waste

National and International Guidance
and Questions for Further Discussion

NEA No. 6836

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FOREWORD

The Regulators' Forum (RF) of the NEA Radioactive Waste Management Committee (RWMC) is a well-established forum of high-level regulators for radioactive waste management and decommissioning of nuclear facilities. The RF was established in 1998 and current representation brings together regulatory bodies from 17 OECD countries. The forum provides its members with an opportunity for open discussion and learning about national experience and good practice in regulation with a view to refinement of the regulatory systems in this field. Effective interaction is promoted among regulators, implementers, R&D specialists, policy makers and social scientists at workshops and within the context of other RWMC activities.

Since its inception, the RF has been examining the nature of the regulatory system and how the regulatory function is fulfilled as regards radioactive waste management. The RF has particular interest in safety criteria, in the regulatory aspects of waste retrievability, optimisation and long-term monitoring of geological repositories as well as emerging regulatory practices in the field of decommissioning. In the area of regulation and society, the RF recognises the importance of keeping abreast of the ethical issues associated with regulators' responsibilities to current and future generations as well as societal expectations regarding their role.

As national geological disposal programmes progress towards implementation, the concept of "optimisation" and related requirements are receiving increased attention. Exchanges within NEA expert groups have shown that both regulators and implementers would benefit from a review of the relevant concepts and available guidance and experience. This report summarises and reviews the concepts relevant to the "optimisation" of geological disposal systems as they are outlined in national and international guidance. It also presents a set of observations and key questions. Overall, the report shows that, when addressing "optimisation", there is ample scope for clarifying concepts, facts and possibilities and for ensuring that regulatory guidance is sufficiently precise and implementable.

The intention is that this report should serve as a basis for exchange within and beyond NEA committees and expert groups. An earlier draft was used in discussions at the Tokyo Workshop of the NEA RWMC-RF on 20-22 January 2009. In the longer term, it is anticipated that the report will help build shared understanding on how optimisation concepts or related requirements may be interpreted, and how these requirements may be formulated in a manner such that regulation is transparent, proportionate and deliverable.

Acknowledgements

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TABLE OF CONTENTS

FOREWORD 3

1. INTRODUCTION 7

2. CURRENT OPTIMISATION CONCEPTS AND RELATED REQUIREMENTS 9

   2.1 ICRP guidance 9

   2.2 IAEA guidance 12

   2.3 European Directive on *Best available techniques* 13

   2.4 Guidance at the national level 14

3. KEY OBSERVATIONS AND QUESTIONS 17

4. CONCLUSIONS 25

5. REFERENCES 28

1. INTRODUCTION

The safety of a disposal system ultimately rests on where and how the system was designed, built and left to evolve, and not on how safety is argued. A sound approach to siting and building a robust disposal system, along with rigorous quality assurance, are thus pre-requisites of safety.

In order to argue the safe performance of a geological disposal system in the long term, the proponent of a safety case is advised by international guidance to rely not only on analyses utilising the classical operational indicators of protection, namely *dose* and *risk*, but also on additional lines of reasoning and analyses, and additional complementary indicators. *Multiple lines of reasoning* and *multiple indicators of performance* help provide confidence in the plausibility of statements that the geological repository system will perform as intended further on in time. The application of *sound engineering and managerial principles* is expressly cited in national and international guidance towards building and licensing geological repositories of radioactive waste. The guidance may also suggest that the approach taken to specifically reduce radiological exposures should be accounted for and documented in the safety reports to provide additional confidence in safety. Overall these concepts are related to the more general concept of *optimisation*, meaning the act of choosing the *optimal* combination amongst several technical provisions for complying with a series of requirements. The objective in principle is to find the *optimal* or *best* combination of characteristics in terms of balancing imperatives of current and future safety while respecting the interests of present and future generations. This is an idealised objective rather than one that can be fully realised in practice.

As disposal programmes approach their industrial implementation, the concept of optimisation and its implications on siting, design, construction, operation and closure of disposal facilities are receiving increased attention. The guidance is, however, generic at this stage. Exchanges within NEA groups have shown that both regulators and implementers would benefit from a review of the relevant concepts and available guidance and experience, both at the national and international level. The present document originates from the strong interest in this area by the NEA RWMC Regulators' Forum (RWMC-RF) and the Integration Group for the Safety Case (IGSC).

The intention of this document is to stimulate discussion of optimisation and promote shared understanding on how optimisation concepts or related requirements may be interpreted and how requirements may be formulated in such a manner that regulation is transparent, understandable and deliverable during the many-decades-long stepwise decision-making process that accompanies the development of any deep disposal project. The document was developed originally as a basis for discussion at the Tokyo Workshop organised by the RWMC-RF, 20-22 January 2009.[1] The workshop served to validate the current text.

The present document is structured in five parts. Following this introductory section,

- Section 2 summarises and reviews the concepts relevant to the optimisation of geological disposal systems as they are outlined in national and international guidance as well as in the work of NEA groups. Important sources of information have been the guidance documents by the International Commission on Radiological Protection (ICRP) and the International Atomic Energy Agency (IAEA), the Integrated Prevention, Pollution and Control (IPPC) Directive of the European Commission, and documentation from initiatives of the RWMC-RF and the IGSC. This section relies on a more detailed literature search that is documented in a supporting report to the present one.
- Section 3 presents a set of observations and key questions regarding the basic concepts relating to optimisation especially as it relates to the long term. In this context, it may be helpful to distinguish between different forms of optimisation, ranging from simple minimisation of radiological dose or risk, regardless of other considerations, to *system optimisation*, namely protecting humans and the environment from all types of hazards taking into account social and economic considerations. Different forms of optimisation do not necessarily lead to the same result.
- Section 4 presents the conclusions of the study.

1. Proceedings slated to appear in Autumn 2009. Lessons learnt and the programme of the workshop are documented in the report NEA/RWM/RF(2009)1, which is publicly available.

2. CURRENT OPTIMISATION CONCEPTS AND RELATED REQUIREMENTS

The present section summarises and reviews the concepts relevant to the optimisation of geological disposal systems as they are outlined in national and international guidance as well as in the work of NEA groups. This section relies on a more detailed literature search where additional citations are provided.[2]

2.1 ICRP guidance

1. The ICRP has developed over time a system of radiological protection that applies to all situations involving radiological exposures. The latest general guidance is ICRP-103 of December 2007 [1]. On the matter of optimisation it incorporates the recommendations of ICRP-101 of January 2006 [2]. A later document also exists on "scope of radiological protection control measures" (ICRP-104), it talks about exclusion and exemption. It too is subordinate to ICRP-103.

2. One of the ICRP basic radiological principles is that of "optimisation of protection". According to this principle, radiological exposures should be kept as low as reasonably achievable, economic and social factors being taken into account (ALARA principle, ICRP-60 [3], ICRP-103). ALARA can be made into a formal approach for facilities over which control can be exercised. Additionally, feedback from performance can be used to improve on the facility's technical characteristics and management in order to keep exposures ALARA.

3. In practical life there may arise, from any facility, exposures that are unexpected or unplanned for, i.e., potential exposures. Potential exposure is the situation typical of a radioactive waste deep-disposal facility in the long term. Specific guidance on deep disposal facilities is given in ICRP-81 (1998) [4]. ICRP-81 (Par. 49), as well as other ICRP earlier guidance, observe that there are no formal techniques for dealing with potential exposures from disposal situations.

2. See report NEA/RWM/RF(2008)3.

4. For potential exposure situations the ICRP recommends that no strict limits be used but only dose or risk constraints. These should be used "prospectively" in a process of "constrained optimisation" (ICRP-81, Par. 36). This process should be made visible. Simply showing compliance with some radiological criteria should not compel acceptance of a proposed safety case (ICRP-81, Par. 77).

5. ICRP-103, whose objective is to improve and streamline the presentation of the previous ICRP recommendations, states that ICRP-81 remains valid for disposal situations (Par. 265). ICRP-103 states further "that, in an optimisation process, the chosen option is not necessarily the one associated with the lowest dose." ICRP-103 also states (Par. 223) "All aspects of optimisation cannot be codified; rather, there should be a commitment by all parties to the optimisation process. Where optimisation becomes a matter for the regulatory authority, the focus should not be on specific outcomes for a particular situation, but rather on processes, procedures, and judgements. An open dialogue should be established between the authority and the operating management, and the success of the optimisation process will depend strongly on the quality of this dialogue."

6. According to ICRP-81, "constrained optimisation" is a "judgemental process … and should be conducted in a structured, essentially qualitative way" during the repository conception and implementation. "The goal is to ensure that reasonable measures have been taken to reduce future doses to the extent that required resources are in line with these reductions" (Par. 50). Estimated doses or risks to individuals are inputs to an optimisation process; what counts for optimisation of radiological protection is that a structured process is in place during conception and implementation. The application of *best practice*[3] is a foundation to a successful process of optimisation as it ensures the robustness and efficiency of the system. Examples cited by ICRP-81, include defence in depth and quality assurance. Another example is recurrent, intermediate safety assessments for identifying vulnerabilities. The ICRP stresses the different nature of analyses of human intrusion and of natural processes scenarios. In particular, different values of the dose constraints are recommended for the two scenarios. Consistency between ICRP-81 Par. 52 and Par. 78 indicates

3. "sound engineering and managerial principles" in the ICRP-81 jargon; *best practice* is used for the sake of convenience in the rest of the document.

that the analyses for human intrusion should stress even more the implementation of *best practice* (see also Par. 51).

7. In terms of reaching a judgement of regulatory compliance regarding optimisation, ICRP-81 insists on the quality of the approach and on the measures that were arrived at for assuring radiological protection. ICRP-81 indicates that judging whether optimisation is achieved should not lead to an open-ended process. Namely, "… provided that reasonable measures have been taken both to satisfy the constraints for natural processes and to reduce the probability or the consequences of inadvertent human intrusion and that sound engineering, technical and managerial principles have been followed, then radiological protection requirements can be considered to have been complied with." (Par. 78) Interestingly, selection among options is not mentioned explicitly in the above paragraph. However, consistency between Par. 50 and Par. 78 of ICRP-8 implies that an optimisation process has been followed in order to arrive at the implemented "reasonable measures" and "to satisfy the constraints" for natural evolution scenarios.

8. ICRP-81 comments also on the concept of "Best Available Technology Not Entailing Excessive Costs" (BAT), proposed by others. Namely, BAT differs from optimisation in the ICRP sense, in that it deals with the environment as a whole and is not a process whereby radiological exposure assessments to man *vis-à-vis* a constraint are made. The ICRP states that it may be a useful concept where radiological assessments become too unreliable. BAT is thus perhaps closer to the ICRP's concept of application of "sound technical and managerial principles" (*best practice*) than that of *optimisation of (radiological) protection.*

9. Finally, whilst in general dose or risk, also for potential exposures, are to be seen as related to health detriment (see ICRP-103 glossary), an exception needs to be made for disposal situations. Both ICRP-81 and ICRP-103 take the position that "doses and risks, as measures of health detriment, cannot be forecast with any certainty for periods beyond around several hundreds of years into the future. Instead estimates of doses can be made". "Such estimates should not be regarded as measures of health detriment". In ICRP-81, Par. 71, the degree to which dose or risk may be regarded as measures of health detriment is related to the degree of predictability of the repository system over time. In ICRP-77 [5], the additional point is made that the

relationship between dose and health effects is likely to change over time, as well.

2.2 IAEA guidance

1. The IAEA current reference standard on geological disposal is document WS-R-4 [6]. This, like other IAEA documents, is based on the recommendations set forth by the ICRP and especially by ICRP-81, and it is deemed to be consistent with the Fundamental Safety Principles enunciated in the document "Safety Fundamentals No. SF-1" of 2006 [7]. Being high level and meant to apply to all kind of facilities and to transportation, the latter document is very generic. It is of interest to note, however, that one of the fundamental safety principles is about optimisation. Principle 5 thus states that for any facility "protection must be optimized to provide the highest level of safety that can reasonably be achieved". In the remainder of the SF-1 text, safety is then very much related to radiation risk.

2. In WS-R-4, optimisation is described as a process to be applied throughout the development of a geological disposal facility with a view to develop an appropriate understanding of the relevance and implication for safety of the options that are developed by the operator with the ultimate goal of avoiding or reducing radiological exposure. The optimisation of radiological protection for a geological disposal facility is recognized to be a judgmental process that is applied to the decisions made during the development of the facility's design. A close connection is made between optimisation of radiological protection and "sound and technical managerial principles" (*best practice*). The latter are seen basically as a tool to arrive at a more convincing radiological optimisation.

3. WS-R-4 closely reflects ICRP-81 (Par. 78) as regards regulatory acceptance and reliance on optimisation. The emphasis in ICRP-81 is on "reasonable measures"; WS-R-4 indicates what some of these measures could be. One compliance requirement states that there should be "reasonable assurance" that the assessed dose or risk *does not exceed* the constraints for the expected natural evolution of the system. This seems to be equivalent to the expression "*satisfy the constraints*" of ICRP 81. Both the IAEA and the ICRP thus seem to draw a distinction between the pre-closure period of the geological facility, where as low as reasonably achievable is required, and the long-term where simply meeting the constraint is asked for.

4. WS-R-4 has additional cautionary words indicating that radiological impact analyses are less and less reliable as time progresses, and that this should be foreseen and taken into account in the final judgement. However, unlike ICRP-81, no indication is given on relevant time frames.

5. WS-R-4 stresses the importance of a graded approach and of the evaluation of alternative options at each major decision point. Conditions for achieving optimisation are given. In particular, long term implications are emphasised for the choice of the best option, the ultimate goal being to provide an optimised level of operational and post-closure safety. There is, however, no recommendation on how to balance operational and post-closure safety. Furthermore, when considering alternative options, IAEA requirements state that other factors may have to be considered such as availability of transport routes, public acceptability and cost.

2.3 European Directive on *Best available techniques*

1. The IPPC (Integration Prevention Pollution and Control) Directive of the European Union [8] requires that installations should be operated in such a way that *best available techniques* are used as preventive or reduction measures against pollution of the environment.

2. The IPPC defines *best*, *available*, and *technique*: (a) *technique* means both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned; (b) *best* means most effective in achieving a high general level of protection of the environment as a whole; (c) *available* means reasonably accessible and existing on a sufficiently large scale. There is, like in ICRP and IAEA, the desire that potentially undesirable effects be kept as low as reasonably achievable. The BAT concept as introduced by the IPPC mainly refers to operational situation; it may, however, also be applied to protection of the environment in the long term. The greater difference between the BAT concept of the IPPC and the ICRP concepts of optimisation lies in the fact that the latter utilise radiological constraints as a yardstick and emphasise radiological exposures, whereas, for the IPPC, BAT is about protection from all sources of danger but no reference criteria are specified. BAT, in the sense of the IPPC, is thus a concept aiming at *optimisation of overall protection* as distinct from *optimisation of radiological protection*.

2.4 Guidance at the national level

Countries have been preparing regulatory guidance on demonstrating long-term safety. The level of detail of the implementation of the optimisation concept varies depending on the country but it remains on a very general level. The terms “as low as reasonable achievable”, “optimisation”, “sound technical and managerial principles”, “best available techniques or technology” or similar appear variously in all regulations. The meaning of these terms, the interpretation of international guidance and the degree of guidance provided vary significantly from country to country. For example:

1. The Swedish radiation protection regulations for geological repositories define both optimisation and best available techniques (BAT). Optimisation is defined as a process aiming to limit dose and risk (also in the long term) as evidenced through recurrent risk assessment analyses. In this formulation optimisation is understood to be a concept very much related to reduction of dose by an amount that may, at least in principle, be calculated. Inspiration is taken from the radiation protection literature, but a more formal and visible approach to radiological optimisation – more quantitative –, than ICRP-81, is suggested. Also, to the “sound technical and managerial principles” of the ICRP-81, the Swedish regulator prefers its own concept of BAT. BAT relates to activities aiming to limit dose and risk using all actions that may prevent, limit or delay releases from the repository’s barriers. BAT is treated as a concept favouring intrinsic robustness and with that better, albeit non-quantifiable, radiological safety.

2. The Swedish guidance identifies examples of potential conflicts coming from the use of radiological optimisation and BAT. When conflict arises, BAT has precedence. Further, BAT becomes the predominant discriminating tool in the very long term when the risk analyses that underlie radiological optimisation become the least reliable. Finally, for enabling assessment of regulatory compliance, the operator’s report should include an account of how the principles for radiological optimisation and BAT were applied in the siting and design of the repository and relevant system components, and how quality assurance was used in the work on the repository and relevant risk analyses. BAT in the sense of the Swedish regulator identifies to some extent with the performance of the engineered barriers in delivering basic safety functions and thus relates to radiological protection. This interpretation of BAT may thus be different in concept but not in substance from BAT in the sense of the IPPC, in that both may lead to reduced overall environmental impact.

3. In Finland, the regulation states that the planning shall take account of the utilisation of best available "technology" and scientific knowledge. The recent amendment of the Nuclear Energy Act includes the SAHARA principle (Safety As High As Reasonably Achievable). No further guidance is specified in the regulations and formal, rigorous assessments demonstrating compliance with the above principles are not required.

4. UK regulatory guidance for solid radioactive waste disposal specifies that optimisation applies only to radiological risks to people. Other living organisms must also be protected from radiological hazards but there is no optimisation requirement. The guidance states that optimisation is a continuing, forward-looking and iterative process aimed at maximising the margin of benefit over harm, which takes into account both technical and socio-economic factors, and requires judgements based on qualitative as well as quantitative aspects. It involves continually questioning whether everything reasonable has been done to reduce risks. In every organisation concerned, it requires commitment at all levels, together with adequate procedures and resources. Optimisation decisions balance the detriment or harm associated with the radiological risk, together with other benefits and detriments (economic, human, societal, political, etc.) associated with disposing of the radioactive waste, to be taken into account both at the time the decisions are taken and in the future, and the resources available for protecting people and the environment. Optimisation decisions are constrained by the circumstances prevailing at the time of these decisions. Optimisation needs to be viewed as part of a bigger picture, recognising that there will be competing technical and stakeholder claims for limited funds, and that there is no completely risk free way of managing radioactive waste. The result of optimisation provides a radiological risk at a suitably low level, but not necessarily the option with the lowest possible radiological risk.

5. In the United States, the Nuclear Regulatory Commission (NRC) regulations require optimisation of radiological protection in the sense of ALARA for the pre-closure phase. The NRC states, however, that the application of ALARA is not appropriate for the achievement of the long-term performance objective since it would require evaluation of benefits and impacts that span many generations. Compliance with strict regulatory requirements, which include a performance objective, is considered protective of public health and safety for the post-closure phase. The US programme follows a process of stepwise development of a repository which allows for changes in design based

on new technology or other considerations. In this sense, one may view that performance can become optimised as the result of the process of repository development. This approach seems very close to the one described in ICRP-81 for judging compliance with regulation. In the United States, because optimisation is a finite process, once repository performance complies with regulatory requirements, public health and safety has been protected and no additional measures are needed.

3. KEY OBSERVATIONS AND QUESTIONS

This section presents a set of observations that can be made and questions that can be raised regarding the basic concepts relating to "optimisation" especially as it relates to the long term.

Four overarching observations that are related to one another are as follows:

1. Radiological protection has different meaning/interpretation in the pre-closure phase and in the post-closure phase of a repository. In the latter phase, the absence of the elements of feedback from operation, and control of protection, and the fact that exposure can only be estimated raise a fundamental issue of whether even the same term can be used to indicate protection before and after closure. Thus a clear distinction should be made between optimisation in the active plant and in the far future. There is a tendency to mix both areas when arguing optimisation and it helps if a clear distinction is made.

2. ICRP and IAEA as well as some national guidance stress the importance of a *graded approach* to optimisation. Suggestions for achieving optimisation are given, the ultimate goal being to provide an optimised level of operational and post-closure radiological safety. There is however no specific recommendation on methods to balance operational and post-closure safety.

3. ICRP-103 states that, in an optimisation process, the chosen option is not necessarily the one associated with the lowest dose. IAEA requirements state, for optimisation purposes, that factors other than radiological protection may have to be considered such as availability of transport routes, public acceptability and cost. Factors that are not necessarily radiological have been put forward in national programmes such as predictability, demonstrability, flexibility, feasibility of construction, operation, maintenance and retrievability. It would be helpful if a clearer distinction were operated between system optimisation and radiological optimisation. There thus seems to be a desire to move from optimisation of radiological protection to system

optimisation, in the sense of taking into account social and economic considerations as well as all types of hazards.

4. One could recognise in the recent literature the emerging view that optimisation ought to be more about procedures than outcome.

Other observations are as follows:

- The concept of optimisation of protection has been propounded and developed over the years by the radioprotection community, and it is embodied in various ICRP documents. These documents emphasize radiological protection and have inspired additional guidance both internationally, e.g., from the IAEA, and nationally, from the relevant regulatory agencies. The reference document dealing with geological disposal within the ICRP guidance is ICRP-81, which was issued in 1998 and whose validity was re-affirmed very recently with the issuance of ICRP-103 in December 2007. The concept of Best Available Techniques developed by the IPPC has also variously influenced the international and national guidance. The latter concept applies to the overall protection of the environment and thus goes beyond radiological protection. The ICRP concept of application of *best practice* may have similar effect as BAT, even if it is cited in the context of protection against radiological exposures.

- The usual ICRP approach for optimisation for practices involving radiological exposures suggests that a dose or risk constraint should be considered as a boundary line for accepting or not an option under consideration. If the option is below the boundary line, then optimisation is still required, resulting generally in solutions that are well within the boundary. However, in theory the solution could be very close to the boundary line. The ICRP-81 approach in the case of disposal is less equivocal, in that, for regulatory acceptance, simply being below the boundary line, and having shown good application of *best practice*, no further optimisation may be needed (Par. 78). That also seems to be the position of the IAEA's WS-R-4.

- In the ICRP view, a geological disposal in the long term corresponds to a very special radiological situation. For disposal we are missing, in the long term, what could be indicators of actual health detriment due to radiological exposure. The position of the ICRP specifically on the use and meaning of dose and risk may be summarised as follows: (a) within a few hundred years from final closure, when dose and risk can be forecast with high reliability, they should be seen as a measure of health detriment; (b) when the forecasts become less reliable dose and risk can be estimated, but they should not be construed necessarily as measures of health and detriment but rather, increasingly, as indicators of performance; (c) for times when forecasts are largely unreliable the concept of BAT may be invoked.

- In terms of documentation, ICRP-81 suggests that the final safety report submitted for regulatory compliance need not argue optimisation of radiological protection per se but that reasonable measures have been implemented for dealing with a series of requirements including those related to the performance of the repository system in the framework of natural evolution scenarios. These measures should have been informed by a process of constrained optimisation against the relevant dose or risk constraints. Thus the existence of this process must be argued as well. It could be reasoned that the normal process of stepwise development of a repository from a conceptual basis to its implementation – whereby designs are subject to analysis, are discussed within the implementing organisation and between this and peer reviewers, and reviewed independently by regulators, and evolve – is by itself an implicit process of optimisation. This consideration underlies perhaps the position of the USNRC on regulatory compliance with long-term performance criteria. Other regulators may want to be more formally informed of the major conceptual changes in time and receive a report on performance indicators, including the estimated effective dose, *vis-à-vis* a series of requirements (or compliance with the dose constraint) as well as on decisions taken from the balance between different performance or safety indicators.

- There is variation in how concepts such as BAT, optimisation of radiological protection and others are viewed or defined and the weight that they are given in the different national regulatory contexts. The distinctions between optimisation of radiological protection, optimisation of overall protection, in the sense of protection of man and environment from all types of hazards, and system optimisation, in the sense of protecting man and the environment from all types of hazards and taking account social and economic constraint are important ones to keep in mind.

Important points arising from this study are:

- The ICRP takes the position that "doses and risks, as measures of health detriment, cannot be forecast with any certainty for periods beyond around several hundreds of years into the future...” and that “Such estimates should not be regarded as measures of health detriment”.

a. It seems clear that the main reason behind this position is the increasing unreliability of the estimates of radiological exposure and of health detriment per unit dose as time progresses. Are there other reasons, such as uncertain human behaviour and characteristics, and uncertainty in the dose-risk relationship? If biosphere parameters are too uncertain, and given that engineering materials and geology are more predictable than biosphere, would not an analysis based on repository safety functions be more defensible? This would shift the emphasis from optimisation of radiological protection, in the sense of reduction of calculated dose, to optimisation of overall protection through analyses of system robustness. Calculations for the far future can be very conservative (full release of the supposed amount of the radioactive inventory in the environment; full use of contaminated water by individuals). Therefore, optimisation in the sense of reduction of a calculated dose does not necessarily result in an optimisation of the system of barriers. It can just lead to optimisation of the calculation model. On the other hand, optimisation of the system of barriers can lead to a lower release of radioactive substances or to a lower probability of release of a certain fraction of the radioactive inventory as well as to reduction of other hazards.

b. The ICRP also recognises that effective dose, which is used by regulators in ordinary situations, is a quantity that is not based on data from individual persons and does not provide an individual-specific risk but rather a risk to a hypothetical Reference Person (an “adult hermaphrodite”) under a given exposure situation. Effective dose is seen as tool for *managing stochastic effects in workers and public* (ICRP-103, Section 4.4.6). The dose-risk relationship should not be used for estimating collective detriment, and *collective effective dose*, which is the sum of all individual effective doses “*is not intended as tool for epidemiological studies, and it is inappropriate to use it risk projections*” (ICRP-103, Section 4.4.7). Effective dose is thus a precautionary tool to limit effects that may exist based on the LNT hypothesis. The link to actual health detriment seems tenuous in all situations and more so for geological disposal.

- There are different national interpretations of the meaning/ interpretation of optimisation in the framework of stepwise development of a repository These are not entirely inconsistent with different emphases being placed on the extent to which optimisation is concerned with protection from radiological exposures in the long term and its wider application to other aspects such as environmental protection, safety at large, protection from exposures during operation as well as other operational requirements.

- Optimisation of a geological repository will involve a judgmental process informed by quantitative aspects such as the assessment of dose estimates and costs. There may also be a need to balance other performance indicators and requirements against those associated with radiation protection in the long term.

- The goal of constrained optimisation in ICRP-81 is to ensure that "reasonable measures have been taken to reduce future doses". The term "reasonable" indicates that judgement is being made in a decision and the question arises of whether we may consider that a decision is reasonable when all concerned parties have agreed on the process to taking that decision.

- Optimisation of radiological protection, in the sense of ALARA, is a well defined concept during the phase of active management and control of a facility. Thus it should certainly play a role during the operational phase of the repository. At that time the doses are real doses to real people. A difficulty may arise if, in order to reduce actual exposures to workers and public during the operational phase, one may have to increase the potential dose to future individuals, or *vice-versa*. Decisions on risk transfer are likely to be required now that repositories are to be built[4] and balancing actual present day risks against future, potential risks might not be straightforward. The issue of risk transfers could be part of the decision-making process that will eventually result in an "optimal" design. The ICRP provides some

4. One relevant area, to this effect, may be that of retrievability. Will provisions for retrievability help for the optimisation of radiological protection? On which timescales or for which time periods?

guidance regarding the balancing of risk transfers: in ICRP-103 (Par. 222) it indicates that, for decision-making purposes, lower weight may be given, to very low doses and to doses to be received potentially in the distant future. It is worth noticing, however, that ICRP-101 (Par. 56) evokes the possibility that doses potentially to be received in the distant future may also be given a higher weight. The same paragraph ends by re-iterating an important position taken by the ICRP both ICRP-81 and ICRP-103. Namely, that "The Commission feels that our current state of knowledge and our ability to predict populations and exposure pathways can appropriately contribute to decision-making for exposures to occur over a time period covering a few generations. Beyond such time frames, the Commission recommends that predicted doses should not play a major part in decision-making."

- Conditions for achieving optimisation are given in IAEA safety requirements. In particular, long-term implications are emphasised for the choice of the best option. However some requirements may need to be detailed further. It is important to identify among the long-term implications of various design options which are those to be considered (estimated doses or risks, impact on the environment, performance of barriers, reduction of uncertainties...). Implications in the long term are not the only criteria. They should be balanced with implications in the short or medium term (protection during the operational phase, retrievability, cost, social factors). This may be considered as system optimisation. Criteria for progress along the successive steps of the program should be identified and end points for optimisation defined. Given that the safety of a repository rests ultimately on where and how it was built, safety is basically a reflection of our best effort before closure of the repository. If this view is valid, should then optimisation of radiological protection not be seen as a part of our best effort to implement a safe repository? In other words, a concept such as BAT – properly defined, taking into account the stepwise decision making process and the feedback from recurrent evaluations of radiological exposures and other indicators, not only of performance – might be developed as the reference concept for the "system optimisation" considering all time frames including pre-closure and long term.

- There is a need for further consideration of whether the term or concept of "optimisation of radiological protection" is needed as a separate, leading concept for the post-closure phase of geological disposal. The present study suggests there are good reasons for incorporating this concept in the broader concept of, for example, BAT or application of *best practice*; these include:

a. Emphasis on radiological exposures may mask risks from non-radiological causes. For example, the chemical toxicity of the wastes may at some point be as significant as the radiological toxicity, and the dangers of both types will be comparable with one another.

b. Dose and risk are accepted as the yardsticks for optimisation of protection against radiological exposures. Placing an emphasis on optimisation of radiological protection over long timescales can mean an emphasis on estimation of doses or risks, which might give a false impression that actual detriments to people's health are being estimated. This raises the wider issue of how dose or risk should be used as the only or the reference indicators in regulation for long-term geological disposal safety. Radiological criteria are being viewed generally in a flexible way as broad indicators of long-term performance of a repository but there remains an issue that use of dose and risk can raise a false expectation of that safety assessments evaluate actual health detriment.

c. Focus on optimisation analyses of radiological protection can relegate to second rank analyses that utilise indicators other than dose or risk and that are meant to assess the robustness of the system. These analyses are typically those that would underscore a statement of application of best available technique or *best practice*. Yet, it would seem from the literature that these often are the preferred analyses for arguing long-term safety.

d. The way the term "optimisation" is used in radiation protection is not standard usage in the scientific literature and may cause confusion. In the ICRP general use of the term, the constraint is used as a "pass/no-pass" level above which a situation is not acceptable and below which one still needs to optimise. In the scientific literature, optimisation is about meeting the constraint.

Additional questions that need to be addressed when considering optimisation of a geological disposal facility include:

- Is the concept of constrained radiological optimisation clearly distinguishable from that of BAT or of *best practice*? Or is one to be subsumed in the other? Is BAT the same as analysis of repository system robustness?

- Should practical measures to introduce retrievability be judged to be part of an overall optimisation of the repository concept? Can they be constructed to be BAT in some sense?

- To what extent should optimisation be linked to timescales? Technical provisions for optimising a system may well be different if optimisation was required over, say 10 000 or 1 000 000 years.

4. CONCLUSIONS

Geological disposal is a very special radiological situation in that, for the long term, we are missing both the element of control and what could be indicators of actual health detriment associated with potential radiological exposures. The position of the ICRP specifically on the use and meaning of dose and risk may be summarized as follows: (a) within a few hundred years from final closure, when dose and risk can be forecast with high reliability, they should be seen as a measure of health detriment; (b) when the forecasts become less reliable dose and risk can still be estimated. However, they should not be construed necessarily as measures of health detriment but increasingly as indicators of performance; (c) for times when forecasts of radiological exposures are largely unreliable the concept of BAT may be invoked. Geological disposal has also additional peculiarity when it comes to the application of the concept of optimisation. The ICRP general approach for optimisation of radiological protection suggests that a dose or risk constraint should be considered as a boundary line for accepting or not an option under consideration. If the option is below the boundary line, optimisation is still required, resulting generally in solutions that are well within the boundary, although, in theory, the solution could be very close to the boundary line. For geological disposal, the ICRP-81 suggests instead, that, for regulatory acceptance, having simply met the boundary constraint, and having shown good application of "best practice", no further optimisation may be needed.

Possibly because of the peculiar situation that geological disposal represents, there are significant differences in the way national programmes approach the questions of the long term and of optimisation. There is sufficient breadth and flexibility in the international guidance to accommodate much of this variation. It is, however, open to question whether there should be greater consistency between different national programmes.

The variety of approaches to optimisation, differences in interpretation of the terms used, and variations in the ultimate objectives of optimisation make for a very varied and potentially confusing backdrop for formulating clear and deliverable regulation, especially concerning long-term repository performance. In this context, the study observes that:

- Radiological protection has a different meaning in the pre-closure phase and in the post-closure phase of a repository. In the latter phase, the elements of feedback from operation, control of protection, and increasing uncertainty over long timescales in assessments of exposures and their effects raises a fundamental issue of whether even the same term should be used to indicate protection before and after closure. A clear distinction should be made between optimisation of radiological protection in the actively managed facility and in the far future – there is a tendency to mix the two periods when arguing optimisation. However, when arguing for selecting design options, an optimisation approach that references both periods may have to be adopted keeping in mind that the final objective is to optimise overall protection.

- A distinction needs to be drawn between optimisation of radiological protection, optimisation of overall protection, in the sense of protection of man and environment from all types of hazards, and system optimisation, in the sense of protecting man and the environment from all types of hazards and taking account social and economic constraints. The national and international guidance seem to be evolving in favour of system optimisation, although this is not always stated clearly. The ICRP makes an important step in that direction in its latest recommendations (ICRP-103), where it recognises that, in any optimisation process, the option that is finally retained is not necessarily the one associated with the lowest dose.

- The difficulty of applying the concept of optimisation of radiological protection in the post-closure phase of a repository is further captured by the observation, of the ICRP-81 that “there are no formal techniques for dealing with potential exposures from disposal situations”. This statement is still applicable today. This difficulty is further highlighted by the observation of the ICRP-101 according to which “…our current state of knowledge and our ability to predict populations and exposure pathways can appropriately contribute to decision-making for exposures to occur over a time period covering a few generations. Beyond such time frames, the Commission recommends that predicted doses should not play a major part in decision-making.”

- One could recognise in the recent literature an emerging view that optimisation, in any practice, ought to be more about procedures than outcome when it comes to regulatory attention. A strong support to this approach is provided by the recent ICRP-103, which states that "All aspects of optimisation cannot be codified; rather, there should be a commitment by all parties to the optimisation process. Where optimisation becomes a matter for the regulatory authority, the focus should not be on specific outcomes for a particular situation, but rather on processes, procedures, and judgements. An open dialogue should be established between the authority and the operating management, and the success of the optimisation process will depend strongly on the quality of this dialogue."

- One way to reach system optimisation for geological disposal facilities might be to consider that the normal process of stepwise development of a repository from a conceptual basis to its implementation – whereby designs are subject to analysis, are discussed within the implementing organisation and between the latter and its reviewers, including regulators, and evolve with time – is by itself a sufficient process of optimisation. Other factors than radiological protection will be typically taken into account during a stepwise decision-making process. For instance, factors dealing with the quality of the design and its conception, such as predictability, demonstrability, feasibility of construction, flexibility of operation, maintenance and retrievability. Factors of more societal nature will include availability of transport routes, public acceptance and cost.

Overall, the present study shows that significant progress has been made in defining the concept of optimisation for geological disposal facilities but there exists scope to clarify concepts, facts and possibilities and to ensure that regulatory guidance is precise and can be implemented. The intention of this document is to stimulate discussion of optimisation and promote shared understanding on how optimisation concepts or related requirements may be interpreted and how requirements may be formulated in regulation in a manner that is transparent, understandable and deliverable during the many-decades-long stepwise decision-making process that accompanies the development of any deep disposal project.

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