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Issues in radioactive waste disposal

Second report of the Working Group on Principles and Criteria for Radioactive Waste Disposal

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FOREWORD

Plans for disposing of radioactive wastes have raised a number of unique and mostly philosophical problems, mainly due to the very long time-scales which have to be considered. While there is general agreement on disposal concepts and on many aspects of a safety philosophy, consensus on a number of issues remains to be achieved.

To assist in promoting discussion amongst international experts and in developing consensus, the IAEA established a subgroup under the International Radioactive Waste Management Advisory Committee (INWAC). The subgroup started its work in 1991 and was called the "INWAC Subgroup on Principles and Criteria for Radioactive Waste Disposal". With the reorganization in 1995 of IAEA senior advisory committees in the nuclear safety area the title of the group was changed to "Working Group on Principles and Criteria for Radioactive Waste Disposal".

The working group is intended to provide an open forum for:

(1) the discussion and resolution of contentious issues, especially those with an international component, in the area of waste disposal safety principles and criteria,

(2) the review and analysis of new ideas and concepts in the subject area,

(3) establishing areas of consensus,

(4) the consideration of issues related to safety principles and criteria in the IAEA's Radioactive Waste Safety Standards (RADWASS) programme,

(5) the exchange of information on national safety criteria and policies for radioactive waste disposal.

This is the second report of the working group and it contains three contributions each dealing with an issue related to disposal of radioactive wastes underground.

The first report was published in 1994 and has the title "Safety Indicators in Different Time Frames for the Safety Assessment of Underground Radioactive Waste Repositories" (IAEA-TECDOC-767).

The reports of the Working Group on Principles and Criteria for Radioactive Waste Disposal contain the developing views of experts within the international community and should be of use to those engaged in producing national and international standards and guidance in this area.

CONTENTS

Chapter 1

INTRODUCTION

The topics discussed in this report are all, in some way, related to the long time-scales that have to be considered in relation to the safety of underground repositories for radioactive wastes. Indeed, this is the single and unique feature of the repositories, which when compared to other types of engineered structures, requires special consideration and new approaches to establishing safety.

Chapter 2 addresses possible actions which might be considered for the purpose of ensuring the continuing safety of geological repositories in the period after they have been finally closed. Geological repositories are designed to provide safety during the hazardous lifetime of the wastes without the need for any further human action after they have been closed. Nevertheless, discussions are taking place among experts on possible post-closure measures which have the purpose of preserving information about the repository, of reassuring the public about the safety of the repository and of preventing misuse of the contents of the repository. Although it will be many decades before such measures have to be finally decided upon, it was considered useful to elaborate the arguments, for and against, implementing the various possible post-closure actions being considered.

One of the basic principles of radiation protection is that radiation doses and risks from a justified practice should be kept as low as reasonably achievable, economic and social factors being taken into account. It is known as "optimization of protection". The principle applies to radioactive waste disposal since waste repositories represent possible sources of radiation exposure to humans. In this context, optimization has the potential for use as an input to decisions involving choices between waste disposal options. There are, however, difficulties in applying the optimization principle in the context of radioactive waste disposal. The difficulties are mainly related to the long time-scales involved. Radiation doses to the public from the geological disposal of radioactive wastes are predicted to occur in the far future, if at all. At these times, the uncertainties in the predicted doses are often too large to allow any distinction to be made between possible disposal options on radiological grounds. Another basic problem in applying the principle is that the costs and benefits of reducing radiation exposures occur at different times, raising the question of whether a cost borne now can be equated with a benefit obtained in the far future. These, and other more practical problems in applying the optimization principle, are discussed in Chapter 3.

Geological repositories for radioactive wastes are designed to provide long term isolation of the wastes from the human environment by means of a system of barriers both natural and man-made. It is important that once a repository has been closed and sealed that it is not disturbed in a way which could impair its safety barriers. For repositories containing spent nuclear fuel (and possibly also for those containing high level wastes) there is a requirement that they be subject to nuclear safeguards to prevent possible diversion of nuclear materials for use in weapons production. A possible issue here concerns the nature of the safeguards needed for repositories and, in particular, whether they could disturb the passive safety features of a repository. Many of the issues which arise in this context are only beginning to be examined and Chapter 4 presents a preliminary look at them.

The three topics covered in this report have had the benefit of critical review by the Working Group on Principles and Criteria for Radioactive Waste Disposal. They were initially prepared by small groups of experts and then submitted to the Working Group for comment, sometimes on more than one occasion. Usually, the material required revision to accommodate the views of the Working Group and only if there was a broad consensus on their content were the final versions approved. Details of the drafting groups and of the membership of the Working Group are provided at the end of the report.

Chapter 2

POST-CLOSURE ISSUES

2.1. BACKGROUND

Geological repositories for the disposal of radioactive wastes are designed to provide isolation of the wastes from the human environment for very long time periods. This is achieved by the use of man-made and natural barriers which prevent or reduce the migration of the radionuclides from the waste. A properly constructed and located repository with such passive safety features is considered by experts to provide adequate safety during the hazardous lifetime of the wastes without requiring further human action after it is finally closed. Nevertheless, it is recognized that there are arguments in favour of certain activities related to the repository in the post-closure phase. These are aimed at, for example, preventing or decreasing the likelihood of intrusion into the repository and providing additional reassurance to members of the public. The present chapter examines these arguments and the various proposed actions in the post-closure period for a geological repository. It focusses on deep repositories for HLW disposal but, in principle, many of the issues considered may also be relevant for L/ILW repositories.

2.2. POST-CLOSURE STATUS

In the development of a repository project a series of temporal phases can be identified beginning with definition of the disposal concept and moving through site-selection and characterization into the phases of construction and operation. At the end of the operational phase, when it has been decided that no more waste is to be emplaced, the closure phase begins. During this phase arrangements are made to seal the shafts, tunnels and other penetrations into the repository. Final observations and measurements in support of the safety case may also be carried out during this time. The time period following the sealing of the repository is known as the post-closure phase [2.1]. The defining characteristic of the post-closure status is that there is no intention to retrieve the wastes and that no further measures are expected to be necessary in order to ensure proper future performance of the disposal facility.

2.3. RATIONALE FOR POST-CLOSURE ACTIVITIES IN A REPOSITORY PROGRAMME

The main reasons for wishing to continue activities in a repository programme, even after technical consensus has been reached that no further measures are required to assure adequate long term performance are:

- to help in ensuring that information about the existence of the repository and basic knowledge built up throughout the repository lifetime is not lost to future generations.

- to provide reassurance to the public that the repository is safe.

- to help in preventing misuse of the contents of the repository.

The rationale for each of these objectives and various possible post-closure activities for achieving the objectives are elaborated in the following paragraphs. A common caveat on all suggestions for post-closure activities must, however, be emphasized at the outset. Repositories are intended to keep radioactive substances out of the human environment by means of passive safety barriers. No actions in the post-closure phase can be allowed if they result in an unacceptable reduction in the degree of protection provided by the repository. Long term safety has precedence over all other potential interests.

2.4. PRESERVATION OF INFORMATION AND KNOWLEDGE

2.4.1. Rationale

There are several reasons for considering taking measures in the post-closure period to help in ensuring that information on the disposal facility will not be lost.

The most obvious of these is to reduce the probability that man or the environment might be endangered by inadvertent intrusion into the repository at a future time. Many countries require that the risks associated with human intrusion be acceptably low even if no measures are taken. However, active measures at the site can ensure, with a high level of confidence, that no intrusion will take place, at least for the first century or so after closure of the repository when the continuity of such measures can be relied upon. Passive measures at the site (e.g. markers) or elsewhere (e.g. archiving of information, obtaining land ownership) can reduce probabilities of inadvertent intrusion on longer time-scales; therefore there is a clear rationale for including the planning of such measures when preparing for the post-closure period.

The probability of intentional intrusion into a repository may, of course, conversely be increased by ensuring that the appropriate information remains available. For some potential activities (e.g. deliberate retrieval by responsible future generations of the materials in a repository) this is positive. For some other conceivable actions (e.g. retrieval of safeguarded material for weapons purposes), it may be negative.

A final argument for taking measures to ensure that information on the repository is not lost in the post-closure phase is that this information provides a database giving more freedom of action to future generations, perhaps including even full retrieval of the wastes. In addition to the extreme course of retrieval, potential future options to be kept open might include re-analysis of the system and possible remedial actions in the highly unlikely case of such action becoming necessary.

2.4.2. Record keeping and markers

The likelihood of inadvertent human intrusion can be reduced by preserving information about the existence of an underground repository until the wastes no longer present a serious hazard. The information should also be effectively communicated to potential intruders. Methods for preserving information for this purpose have been studied by Nordic and NEA Working Groups [2.2, 2.3]. The most effective means of communicating information about the existence of an underground repository is generally thought to be by on-site markers or monuments supported by national or international archives and by a variety of other records and regulations such as mining databases, land-use controls, regulation of drilling and government ownership of the site.

Conservation of information

An international working group on the subject has recommended that the primary information to be conserved should include [2.3]:

- The geographical location of the repository.
- The design of the repository, its physical shape and barriers.
- The radionuclide inventory.

Secondary information to be retained might include:

- Laws and criteria governing waste disposal.
- Licensing documentation submitted for the repository, including the final safety assessment.
- Records from the operational phase of the repository, such as databases on locations of waste packages and design modifications.
- General information about the society disposing of the waste.
- Potential risks associated with the wastes.

While it is desirable for the information to be preserved for thousands of years, human history warns us that the best that can be expected is several hundred years. Duplication of the information at several locations, both national and international, seems to provide the best chance of long term conservation.

On-site markers

Long term markers in the form of monuments, or other structures have been proposed as an effective means of warning potential intruders. The markers should last for long periods and the associated messages ideally should be capable of being interpreted by societies living in the far future. Proposals have been made for site markers to be placed at the surface or in the sub-surface [2.3]. One view is that such markers would be beneficial from the safety viewpoint. Another view is that they may draw unwanted attention to the repository at some future time and also that the hazard warning might not be understood.

2.5. PUBLIC REASSURANCE

2.5.1. Rationale

The technical safety case for the long term behaviour of a repository system is, of necessity, based on assessments of future behaviour. The methods used are interdisciplinary and are often complex. Much effort has been devoted by specialists to confirming to the greatest extent possible that the predictions are sufficiently reliable for the purpose of making the safety case. This process involves comparison of modelling results with laboratory and field results and with observations on natural or archeological analogue systems. A variety of independent lines of reasoning are usually necessary to help establish the basis for the safety of the facility as well as to help develop confidence in the analyses themselves. The technical safety case prepared by the repository implementor must obviously be understood and accepted by the regulatory bodies. For the general public, however, it is difficult to make all of the arguments sufficiently transparent to ensure they share the same level of confidence as the technical specialists. Furthermore, the confidence of the public that no major gaps exist in our knowledge that could lead to totally unexpected consequences from a repository is generally lower than that of the technical community.

Accordingly, public opinion may dictate that direct monitoring of a repository site be carried out for an extended period after operations cease. Consequently, even if the technical judgement of the regulator is that no significant additional safety benefit would be gained by continued monitoring, it may still be appropriate to undertake further monitoring.

Also, in the context of public reassurance it may be necessary to discuss the possible retrieval of the wastes. The public may wish to be reassured that in an extreme situation the wastes could be recovered. The view from the side of technical experts may be that such an eventuality is so extremely unlikely as not being necessary to plan for — but nevertheless the proponents of the disposal facility should be prepared to discuss the matter.

2.5.2. Monitoring activities

Geological repositories are designed to provide safety without the need for monitoring. There is, therefore, no implication here that monitoring is a necessary element in assuring the safety of closed repositories. Rather, it is an optional measure which may be adopted by countries if, for political or social reasons, it is considered to be appropriate.

A monitoring programme for public reassurance would have to be established through consultation between the public and the responsible authorities, but it must preclude any monitoring which might impair the performance of the multi-barrier safety system.

It has to be recognized that there are technical difficulties in devising a suitable and useful post-closure monitoring programme for a geological repository. A monitoring programme should in principle be focused on measuring parameters of significance to the system performance. Since intrusive methods are excluded for safety reasons, this severely limits the possible range of monitoring options. Monitoring in the surface or near-surface environment may be useful as a means of providing public reassurance but is likely to be of little value in relation to assessing the performance of the repository. Various parameters associated with the thermal and hydrological impact of the repository on the host rock could, potentially, be monitored, for example, (repository) temperature, (repository and near field rock) stress fields, the related area of (repository and near field rock) displacement and (near field rock) pore pressure and hydraulic heads. However, there could be severe problems in measuring and interpreting such parameters and thus obtaining from them an unambiguous indication of system performance. It is clear that techniques which could produce spurious or misleading results should be avoided since such results could invoke expensive confirmatory investigations. In all cases, it would be important to begin measurements in advance of repository excavation (or at least closure) to provide a baseline of data against which significant changes in the environment can be detected and interpreted.

Public reassurance is likely to be most effectively achieved by carrying out monitoring for radionuclides in the surface environment of the repository (soil, air, water). This would provide evidence that the environment in which people live is unaffected by the presence of the repository. However, as stated earlier, while this type of monitoring may be most effective in satisfying public concerns, it will be rather insensitive to changes which could affect repository safety.

2.5.3. Closure planning and retrievability

Decommissioning and closure should be an integral part of the planning of any new disposal facility and not thought of as a stage to be added on at the end of the operations. It is considered appropriate to manage the disposal of wastes in an incremental or step-wise fashion. Thus a series of stages such as site selection/investigation, facility design, demonstration, operation, decommissioning, monitoring, and closure could be envisaged with public consultation taking place during each. It is important to note that these stages will probably take place over many decades and thus several generations will need to be involved in decision making. Final decisions on issues such as long term monitoring or arrangements for retrieval therefore may not have to be made until the middle of the next century. Furthermore, the activities of each subsequent generation will depend on the experience gained with all preceding stages as well as any overall evolution of societal values. Thus the present generation does not have to anticipate (nor is it able to) future evolution. Its responsibility is to act in good faith using existing information and making the best judgements it can [2.4].

A geological disposal facility is defined as one where there is no intent to retrieve and where no institutional control is needed to ensure safety. Thus retrieval is not precluded, but it is not intended and the safety analysis does not anticipate that it would ever be needed to ensure long term safety. Some countries encourage or require that retrieval is possible as a contingency during the operating period of a disposal facility (i.e. prior to closure). After closure it would be possible to retrieve waste if it were absolutely necessary, albeit at considerable monetary cost and possibly involving significant radiation doses to workers. As a practical matter, in the case of deep geological disposal, retrieval will be facilitated by stable waste forms, durable containers and a knowledge of where the waste is located. Most HLW concepts today already include, for safety reasons, both a very stable waste form (UO_2 or vitrified waste) as well as durable containers of steel, copper or titanium which have expected lifetimes of five hundred years to one million years. Thus, in most cases no additional engineering would be needed to facilitate post-closure retrieval. The design of a disposal facility, therefore, may not need any special provisions to aid retrievability beyond that which exists prior to facility closure.

2.6. PREVENTION OF MISUSE OF REPOSITORY CONTENTS

2.6.1. Rationale

The contents of waste repositories, especially those containing spent fuel are of potential interest for the purpose of making nuclear weapons. Although the removal of spent fuel from a geological repository would undoubtedly be a costly, time consuming and difficult operation, it is the view of international safeguards experts that such scenarios are feasible and must be prevented from occurring. Accordingly, IAEA Safeguards policy in relation to spent fuel repositories is that the repositories should be kept under surveillance after closure.

Plans to keep geological repositories under surveillance might be seen as making post-closure activities aimed at preserving knowledge of the repository unnecessary. However, it can be argued that the requirement for international safeguarding of fissile materials is transitory when seen in the context of the period of concern for repository safety. Thus, although planned surveillance activities would prevent inadvertent as well as deliberate intrusion into the repository while they are maintained, they should not be seen as removing the need for preservation of knowledge about the repository in the longer term.

A more detailed perspective on the Safeguards/Waste Management interface is given in Chapter 4 of this report.

2.6.2. Surveillance

As mentioned earlier, any potential post-closure activity should be developed in such a way that it does not affect the integrity of the waste repository safety barriers. Drilling to obtain deep samples or to install instruments within geological formations are obvious examples of unacceptable activities.

Although detailed plans for implementing a non-intrusive surveillance policy have still to be developed, various proposals have been made:

- since excavation of a sealed repository could not be carried out in a short time, nor made invisible, one approach would be through the analysis of periodically obtained satellite images.

- the use of remote seismic techniques for detecting drilling activities in the neighbourhood of the repository has also been proposed. However, there is discussion about the viability of this approach because of the difficulties in separating real signals from background.

- the above-ground site of the former repository could be subject to periodic inspection by international inspectors.

Since the first geological repositories for spent fuel are not expected to be closed until the second half of the next century, there is ample time to develop and elaborate safeguards surveillance strategies.

2.7. CONCLUSIONS

1. The safety of a geological repository should not rely on institutional activities in the post-closure period. There may be, however, valid reasons for wishing to implement such activities.

2. Keeping records is a sensible post-closure activity since it can help maintain an awareness of the existence of the repository and of its associated hazard potential.

3. A repository is designed to provide safety without the need for monitoring in the post-closure phase. If, however, monitoring is required for public reassurance purposes, it may be provided as long as it does not compromise the integrity of the multi-barrier safety system, recognising, however, that such monitoring is unlikely to be capable of detecting changes that could affect repository safety.

4. A geological repository is designed to provide long term safety without the need for retrieval of the wastes. However, provisions to ease any future retrieval are not precluded, provided that they do not impair the safety of the repository.

5. International safeguards treaty obligations may compel countries to introduce long term institutional measures to prevent the misuse of spent fuel in geological repositories. Any such measures should not affect the integrity of the repository and its safety barriers.

6. It is important that possible post-closure actions are considered in advance of closure and are part of an overall plan to implement disposal.

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Chapter 3

OPTIMIZATION OF RADIATION PROTECTION — A REVIEW OF ITS APPLICATION TO RADIOACTIVE WASTE DISPOSAL

3.1. INTRODUCTION

A fundamental requirement of the ICRP system of radiological protection for proposed and continuing practices is that once a practice has been justified, the radiation protection should be optimized [3.1]. This means that consideration has to be given on how best to use resources in reducing the radiation risks to individuals and the population. "The broad aim should be to ensure that the magnitude of the individual doses, the number of people exposed and the likelihood of incurring exposures where these are not certain to be received, are all kept as low as reasonably achievable, economic and social factors being taken into account" [3.1]. The terms "Optimization of Protection" and "ALARA" are considered to be synonymous. This requirement for optimization of protection may be implemented by formal or informal analyses of the available alternatives to achieve an optimal balancing of the radiological impacts, economic costs and other factors.

Application of the optimization concept can aid decision making in matters related to radiological protection. However, it is recognized that other non-radiological factors may have to be taken into account in taking decisions and making choices and that these too have to be included in the decision making process. Techniques such as cost–benefit analysis and multi-attribute analysis find use in formal optimization analyses. They help in structuring judgements and in achieving consistency, clarity and well-defined reasoning which is necessary in applying the optimization principle. It is also recognized that in many day to day operational radiological protection situations, optimization is simply a more formalized version of "common sense" decision making.

Since radioactive waste management has, as one of its fundamental objectives, the protection of humans from the effects of ionising radiations, it is clear that the optimization concept should also be applied to waste management practices. Radiation protection principles can be applied at operating waste management facilities in the same way as at any other type of facility at which radioactive materials are being used or where machines are producing ionizing radiations. The concern is with protecting the worker from radiation in the optimum way and within dose limits and with optimising environmental release levels so that members of the public are adequately protected. Optimization has a clear and well-established role to play in the siting, design and operation of all types of pre-disposal waste management facilities. It is in the disposal phase of radioactive waste management that difficulties arise in relation to the application of the optimization concept.

It is the objective of this chapter to discuss the application of optimization of radiation protection to the disposal of radioactive wastes. The discussion is focussed mainly on the disposal of solid wastes underground; it does not relate directly to the disposal of the larger volumes of wastes arising from the mining and milling of uranium.

3.2. APPLICATION OF OPTIMIZATION TO RADIOACTIVE WASTE MANAGEMENT

3.2.1. Scope of application

In ICRP Publication No. 46 [3.2] a task group of ICRP discussed the application of optimization to radioactive waste management. The group considered that optimization of protection was a requirement that should apply at all levels in developing systems and procedures for radioactive waste management and suggested that it could be in principle applied at four basic levels:

(1) Comparison of design alternatives for a specific facility such as a waste repository or an effluent treatment plant;

(2) Comparison of different options for particular waste streams (e.g. shallow land burial or geological disposal for low level wastes; discharge of ^{14}C as an effluent or trapping it for disposal in solid form);

(3) Comparison of different overall management systems for particular waste streams;

(4) Comparison of complete waste management sytems for a given source or practice.

It was recognized that radiation protection considerations would be only one input into the complex process involved in deciding the whole waste management strategy for a practice or group of practices and that the decision-making process may lead to the selection of a strategy different from that indicated by optimization of protection.

The feasibility and usefulness of the optimization principle as an input to decision making has been demonstrated in different areas of radioactive waste management [3.3–3.5]. However, there are some technical and philosophical problems which arise associated mainly with the long time-scales involved in radioactive waste disposal and with the nature of the radiation exposures which can occur in this context. These are discussed in the following paragraphs.

3.2.2. Time-scales

The ICRP task group noted that when comparing waste management options involving radiological health detriments which extend into the far future, it is only those components of the radiological impact that clearly differ that are relevant. For collective dose commitments this means that the time integration should be truncated, to give incomplete integrals, at the point where subsequent contributions are common to all alternatives and it is no longer possible to distinguish between options. For many disposal options for the same wastes, the long term tails of the likely collective dose rates are indistinguishable; they cancel out and do not influence the choice between options. Another reason for truncation may be that the long term uncertainties associated with the long term components of the collective dose rate may prevent this measure of radiological impact being used as a discriminator between options.

3.2.3. Ethical considerations

The ICRP task group recognized that there had been debate over whether, in principle, to assign to detriments in the distant future the same weight as detriments which are received either at present or in the immediately foreseeable future. The problem is twofold: on the one hand, because of social time preferences, there may be a desire to assign less weight to far future detriments; on the other hand, should future detriments actually occur, they will be incurred by people who had no influence on the decision leading to their exposures and who may be unable to control them, raising concerns on whether it would not be ethically desirable to assign higher weight to such detriment. Although discounting, to obtain the present value of a future option, is a common accounting practice, conventional economic considerations are insufficient when applied to situations well into the future, especially in radiation protection. There is a need to involve social and ethical considerations, since a clear distinction between the detriment and the cost of the detriment is often difficult to sustain. Therefore, economic, social, and ethical considerations should be included in unison when determining any weighting factors to be used, preferably as part of a sensitivity analysis.

The task group recognized that the degree to which estimates of significant differences in future radiation detriments associated with various options should influence present decisions on radiation protection is an issue of an ethical and political nature to which there is no simple answer.

More recently, the NEA Radioactive Waste Management Committee has reviewed the environmental and ethical basis of geological disposal and, inter alia, has concluded that there seems to be no ethical basis for discounting future health and environmental damage risks [3.6].

3.2.4. Probabilistic events

The ICRP task group recognized that, in situations where some events leading to exposures can be attributed to probabilities of occurrence and calculable radiation impacts, their probabilities and consequences should be taken into account in the decision-making process. If a low probability event has an associated large consequence, then the outcome would be either zero or large, whereas the expectation value is small. This must be borne in mind and will clearly detract from the extent to which the expectation value can contribute in a useful way to the decision-aiding process.

In addition, very low probabilities, whether or not associated with events having large consequences, are liable to have a large intrinsic uncertainty. This is another reason for placing little reliance on the expectation value of the consequences.

The ICRP task group suggested possible ways for dealing with the problem but acknowledged that a precise mechanism had not yet been developed such that it could be formalized.

3.3. OPTIMIZATION IN THE DISPOSAL PHASE

While the potential usefulness of optimization as a decision aiding technique in the pre-disposal phase and for structuring decision making in relation to overall waste management systems has been demonstrated, its limitations for application in relation to radioactive waste disposal have also been noted [3.7–3.10]. In the following paragraphs some of the specific problems are discussed as well as situations where optimization may be usefully employed.

3.3.1. Radiological impact evaluation

In any formal optimization procedure both the individual and collective doses must be evaluated as well as the probability of the occurrence of events where potential exposures are concerned. For well designed geological repositories, performance assessment studies indicate that radiation exposures due to normal release scenarios will only occur in the far future, if at all. The uncertainty associated with these dose predictions is large due, amongst other things, to the lack of knowledge of the nature of the biosphere and of critical exposure groups at such times and due to uncertainties related to the transport of radionuclides in the near field and in the geosphere. For collective dose evaluation, the uncertainty in predicting individual doses is compounded by the difficulty in postulating appropriate exposed population groups in the far future. The likelihood of occurrence of events leading to potential exposures is also difficult to predict.

The uncertainties in all of these components make formal optimizations difficult. In some cases, the uncertainties may be large enough to mask the difference which exist between the options being compared. Recognising both the difficulties in, and the limited potential for, optimising the radiation protection, it has been proposed that if the predicted risk to a typical member of the critical group attributable to a waste repository is extremely small, then the optimization requirement should be relaxed for that facility [3.9].

3.3.2. Disposal option

Optimization of radiation protection has a role to play in the selection of a disposal option, that is, in selecting between the available environmental media into which disposal could be made. As an example, a comparative study of land-based and marine disposal options for intermediate level wastes in the UK showed that on radiological and other grounds the marine disposal option was to be preferred [3.11]. In this case, however, for reasons of public pressure, both national and international, the marine option was not adopted.

In the case of the land based options currently being considered for high level wastes, the predicted radiological impacts of deep disposal in different media are likely to be very small [3.12] allowing little discrimination to be made between different options on radiological grounds. In fact, the available disposal options in individual countries are likely to be restricted because of geographic and/or political reasons. Thus, in most cases the choice of disposal option will not be significantly influenced by optimization considerations.

3.3.3. Repository design

Optimization studies may be useful in relation to the detailed design of a disposal facility. Techniques such as cost–benefit analysis may be used to compare options which are, to a large extent similar. In such situations, even though the absolute values of collective dose are not likely to be reliable, comparisons between collective doses for different options are likely to be useful.

In practice, political and social pressures are likely to have a strong influence on repository design. There has been a tendency in the countries most advanced in planning for geological disposal to ensure safety by designing for redundancy in barriers. In such cases there may be little scope for optimising radiation protection with barriers being chosen with more regard to their effectiveness than to their cost.

3.3.4. Siting analysis

One of the key areas where optimization may find application in relation to other nuclear facilities is in selecting between various siting options. In such analyses information is needed on the characteristics of the sites so as to allow a proper comparison to be made. In the case of potential sites for geological disposal, the necessary information only becomes fully available after a comprehensive site evaluation, including deep drilling and shaft sinking.

For political, economical and resource reasons, such comprehensive site evaluations can only be performed for a very limited number of sites.

In the case of near-surface disposal, facilities are nowadays being designed so that there will be no releases to the environment during the hazardous lifetime of the wastes irrespective of the location of the site. This allows no discrimination to be made between sites on radiological grounds. Overall, the scope for optimization is limited in the context of siting.

3.3.5. Optimization at a specific site

Once a site and repository concept has been selected, optimization of radiological protection is likely to have a role to play in refining the repository design and in planning for its operation. Possible examples are in selecting the repository depth, in designing detailed repository features and in planning operational methods. During the operating phase of the repository optimization will have an important role to play in ensuring that the radiation exposure of the work force is as low as reasonably achievable.

3.4. CONCLUSIONS

Although the principle of optimising radiation protection is valid and appropriate in the context of radioactive waste disposal, a detailed quantitative optimization procedure does not usually play a major role in the decision-making process. However, a judgmental and qualitative optimization is certainly included in the development of detailed repository design options, in planning for their operation and during the operational phase, in particular, to ensure that all reasonable or practical opportunities to reduce doses are explored. In summary, the optimization of protection principle is valid, but its application has to be adapted to what is achievable in practice.

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Chapter 4

INTERFACE ISSUES BETWEEN NUCLEAR SAFEGUARDS AND RADIOACTIVE WASTE MANAGEMENT

4.1. INTRODUCTION

4.1.1. Background

The general requirement that certain nuclear materials should be safeguarded to prevent their diversion for the purpose of creating nuclear weapons is well known. Nuclear fuel clearly has to be safeguarded throughout its production, use, storage as spent fuel and during reprocessing. Alpha bearing wastes from the nuclear fuel cycle require safeguarding, if they contain significant amounts of material usable in weapons production. Other waste streams containing significant amounts of nuclear materials may also require safeguarding.

In the view of an Advisory Group organized by the IAEA Safeguards Department in 1988, it is necessary to continue safeguarding spent nuclear fuel, even after it has been sealed in a deep geological repository [4.1]. Similarly, for certain types of waste the stage at which safeguards requirements could be terminated has not been defined.

The recommendations of the 1988 Advisory Group meeting have subsequently been acted upon by the IAEA Safeguards Secretariat and proposals have been developed for safeguards approaches applicable to spent fuel before and after disposal and for termination criteria applicable to wastes. These proposals and criteria have been developed by the IAEA Secretariat working with various international expert groups and have been issued in the Department of Safeguards STR series.

Programmes for managing radioactive wastes are primarily based on safety considerations and it is therefore necessary to examine the various constraints and requirements imposed by safety considerations on the one hand and safeguards concerns on the other, to see whether they are compatible.

According to the IAEA Safety Fundamentals report on "The Principles of Radioactive Waste Management" [4.2]

> "The objective of radioactive waste management is to deal with radioactive waste in a manner that protects human health and the environment now and in the future without imposing undue burdens on future generations".
>
> It also states that
>
> "Conflicting requirements that could compromise operational and long term safety should be avoided".

There is, in fact, some concern on the part of the radioactive waste management community that the requirements for safeguarding nuclear material could compromise safety. This chapter draws attention to some of the issues in the developing safeguards plans and procedures which could have an influence on the safety of waste management and, in particular, of disposed spent fuel. The possible safety implications of applying safeguards at the waste/spent fuel conditioning stage and during the operational and post-closure phases of a repository are examined and the meaning of the term "practicably irrecoverable" in the context of spent fuel and radioactive waste sealed in a deep geological repository is discussed.

4.1.2. Philosophical aspects

Because of their long lived radioactive components, high level wastes and spent nuclear fuel have to be managed for periods far into the future. This concern for the long term has led to the development of principles such as the following:

> "Radioactive waste shall be managed in a way that predicted impacts on the health of future generations will not be greater than relevant levels of impact that are acceptable today" [4.2].

This principle is derived from an ethical concern for the health of future generations. In order to achieve this, the wastes should be isolated from the human environment over extended time-scales, and while it is not possible to ensure total containment indefinitely the intent is that there will be no significant impacts when radionuclides enter the environment. In deep geological repositories isolation will be achieved by a system of barriers surrounding the waste, some engineered (the waste cannister, the backfill material) and some natural (the geosphere, the biosphere).

An additional objective of waste management is that:

> "Radioactive waste shall be managed in such a way that will not impose undue burdens on future generations" [4.2].

The ethical principle for this is the premise that the generation that produces waste should bear the responsibility for managing it. The responsibility of the present generation includes developing the technology, operating the facilities and providing funds for the management of radioactive waste. This includes the means for disposal. Long term management of radioactive waste should, as appropriate, rely on containment without reliance on long term institutional arrangements as a necessary safety feature. This does not exclude the possible use of institutional control arrangements, such as, monitoring and record keeping, but, because of the time-scales involved, the primary reliance for safety should not be on such measures.

In contrast to the long term provisions of the radioactive waste management system, nuclear safeguards have been primarily developed to provide assurance for the present and for the short term future. The safeguards system, as presently organized, relies on the active participation of humans. Its extension into the future would place an obligation on future generations to provide surveillance and accounting thereby introducing some conflict with the waste management principle that the burden on future generations be limited. Furthermore, some possible methods of demonstrating that material has not been diverted could, in the case of waste repositories, pose a threat to the isolation system of the repository and thus, to the health of future generations.

However, safeguards requirements do not always conflict with those of waste management, in some cases the requirements are mutually beneficial, for example, the proposed long term surveillance of closed repositories, would place a burden on future generations but, on the other hand, would benefit safety assurance. These issues are explored in more detail in the following sections.

4.2. SAFEGUARDS AND WASTE

4.2.1. Introduction

In order to determine whether there are any conflicts between requirements demanded by safety and safeguards in waste management, or possibly, whether there are requirements of mutual benefit for both these aspects, it is necessary to first give an outline of the existing practice.

Radioactive wastes containing nuclear material are generated in all parts of the nuclear fuel cycle. Six waste categories have been identified [4.1, 4.3]:

(1) waste from ore processing
(2) refining, conversion and enrichment waste
(3) waste from fuel element fabrication
(4) reactor operational waste
(5) reprocessing waste
(6) spent fuel.

Of these categories (1), (4) and portions of (2) are not subjected to safeguards. Category (6) is considered in the other sections of this chapter. A short description of wastes under safeguards follows in Section 4.2.2. The safeguards concerns at those facilities where the waste is generated, stored or processed are briefly reviewed in Section 4.2.3.

Since the termination of safeguards for waste also means that thereafter no conflict can exist with the safety requirements, it is important to consider the criteria for termination. An outline of the principles proposed for termination is given in Section 4.2.4.

4.2.2. Wastes subjected to safeguards

There are numerous waste streams subjected to safeguards and here it is sufficient to a list of only the most important ones:

- Residues from fabrication of natural or low enriched uranium fuel.

- Residues from plutonium conversion and MOX fuel fabrication.

- Reprocessing residues:

    . Hulls
    . Feed fabrication sludges and filters
    . High level (aqueous) waste
    . Other residues, with and without significant concentrations of plutonium.

- Decommissioning waste from facilities handling nuclear material, particularly waste from dismantling of process equipment.

The characteristics of the above wastes vary considerably in both chemical and physical form, activity level and content of nuclear material. These characteristics are important not only for choice of safe conditioning and disposal methods, but also in determining whether nuclear material in the waste might be potentially recoverable.

Plutonium is regarded as the nuclear material of greatest concern in the context of safeguards. Highly enriched uranium is theoretically of similar concern, but there are only small amounts of this material in the current nuclear fuel cycles. Natural and low enriched uranium cannot be used directly as nuclear explosives and are of lesser safeguards concern.

Waste can be conditioned in various ways depending on its characteristics. Solid wastes, e.g. scrap materials, paper and plastics can be packaged in containers with or without grouting with a suitable matrix, e.g. concrete. Hulls are also embedded in a concrete matrix. Liquid and wet wastes are commonly solidified into a matrix of concrete or bitumen. The high level aqueous waste from reprocessing is first calcined and then vitrified with borosilicate glass.

Current practices for treatment and conditioning of wastes are described more in detail in several IAEA publications (e.g. Refs [4.4–4.7]). Conditioning of spent fuel is described separately in Section 4.4.3.

4.2.3. Safeguards concerns with regard to waste management

There are two basic concerns related to waste nuclear materials:

- the waste itself might be diverted and processed to recover the nuclear material,
- the nuclear material might be deliberately overstated, which could provide a means to divert material from other sources in a facility.

A third concern is the resubmission of previously terminated materials for concealment of a diversion of other nuclear material.

However, it is the possibility of recovery of material through processing of waste on which safeguards have previously been terminated that is the more commonly recognized concern [4.8]. Thus, the practicability of recovering material must be considered in criteria for termination of safeguards.

4.2.4. Termination of safeguards

Provision for termination of safeguards is provided in INFCIRC/153, Section 11 [4.9], and INFCIRC/66/Rev.2, Section 26c [4.10]. However, application requires technical criteria based on the nature of the material, the conditions under which termination of safeguards would be appropriate and the facility of implementation.

The Advisory Group meeting convened by the IAEA Safeguards Secretariat in 1988 recommended [4.1]:

- that "the IAEA not terminate safeguards on spent fuel";
- that "most waste generated under normal operating conditions might be described as practicably irrecoverable and, accordingly, might qualify for classification as measured discards and termination of safeguards".

It was also recommended that the IAEA should undertake to define specific criteria. In May 1988 the Secretariat issued a Working Paper for development of these criteria [4.11] followed by a consultants meeting in 1990 [4.8]. A proposal for technical criteria was published in November 1990 [4.12].

In short, the basic criteria referred to above allow termination of safeguards if the IAEA can determine that the nuclear material in question has been either

- consumed;
- diluted in a way that it is no longer usable for weapons production; or
- become practicably irrecoverable.

Unfortunately, no rigorous definition of the expression "practicably irrecoverable" (PI) has been provided in the IAEA documents and this has led to some confusion about its meaning.

Termination of safeguards has been thoroughly discussed for the waste streams of the nuclear fuel cycle [4.8, 4.11]. The consumption criteria causes little problem, but the difficulties are highlighted by the fact that it is only the PI criterion that counts and that the dilution criteria is included in the latter.

It has been proposed [4.11, 4.12] that the following aspects must be considered in order to make a decision on whether safeguards should be terminated:

- the quantity, or flow, of material is below a given level (e.g. in the range of 0.01–0.1 Ekg/month[1]);

- the type of material (e.g. Pu, HEU or LEU);

- nuclear material concentration, including concentration in total dissolved solids, for liquid waste;

- chemical and physical form, (that may render recovery more or less costly and difficult);

- facility design features;

- methods of disposal.

The proposed criteria are complex, but in the present context it may be sufficient to note that termination of safeguards for waste may be applicable,

- without verification by the IAEA if the waste contains nuclear material below a prescribed limit (e.g. 0.01 Ekg) per month and facility;

- with verification by the IAEA if the waste has certain defined characteristics;

- for certain specified types of wastes only after a certain degree of conditioning.

In the present case "verification" means that the nuclear material content must be measured by appropriate methods and instrumentation. Measurement or other means for

[1]Ekg means an "effective kilogram" — a special unit used in safeguarding nuclear material [4.9].

determination of the radionuclide content in the waste is a fundamental safety requirement of importance for both the short term and the long term. However, for certain waste types it may, from the viewpoint of safety, be sufficient to ensure an upper limit for the inventory of long lived alpha emitters such as plutonium. In particular, this applies to wastes with a low content of those radionuclides. Therefore, it seems that the safeguards requirements are in conformity with the safety requirements in this respect. In fact, no other negative effects on safety from safeguards have been identified.

It is required that certain waste types be conditioned before termination of safeguards in order to render the nuclear material irrecoverable and preclude illicit resubmission of the waste.

The general idea is to terminate safeguards of waste as early as possible in the handling sequence, the main reason being to facilitate verification by measurements. On the other hand, the difficulties of recovering nuclear material increase for each step along this sequence. Also, for some waste types conditioning means that the waste is homogenized, which, in fact, might increase the accuracy of measurements.

According to the IAEA Safeguards documents [4.8, 4.11, 4.12] for some types of waste, termination of safeguards may not be possible even after conditioning.

4.3. SAFEGUARDS DURING THE CONDITIONING OF SPENT FUEL

4.3.1. Conditioning facility

The objective of conditioning[2] of spent fuel is to put it into a form that meets the acceptance requirements for disposal. A model design of a conditioning facility for discussion of safeguards issues has been presented [4.13]. The facility can be sited at a NPP, at an interim storage facility or at the repository.

4.3.2. Operation of a conditioning facility

The operations carried out in a conditioning facility obviously depend on a range of factors, e.g. the disposal method, the transport system and the location of the facility. Most generally, assuming that the facility is located separately from the other parts of the management system, it may accommodate the following activities:

- receipt and storage of incoming transport casks with spent fuel,
- unloading,
- pretreatment (e.g. disassembly, consolidation of the fuel),
- final conditioning (e.g. emplacement, embedding, immobilization in a disposal container),
- interim storage and preparation for transfer of canisters to the disposal facility.

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[2]At the Advisory Group meeting (AGM) in 1988 [4.1] it was observed that the use of the term "conditioning" in this context is not necessarily synonymous to its use for conditioning of *waste* for disposal. According to the AGM, waste conditioning effectively renders any residual nuclear material content irrecoverable. Conditioning of spent fuel does not make it particularly difficult to access or recover The present document uses the term conditioning also for spent fuel according to established practice in the waste management community

Pre-conditioning and final conditioning are the only steps in the above scheme that significantly deviate from the more "conventional" handling sequences normally applied at NPPs and interim storage facilities. Accordingly, the usual steps are not assumed to raise any new safeguards issues, neither will they be of any relevance from the safety point of view. Thus, the following description concentrates on the conditioning process itself.

The following three routes for the conditioning processes can be identified [4.14]:

(a) The items (e.g. fuel assemblies) are transferred to the disposal container without change in integrity. Items are rebatched into containers.

(b) The items are consolidated before being placed in containers. Consolidation would require rebatching of assemblies into new items, e.g. canisters of fuel rods. Consolidation could include, in some cases, chopping of fuel rods. An additional possibility would be rebatching of consolidation canisters into disposal containers.

(c) The items are mixed and consolidated, losing the continuity of knowledge of the original items. The material in one assembly could be distributed into several items.

The last of these options is the least favourable from the safeguards point of view. No Member State is known to be planning to implement route (c).

4.3.3. Safeguards for conditioning of spent fuel

The effective application of safeguards to spent fuel conditioning and disposal should be based on an unbroken continuity of knowledge of the nuclear material content of the spent fuel within the framework of an Integrated Safeguards Verification System (ISVS) [4.14]. Any rebatching will still make it possible to account for the material on an item basis. The conditioning process will then have to be designed so as to minimize broken rods, loose pellets and the spread of particulate matter. This aspect is in conformity with safety requirements both for the operational phase in the conditioning facility and the long term phases in the repository.

The continuity of knowledge will depend on a containment/surveillance (C/S) system and verification of the integrity of items being counted. Other important components of the safeguards system are:

- verification of design,
- monitoring of all movements into or out of the process area.

The identification and evaluation of incoming and outgoing items is crucial to the safeguards approach. The preferred approach is the establishment of safeguards measures external to the process cell, confirming the flow in and out of the process area.

If continuity of knowledge is not maintained non-destructive assay (NDA) measurements may be required. This might be of particular importance for odd items, e.g. damaged fuel assemblies, damaged fuel rods and fuel residues from examinations of fuel. This verification might also be regarded as a way to determine the transuranium (TRU) content in other waste streams. Unfortunately, current NDA procedures are not very accurate. In any case, they are not accurate enough to establish a measured material balance around the conditioning area.

When the spent fuel is to be transferred to the disposal facility its nuclear material content should be verified at the same level as is required by the IAEA for difficult-to-access areas or for long term storage facilities. This verification should be carried out as late as possible before emplacement of the material within the final disposal container.

Safeguards techniques currently available could be applied at a spent fuel conditioning facility. Further research and development is needed, however, particularly to reduce their impact on the conditioning process, ease their authentication and permit unattended operation of the equipment. Specific areas of interest include:

(1) methods for identification and integrity assurance of final disposal containers (e.g. fingerprinting with microstructure analysis and NDA);

(2) authentication techniques for safeguards instrumentation;

(3) design and evaluation of an integrated safeguards verification system;

(4) NDA fissile assay measurement techniques for fuel rods and spent fuel assemblies.

(5) methods to facilitate non-destructive verification of the disposal container integrity, e.g. weld seam interrogation and bar code identification.

The last point above may be important from the long term safety aspect. For at least some canister designs it may be important to employ a marking method that minimizes the impact on the outer metal surface.

4.3.4. Safety implications of safeguards at a conditioning facility

From the above discussion it is clear that the safeguards approaches envisaged for a conditioning facility for spent fuel will impose small, if any, problems from the safety point of view. No destructive verification methods are foreseen. On the contrary, an effective safeguards system would require care in handling of the fuel itself and of the produced disposal packages. However, for certain containers, special attention may be needed to ensure that their marking does not cause any negative effect on their long term corrosion resistance.

It is important to note that the anticipated safeguards system will put requirements on the design and layout of the conditioning facility. This issue should urgently be considered in a joint effort by competent national authorities, the implementors, and the IAEA.

4.4. SAFEGUARDS IN THE OPERATIONAL PHASE OF A REPOSITORY

A geological repository for disposal of long lived radioactive waste and/or spent fuel consists of a large number of emplacement rooms excavated deep within a suitable rock formation, emplacement boreholes, access tunnels to the rooms, shafts or ramps for access from the surface, various supporting surface and underground facilities. An alternative repository concept consists of a matrix of deep disposal boreholes drilled either from the surface or from an underground mine.

The basic requirement of such a permanent repository is to dispose of radioactive waste (e.g. spent fuel, HLW and/or TRU wastes) in a way which isolates it from the biosphere.

According to INFCIRC/153 (corrected) paragraphs 42–48 [4.9] it should be stipulated that "Design Information (DI)" shall be provided to the Agency as early as possible before nuclear material is introduced into the facility to enable the Agency to do "Design Information Verification (DIV)".

A unique feature of a repository in deep geological formations is that, due to mining requirements, construction will continue after the beginning of operations, i.e. during emplacement of containers in underground rooms and boreholes.

At any time, excavation of a room, drilling a borehole, emplacement in another room or borehole, and backfilling will take place simultaneously (although excavation/drilling and emplacement would always be confined to separate rooms and areas). This means that re-examination and verification of design information will be an ongoing process. A methodology and technique for such a continuous DIV will be required to maintain an effective and efficient safeguards regime.

IAEA verification activities should be matched with the schedule for design, construction, tests, start-up and operation as well as during the backfilling period. Safeguards concerns could thus be addressed whenever it is considered essential.

Most conditioned waste generated under normal operating conditions might be described as containing nuclear materials that are diluted and practicably irrecoverable and, therefore, might qualify for classification as "measured discard" and termination of safeguards.

Wastes which meet the termination criteria and which have been verified by the IAEA should be considered to have no further safeguards relevance. The termination should take place at the exit of the process area of the conditioning plant when the final disposal container will be closed.

For wastes that do not meet the termination criteria, safeguards will continue. After the closure of the container, the nuclear material in the container will not be readily accessible for the normal range of verification measures. Therefore methods of item identification and integrity assurance, items accountancy (and item transfer) have to be developed.

Disposal containers received at the repository surface facilities will be safeguarded by the ISVS and checked by the IAEA until they are transported underground, so that continuity of knowledge of the items and their contained nuclear material is maintained. The accesses to the repository will be the locations of the final counting of the safeguarded disposal containers, that is, the items containing the nuclear material.

Within the geological repository, it would not appear to be important, from the safeguards viewpoint, to know the location of emplaced containers. It is only necessary to verify that the waste package containing waste under safeguards has entered and remains within the confines of the repository. Within the geological repository the "item", or disposal container being safeguarded becomes part of the nuclear material inventory in the geological repository. After the disposal, containers will be placed in their boreholes or emplacement rooms, and all remaining openings in the particular underground area will be backfilled and sealed. This means, especially in an operating repository in a salt mine, that the disposal containers, could be considered to be virtually inaccessible for physical verification.

4.5. SPENT FUEL IN A SEALED REPOSITORY — IS IT "PRACTICABLY IRRECOVERABLE"?

4.5.1. Introduction

The basic criteria for termination of safeguards are given in Refs [4.9] and [4.10] and discussed in Section 4.2.4. The question is whether these criteria can be met for terminating safeguards on spent fuel in a repository.

As mentioned earlier, no rigorous definition of the expression "practicably irrecoverable" (PI) has been provided in IAEA documents; this has led to some confusion about its meaning. It has been noted also that:

> "An opinion does exist that spent fuel which is stored in a geological formation becomes practicably irrecoverable due to lack of access to the material" [4.15].

On the other hand several documents issued by the IAEA Department of Safeguards state that spent fuel can never be considered practicably irrecoverable.

In this chapter some of the issues are discussed that have to be considered in determining whether safeguards on spent fuel in a geological repository, after closure, can be terminated or not.

4.5.2. The actual meaning of "practicably irrecoverable" — the proposed practice

As mentioned previously, the exact meaning of PI is not clear. When applying the IAEA criteria for termination of safeguards for spent fuel in a repository, it is quite clear that its nuclear material content is neither "consumed" nor is it sufficiently "diluted". The question is whether it "might" be determined as being PI.

Requirements related to the aspects listed in Section 4.2.4 must be fulfilled if safeguards are to be terminated. Consideration of these aspects in relation to spent fuel indicates that it would not qualify as being practicably irrecoverable except, possibly, in relation to the last point concerning "methods of disposal".

4.5.3. The practicability of illicit recovery of nuclear material from spent fuel in a repository

Motivations

For an action to be practicable it is not only necessary that it is possible in a strict technical sense, in addition, the necessary resources, both economical and manpower, must be available. Altogether, and considering that the repository is positioned deep underground (at least 200 m) this means that most probably only organizations sponsored by the state containing the repository would be able to undertake such a diversion operation. A further discussion of these issues is presented in the next Section.

Still one more requirement must be fulfilled for an action to be practicable — it must be profitable — at least in the sense that it is the most convenient alternative if more than one way to attain the objective is available. Is recovery of nuclear material from disposed spent fuel practicable in this sense?

Two main routes exist for making nuclear weapons, either by reprocessing of spent nuclear fuel and using the plutonium as a nuclear explosive, or by enrichment of uranium to a concentration of ^{235}U which makes it suitable for that purpose. For a state with the ambition to acquire a lasting nuclear weapons potential of strategic importance the easiest way is to use the uranium option. An obvious condition is, of course, that a sufficiently large amount of natural uranium is available. Among arguments in favour of this choice are the following:

- the processing of the raw material can be done with a minimum degree of radiation protection;

- the fissile material is considerably more stable, which means that it is easier to employ in a nuclear weapons system;

- the detonation equipment does not require high technology in electronics and explosive materials.

Some drawbacks of the uranium route can be mentioned, however, such as:

- it requires enrichment of ^{235}U, an operation that, for the time being, implies access to safeguarded technology;

- the total amount of fissile material needed is greater, by a factor between 3 and 5, than the corresponding mass in plutonium devices.

Among arguments against the plutonium option the following can be mentioned:

- the detonation of a plutonium device is much more difficult and the difficulties increase in proportion to the burnup of the source material, i.e. spent fuel from power reactors is particularly unsuitable in this respect,

- plutonium, and especially plutonium from power reactors, is a physically unstable material, e.g. due to the ingrowth of americium (this inconvenience decreases with storage time).

- plutonium extraction requires reprocessing of the spent fuel; an operation burdened by considerable radiation protection problems.

The above considerations do not mean that incentives for recovery of plutonium from disposed spent fuel may not exist. In a desperate situation, probably under authoritarian rule, when the usual radiation protection measures are set aside, the plutonium option might be faster than the uranium route. Without high technological skill and considerable experience of building plutonium weapons, such an action would probably not lead to a real military threat.

Recovery of spent fuel from a repository

The difficulty of recovering the spent fuel from a closed repository depends on several factors:

- type of host rock;
- depth of the emplacement horizon;
- repository design and layout;

- kind of backfilling material;
- type of disposal container;
- the temperature level;
- any special measures taken in order to facilitate retrievability, or conversely, to hinder human intrusion.

A repository designed to allow for retrieval of the spent fuel even after closure can evidently never be regarded as fulfilling the requirements of PI.

A clandestine operation for recovery of spent fuel for illicit purposes would, in most cases, be as difficult and require as large resources as the initial excavation of a repository. The time to reach the emplacement chambers would depend on the methods employed for sealing the shafts and tunnels and for backfilling the emplacement areas.

Thick walled containers or casks, would make it easier to get access to the emplacement chambers, due to radiation shielding, and in addition, would facilitate further handling.

An additional obstacle to the recovery of spent fuel is the heat generation. Temperatures in the vicinity of the disposed canisters may well be in the order of 100°C or more. This means that greater ventilation of the underground workings would be necessary than during the operational phase.

Some disposal methods might seem to render illicit recovery particularly difficult, e.g. concepts where the disposal containers are emplaced in deep boreholes, between several hundred and a few thousand meters down into the host rock. Recovery of canisters, by redrilling and remote handling, or by overcoring would be almost impossible with current drilling technology. However, considering the possibility of future technical advances, particularly in the area of precise positioning of deep boreholes it is very uncertain whether deep borehole facilities would be more or less attractive for diversion than repositories with shafts and tunnels.

4.5.4. The practicability of recovering spent fuel from a closed repository — Conclusions

According to present safeguards practice, termination of safeguards for a waste stream is only possible if certain criteria are met that makes the nuclear material in the waste practicably irrecoverable. Spent fuel does not fulfill these criteria except, possibly, for the criterion relating to the disposal method.

There would seem to be little motivation for chosing to divert spent fuel from a closed repository except possibly for the case of desperate action by a state without access to any other source of nuclear material. A repository for spent power reactor fuel does not contain any nuclear material that can be used directly for manufacturing of nuclear explosive devices. The plutonium obtained after reprocessing is unsuitable for nuclear weapons without further treatment. Nevertheless, it might be used for such purposes, but this is unlikely for a state striving to build up a nuclear weapons arsenal as the alternative of using enriched uranium is more attractive. In an extreme case, however, it cannot be excluded that a state would attempt to recover nuclear material.

Diversion of spent fuel from a closed repository would require large resources, and it would take a long time (years?). The level of difficulty would depend on the host rock and the disposal method.

In conclusion, most arguments point to the fact that spent fuel in a closed repository would be "practicably irrecoverable" — it would not be an attractive target for diversion and it would be difficult to recover without large efforts. Still, for extreme scenarios, diversion by this route cannot be excluded.

4.6. POST-CLOSURE PHASE OF A REPOSITORY

Deep geological repositories are designed to provide long term isolation of radioactive waste. Waste isolation is ensured by a combination of engineered and natural barriers. Long lived radioactive wastes, including spent fuel, require almost complete isolation for time periods of many thousands of years. Since it is not conceivable that human society will be able or willing to maintain controls on repository sites for many thousands of years, isolation systems are designed to be passive in nature. In other words the safety of the systems depends on the intrinsic properties of the isolation barriers and not on the existence of surveillance and maintenance procedures.

On the other hand it is admitted generally that public opinion will demand that some form of monitoring be maintained at repository sites for an undefined period of time. The purpose of such monitoring programmes could be to provide reassurance that the system behaves as assumed in the safety assessment and that no unforseen events are taking place. It goes without saying that any such monitoring programme must be non-intrusive, that is, it cannot require activities potentially capable of decreasing the performance of the isolation barrier. Drilling to obtain deep samples or to install instruments within the barrier formations are obvious examples of unacceptable activities.

Since monitoring activities are not required for technical reasons, but can be justified only on psychological grounds it is clearly impossible to make predictions on their duration. We can assume that, at some future time, as a result of a cost–benefit analysis, the monitoring programme will be intentionally discontinued or some major disruption of society will eliminate its justification. In the context of shallow land disposal of short lived radioactive waste, option for which safe isolation depends on maintaining institutional control of the site, it is generally agreed that it would not be reasonable to expect institutional controls to last more than a few hundred years.

Concerning the issue of safeguarding any nuclear material present in a deep geological repository that has been backfilled and sealed, some considerations are in order. A distinction is necessary between repositories, that contain different kinds of radioactive waste, but no spent fuel, and repositories containing spent fuel.

In the first case, most of the wastes are likely to have met the criteria for termination of safeguards; those wastes that do not meet the criteria contain fissile materials in concentrations and/or in forms that have made their recovery non-justifiable during the waste producing operations. The enormous difficulty and cost of recovering the waste from a sealed repository should be enough to allow the conclusion that a recovery operation that was not justifiable when the waste was generated has become truly inconceivable. This conclusion is strengthened further by the fact that conditioning operations, prior to disposal, are likely to have made any occurring nuclear materials even harder to extract. This is particularly true for vitrified high level waste, since the glass matrix would be so difficult to dissolve. Therefore it is considered that, as soon as a deep geological repository has been closed, provided it does not contain spent fuel, safeguards should be terminated.

These considerations do not apply to repositories containing spent fuel, since the large amounts of nuclear materials present in the fuel make the motivation for excavation and recovery at least credible. Thus if we accept the principle that spent fuel needs to be safeguarded after closure of the repository, two difficult questions emerge immediately:

(1) how to design an effective safeguards procedure that has no negative impact on the safety of the disposal system?

(2) how long should the safeguards last since the spent fuel will remain a potential source of nuclear material for thousands of years (e.g., the half-life of ^{239}Pu is about 24 000 years)?

Tentative answers are:

(1) The repository should be safeguarded by a non-intrusive surveillance mechanism that would allow the repository site to be checked periodically. Since excavation of a sealed repository could not be carried out in a short time, nor made invisible, an obvious approach would be through the analysis of periodically obtained satellite images. Additionally, the above-ground site of the former repository could be subject to periodic inspection by international inspectors. Incidentally, such safeguards surveillance mechanism would increase the safety of the repository, since it would protect it from the risks associated with human intrusion scenarios.

(2) The duration of safeguards will be decided by future generations and will depend on unpredictable developments. Scenarios can be imagined where the evolution of society would make safeguards a totally irrelevant issue. On the other hand, alternative futures are conceivable where the safeguarding of nuclear materials would remain a high priority of society for centuries or millennia. Speculations on this particular aspect seem to be pointless.

An additional interesting question is: who will pay for the cost of this open-ended safeguards surveillance mechanism?

4.7. CONCLUSIONS

The main purpose of the present analysis was to assess the implications of safeguards requirements on the management of radioactive waste and spent fuel. In particular, there was concern that a conflict might exist between safeguards requirements and the main objective of waste management, that is, ensuring that the radioactive substances in the waste are safely isolated from the biosphere as long as necessary to reduce the radiological impacts to acceptable levels.

The following conclusions are the result of this first assessment of the interface between safeguards and radioactive waste management.

1. Provided some conditions are met, the application of safeguards to the management of radioactive waste and spent fuel can be affected without negative impacts on safety.

In the first place, it can be observed that the management steps prior to disposal do not appear to present any problem since safeguards procedures are already in effect or could be introduced easily. With respect to disposal, the primary condition is: that safeguards procedures must be designed keeping in mind that the safety of the isolation system is an absolute priority. In other words, neither the integrity of the engineered barriers within the repository can be endangered, due to surveillance and control measures during operation, backfilling, and sealing of the disposal zones, nor can the integrity of the natural barriers be threatened, due to surveillance and monitoring after repository closure.

2. It is assumed that deep geological repositories receiving safeguarded waste material have to be kept under safeguards during the operational phase. From the perspective of waste management, and assuming that the safety system of the planned repository remains intact, safeguarding based on surveillance and control at the surface accesses to the repository (shafts and/or ramps) would cause no difficulties. Similarly, visual inspections underground would be acceptable. However, intrusive geophysical techniques for locating waste packages inside the repository are to be avoided.

3. After repository closure, a distinction should be made between disposal facilities containing only waste and repositories containing only spent fuel or a mixture of waste and spent fuel.

4. At the present time no clear safeguards policy for closed repositories containing only wastes seems to exist. Because of the relatively low concentrations of nuclear materials in the various categories of radioactive wastes and the enormous difficulties of recovering waste from closed, deep disposal facilities, it is considered that there is no need to maintain safeguards requirements for the waste-only-repositories.

5. For spent fuel in repositories, the difficulties in recovering material from a closed repository would also be considerable and it is extremely doubtful as to whether it can be regarded as a realistic diversion scenario. However, if it is accepted that safeguards must be maintained after closure of such repositories, proposed surveillance techniques such as a combination of satellite imagery and inspections would ensure the continuing integrity of the repository and would not impair its safety system.

6. The expected duration of safeguards surveillance at the sites of deep geological repositories containing spent nuclear fuel cannot be defined, but, on the basis of spent fuel compositions, safeguarding requirements could last for thousands of years. The acceptance of a requirement for open-ended surveillance of spent fuel repositories creates two difficult problems:

   - a contradiction with one of the objectives of radioactive waste management, that is not to impose a burden on future generations;

   - the troubling aspect of making economic provisions for an activity of unknown duration and, therefore, with a cost that cannot be estimated reliably.

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