DISPOSAL OF HIGH-LEVEL RADIOACTIVE WASTES

RADIATION PROTECTION

AND

SAFETY CRITERIA

Proceedings of an NEA Workshop
Paris, 5-7 November 1990

NUCLEAR ENERGY AGENCY
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QUANTITATIVE HIGH-LEVEL WASTE DISPOSAL OBJECTIVES/CRITERIA AT INTERNATIONAL LEVEL AND IN OECD COUNTRIES

(November 1990)

SUMMARY TABLE*

Organisation/ Country	Main Objective/Criteria	Other Main Feature(s)	Comments
NEA (1984)	Max. indiv.risk objective 10^{-6}/y (all sources)	Individual risk/dose = best criterion to judge long-term acceptability	No consensus on ALARA/ optimization
ICRP Publication 46 (1985)	1 mSv/y (normal evolution scenarios) 10^{-5}/y (probabilistic scenarios) for individuals (all sources)	Both prob. and doses should be taken into account in ALARA	ALARA useful, notably to compare alternatives, but may not be the most important siting factor
IAEA Safety Series 99 (1989)	idem ICRP Publication 46	-	Also includes qualitative technical criteria on disposal system features and role of safety analysis and QA
CANADA (AECB regul. Document R.104) (1987)	Max. indiv. risk obj. 10^{-6}/y	- Period of time for demonstrating : 10^4y - No sudden and dramatic increase for times > 10^4y	Additional qualitative, non-prescriptive requirement and guidelines in regulatory documents No explicit optimization required
FRANCE	Under development: likely Ref. to ICRP Publication 46	-	Technical criteria for siting established in 1987
GERMANY (Section 45, para 1 of Radiation Protection Ordinance (1989)	Individual dose < 0.3 mSv/y for all reasonable scenarios	Calculation of individual doses limited to ~ 10^4y but isolation potential beyond 10^4y may be assessed	Additional qualitative technical criteria in guidelines and regulatory documents
THE NORDIC COUNTRIES Consultative document (1989)	Individual dose < 0.1 mSv/y (normal scenarios) Individual risk < 10^{-6}/y (disruptive events)	Additional criterion on "total activity inflow" limiting releases to biosphere, based on inflow of natural alpha radionuclides	- Under revision following broad consultation - Includes other qualitative criteria

*This table was established by the NEA Secretariat, based on national presentations made at a Joint RWMC/CRPPH Workshop on Radiation Protection and Safety Criteria for the Disposal of High-Level Waste, Paris, 5th-7th November 1990. It presents national criteria in a very simplified form, and should always be read in conjunction with the descriptions reproduced in the Workshop Proceedings published by NEA. Despite apparent differences, all criteria share the same common basis and aim at a relatively uniform safety level.

Organisation/ Country	Main Objective/Criteria	Other Main Feature(s)	Comments
SPAIN (Statement by Nuclear Safety Council, 1987)	Individual dose <0.1 mSv/y Individual risk $<10^{-6}$/y in any situation	-	Further development under study
SWITZERLAND Regulatory Document R-21 (1980)	Individual dose < 0.1 mSv/y at any time for reasonably probable scenarios	Repository must be designed in such a way that it can at any time be sealed within a few years without the need for institutional control	Revision of Regulatory Document R-21 envisaged
UNITED KINGDOM	No specific criteria for HLW - but likely application of principles similar to existing objectives for L/ILW: $< 10^{-6}$y target for individual risk from a single facility	No time-frame for quantitative assessment specified	ALARA to be used to the extent practical and reasonable
UNITED STATES EPA 40 CFR Part 191 (1985)	Limits on projected radionuclides releases to the accessible environment for 10^{4}y, based on objective to limit serious health effects to less than 10 in the first 10^{4}y after disposal for each 1000 t of spent fuel or HLW disposed	- Individual dose (over 1000 y)<0.25 mSv/y - Other requirements on drinking water contamination	1985 EPA standards were remanded and are in the process of being revised
NRC 10 CFR Part 60	Minimum levels of performance: - waste package ("substantially complete" containment for 300-1000 y) - Engineered barrier system (releases $< 10^{-5}y^{-1}$ of the inventory at 1000 y after repository closure) - pre-waste-emplacement groundwater travel time between "disturbed zone" and "accessible" environment > 1000 y	-	NRC subsystem requirements are intended to help achieve compliance with the EPA Standard and alternative criteria may be approved if appropriate

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F O R E W O R D

The long-term management of radioactive waste and their ultimate disposal, deep underground in stable geological media, in conditions such that future populations and the environment are adequately protected against radiation, are the subject of considerable attention and increasing consensus at the international level. Current discussions focus on various scientific and technical aspects of the geological disposal concept, notably on the assessment of the suitability and safety of potential repository sites in the long-term. In this context, the licensing of repository systems proposed for the disposal of high-level radioactive waste from the reprocessing of spent nuclear fuel, spent fuel itself and other long-lived wastes requires the existence of specific radiation protection and other safety criteria, against which the safety and acceptability of such systems can be assessed.

The topic of radiation protection and safety criteria for the disposal of high-level radioactive waste was the subject of an international workshop, sponsored in November 1990 by the two NEA Committees on Radioactive Waste Management and on Radiation Protection and Public Health. All the major countries engaged in nuclear programmes were represented at the workshop. These proceedings include the presentations made at the workshop on the general safety background, national regulatory situations and current criteria, as well as a summary and conclusions of the discussions prepared by the NEA Secretariat. The opinions, conclusions and recommendations provided are those of the authors only, and do not necessarily express the views of any Member country or international organisation.

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B A C K G R O U N D

Licensing of a repository system for the disposal of radioactive waste needs to include reference to a set of criteria against which all the groups concerned and notably the regulatory authorities can judge the safety and acceptability of the proposed system. While the underlying basic principles and objectives of radiation protection have been laid down at international level, detailed radiation protection and safety criteria for high-level waste disposal are, in most cases, still under development. This is due, among other reasons, to the fact that high-level waste disposal is not planned to be implemented until around 2010 at the earliest.

Safety issues related to high-level radioactive waste are of a global and long-term character. Therefore, it is of great importance that these issues be thoroughly discussed at international level. Indeed, many international organisations have been active in this area. In 1985, the NEA published an expert group report on "Long-Term Radiation Protection Objectives for Radioactive Waste Disposal", which introduced the concept of a basic individual risk criterion for radioactive waste disposal practices. In 1985, the International Commission on Radiological Protection (ICRP) released its Publication No. 46 "Radiation Protection Principles for the Disposal of Solid Radioactive Waste", with a similar approach. Since then, several countries have incorporated risk criteria in their regulations. Most recently, the International Atomic Energy Agency (IAEA) has adopted "Safety Principles and Technical Criteria for the Underground Disposal of High-Level Radioactive Wastes" (Safety Series No. 99), and the Radiation Protection and Nuclear Safety Authorities in the Nordic countries have issued a consultative document called "Disposal of High-Level Radioactive Waste - Consideration of Some Basic Criteria".

In response to a proposal from the National Radiation Protection Institute in Sweden on behalf of the Nordic Authorities on Nuclear Safety and Radiation Protection, and considering the extensive work being done or underway related to radiation protection and safety criteria for high-level waste disposal, the NEA Committees on Radioactive Waste Management (RWMC) and Radiation Protection and Public Health (CRPPH) agreed to organise a workshop around these issues.

The scope of the workshop was limited to radiation protection and safety criteria regarding the post-closure phase of deep geological disposal of high-level radioactive waste. The objective was to provide an up-to-date review of the state of development in this area through information exchange and discussion of existing and proposed international and national safety criteria, including the conceptual basis and approaches to their practical application.

SUMMARY AND CONCLUSIONS

FORMAT OF THE WORKSHOP

The format of the workshop was designed to allow a detailed discussion of the major issues influencing the definition of high-level waste disposal criteria. In an introductory session two invited papers were presented. The first dealt with the main approaches and key issues regarding predicting and judging long-term safety of high-level waste disposal. It provided the perspective of those dealing with safety assessment of waste repositories. The second invited paper gave an overview of existing international guidelines and criteria on high-level waste disposal and the underlying basic radiation protection criteria and objectives. These two papers stressed the fact that high-level radioactive waste repositories are designed as long-term isolation systems with the objective of containing radioactive materials for extremely long periods of time. Radiation risks for human beings and the environment from such systems are supposed to occur only after a long isolation period and will be associated in the long-term with the gradual deterioration of the isolation barriers and the slow migration of the remaining radioactive materials to the biosphere.

In the next session, reports from Canada, France, Germany, The Netherlands, the Nordic countries, Spain, Switzerland, the United Kingdom and the United States were presented. These reports provided details about existing national radiation protection criteria for radioactive waste disposal and the rationale behind them. Some of the reports also dealt with ongoing work by national authorities to further develop detailed criteria to be applied in the licensing procedure of a high-level waste repository in their respective countries. All the reports presented at the workshop are reproduced in these proceedings.

Finally, a significant part of the workshop was devoted to topical discussions of themes identified to be of a general interest:

- limitations and constraints in the application of basic radiation protection and safety criteria in a long-term perspective,

- consideration of probabilities and uncertainties in the formulation and application of criteria,

- needs and approaches regarding subsystem performance criteria, and

- licensing approaches and guidance on the demonstration of compliance.

In addition, more specific issues were discussed during the meeting:

- risks related to human intrusion and possible approach to handle them,

- the use of various safety reference indicators, e.g., flow of natural contaminants into the biosphere, as in criterion no. 4 of the Nordic countries consultative document, and

- *formulation of criteria as a function of time periods of reference* (e.g., quantitative up to 10^4 y, qualitative after 10^4 y).

GENERAL OBSERVATIONS

Three general observations can be derived from the presentations and discussions at the workshop.

1. The ICRP radiation protection principles and national regulations in this field provide a basis for the development of safety criteria for the disposal of radioactive waste. An international consensus exists on the following principles:

   a) no practice shall be adopted unless it produces a positive net benefit (the justification of a practice); there is general agreement that justification refers to an entire practice (e.g., electric power generation), rather than to each part of it. Thus it is not necessary to justify, in the ICRP sense, waste management in isolation.

   b) all exposures shall be kept as low as reasonably achievable, economic and social factors being taken into account (the optimisation of protection or the ALARA principle);

   c) the dose limits recommended for individuals by the ICRP shall not be exceeded.

2. The approaches to application of the general radiation protection principles are largely similar in all countries. Their translation into quantitative safety criteria for radioactive waste disposal, however, may differ somewhat in the different countries, as illustrated in the papers presented. Such differences, which may be influenced by public perception of the risks involved, concern:

   - the explicit use of limits expressed in terms of dose or in terms of risk,

   - the use of individual and/or collective dose/risk limits,

   - the level of detail of the criteria, e.g., use of subsystem criteria, special criteria for certain scenarios, and

   - the period for which compliance has to be shown.

   However, in spite of these differences in the formulation of criteria, the level of safety of high-level waste disposal systems in different countries may not differ significantly, notably in view of

- the criteria being based on the same radiation protection principles and dose limitation system,

- the need to cope with uncertainties in safety assessment and introduce associated safety margins, and

- the need to fulfil other technical criteria which are largely similar in all countries.

All of these elements are intended to keep actual doses or risks in the long-term well below the safety levels suggested by the quantitative criteria. In this respect, regulatory approaches concerning high-level waste disposal systems have to be seen in a broad perspective, quantitative radiation protection criteria being only one element of such approaches.

3. If the safety criteria for radioactive waste disposal are met, then both current and future generations should in principle be protected at a level which corresponds to the level of safety provided today by the application of the basic radiation protection standards. A key issue in radioactive waste disposal safety, however, is not the safety criteria as such, but the difficult question of demonstrating compliance through the use of safety assessment methods. In particular, safety cases need to be "robust" and should be based on reliable data and modelling. Thus, any licensing process of a waste repository will inevitably have to deal with questions such as the following:

   - Do the models and data used in the safety assessment adequately represent the disposal system?

   - Have all important scenarios for future development of the system been considered?

   - Have the models and data been correctly used and are the results correctly interpreted?

   - As proof of compliance will never be absolute, to what extent elements of judgement need to be taken into account and under which circumstances?

   Many national authorities are now working on developing requirements concerning such issues as guidelines on how to show compliance with the safety criteria.

'OPICAL ISSUES

The discussions centered around two main themes:

- how to translate the radiation protection principles into measures of performance (safety criteria) to be used for judging the acceptability of proposed radioactive waste disposal systems, and

- how to demonstrate and judge compliance with the safety criteria.

The national presentations that are reproduced in these proceedings provide detailed material about approaches in this respect.

Dose and Risk as Performance Measures

All existing regulations make use of either dose or risk (or both) as a fundamental measure of performance (safety indicator). As discussed in the key NEA, ICRP and IAEA publications mentioned earlier, there is a need within safety assessments of radioactive waste disposal to consider not only the most likely scenario and related expected releases (if any), but also a set of scenarios that are uncertain or even unlikely to happen. To account for this situation, a consistent theoretical framework has been developed within the ICRP recommendations using the risk concept and recommending a constraint on the annual individual risk of severe health effects to a level of about 10^{-5} (this risk level is consistent with the risk implied by the annual dose limit recommended by the ICRP for individual members of the public). Several national regulations (UK, Canada) explicitly follow this recommendation, but set the risk limit at 10^{-6} for radioactive waste disposal practices because waste disposal is just one of several potential sources for exposure. Although risk can be seen as a more fundamental measure of protection than dose, some authorities have chosen to use dose limits for the most likely scenarios and to consider low-probability disruptive scenarios separately. Thus, several countries (Switzerland, Germany) have regulations using dose limits and make no explicit use of the risk criterion. This does not necessarily mean, however, that those using only dose limits do not recognise the need to consider the risks associated with probabilistic events and the need to try to estimate them when appropriate.

It was concluded that both risk and dose are valid <u>indicators</u> of safety, but both concepts have limits attached to them when applied for judging the safety and the environmental impact of radioactive waste disposal (see further below).

Other Measures of Performance

Risk and dose assessments have to use assumptions about the far future regarding supposed receivers of radiation exposures related to waste disposal practices. Very little is known, however, concerning demography and living habits and radiation sensitivity of human beings living in the far future. Such dose calculations should, therefore, be viewed as an indication of what the doses would be were the calculated releases to occur in the near future, rather than as predictions of actual doses to human beings living in the far future. In order to avoid considering the inevitable uncertainties related to future society and humans, and the impact of such uncertainties on long-term safety assessments, some authorities propose to use calculated releases of radioactivity into the environment as an alternative complementary measure of performance for the far future. In the United Kingdom, for example, where the competent authority, the Department of the Environment, has set an individual risk target, $10^{-6}y^{-1}$, for the probability of fatal cancer, there is also the requirement that "the radionuclides released from the repository should not lead to a significant increase in the radioactivity naturally occurring in the general locality of the facility". The Nordic document proposed a criterion limiting the total activity inflow rate of the disposed radionuclides to the biosphere, to less than a given reference value based on the release of natural alpha emitters (uranium, thorium and radium inflow via the pathway geosphere → human environment → sea and ocean sediments). The proposed level is set so that it would limit the average exposures from the disposed radionuclides to about the same level as the average exposure received locally from natural alpha emitters currently of the order of 0.1 mSv/y, and to insignificant levels regionally and globally.

In the United States, the main quantitative probabilistic radiological criterion in the Environmental Protection Agency (EPA) standards is based on cumulative releases within 10 000 years of various radionuclides into the accessible environment. These release limits have been determined using relatively simple models for the biosphere with the objective of limiting the global collective dose so that disposal would result in less than 1000 severe health effects in 10 000 years. This type of criterion is unique to the United States, and similar criteria are neither used nor under consideration in other countries.

The Use of Collective Dose Calculations and the ALARA Principle

A fundamental requirement of the ICRP radiation protection principles is that all exposures should be kept as low as reasonably achievable, economic and social factors being taken into account (ALARA). This requirement for optimisation of protection is sometimes implemented in other radiation protection activities by a relatively rigorous analysis of the available alternatives to achieve an optimal balancing of the radiological impacts, economic costs and other factors. Although the optimisation principle remains valid also for deep geological disposal of radioactive waste, a detailed quantitative optimisation procedure dealing with long-term situations is severely constrained and does not usually play a major role in the decision-making process related to the disposal of radioactive waste for several reasons:

- The safety level of proposed systems may be so high that it may go beyond what would result from a strict optimisation of the economic costs of safety measures (waste form, barriers, depth of repository, etc.) against related reductions in radiological impacts. Factors other than economics and radiological impact - such as social, political and public perception factors - lead to an "overly" stringent safety level for most proposed deep disposal systems.

- Systems for deep geological disposal are typically characterised by the fact that "normal" (most likely) scenarios have releases which will only occur (if any) in the far future and that their radiological impact, although associated with large uncertainties, will still be far below ICRP limits. In addition, releases might occur owing to potential disruptive geological events, the probability of which is normally considered low but difficult to estimate with precision. The long time frames and large uncertainties associated with estimated potential radiological impacts do not provide a reliable basis for detailed quantitative optimisation of radiological protection. In most cases, any differences between alternatives will be masked by the uncertainty ranges of the estimated impacts.

- Detailed information on system performance and system costs is a Bprerequisite for quantitative optimisation. However, such iB[Bnformation will only become fully available for a particular site 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. This will from the outset limit the scope of optimisation procedures applied in a broad sense.

Having considered the limits of detailed quantitative optimisation procedures, it should be stressed, however, that a judgemental and qualitative optimisation is certainly included in the development of detailed repository design options and in the selection of sites for detailed investigations, in particular to ensure that all reasonable or practical opportunities to reduce doses are explored. This means that the optimisation of protection principle is valid, but its application has to be adapted to what is achievable in practice.

The Use of Subsystem Criteria

Subsystem criteria mean regulatory requirements concerning the performance of subsystems within a disposal system. Typically, subsystem criteria may concern waste form stability and leach resistance, near-field properties, and properties of the geological formation at a disposal site. Such criteria may be used to provide regulatory guidance concerning repository design and siting. They may also serve to impose a certain degree of redundancy and optimisation within a multiple barrier system.

Most commonly, derived criteria are expressed in qualitative terms. This allows the regulator to provide guidance without specifying required subsystem performance in detailed quantitative terms. At the workshop, it was considered that detailed quantitative subsystem criteria might be premature or even potentially counterproductive to a flexible and gradual process of developing the repository system and establishing the optimal balance between different barrier functions.

The high-level waste repository regulations of the United States Nuclear Regulatory Commission (NRC) include quantitative subsystem performance criteria concerning the waste package, releases from the engineered barrier system and pre-emplacement groundwater travel time. They intend to promote the use of at least partially redundant multiple barrier systems for the isolation of high-level waste. These subsystem criteria also help to achieve compliance with the overall system performance standard, but they are neither necessary nor sufficient to ensure compliance. In fact, the NRC regulations explicitly provide for approval of alternative subsystem criteria, if appropriate. Thus, the subsystem criteria serve as default specifications for the level of performance to be achieved. If these default criteria prove unsuitable for a specific proposed disposal site, alternative criteria may need to be approved or specified by the NRC.

Time-Frames, Cut-Offs and Discounting

Several issues related to the long time frames for which safety of disposal systems has to be assured were discussed at the workshop. There was a consensus that the fundamental safety principles should be time invariant, so that a similar level of safety is provided for all future generations as that provided for the current generation. It was recognised, however, that two basic facts will influence the type of approach required to demonstrate and judge compliance with basic protection principles. The first is that uncertainties associated with assessment results will increase with time. The second is that the radioactivity of the waste decreases with time. These two general trends, taken together, suggest that the meaningfulness of and the need for detailed quantitative assessments become less and less the further into the future the assessment is carried.

All countries examine potential radiological impacts over long time frames. Formal requirements for quantitative assessment up to at least 10 000 years are included in some regulations, for instance those in Canada, Germany and the United States. Other countries do not use such "cut-off" times and consider quantitative assessments for one million years or even more. There was a consensus that, in any case, assessors should adapt their approach and their presentation of results to the period under study. Thus, detailed quantitative assessments, including dose calculations, could be justified for the shorter periods, and a less detailed, more qualitative approach could be used for times far into the future. In any case, presentations of the results of assessments should always be made in the light of when the impact is calculated to occur, its magnitude, how likely it is to occur, and what uncertainties are associated with the result. Thus, so-called "cut-off" times should rather be viewed as transition points on the method and detail of the assessment, with a gradual shift from quantitative to qualitative assessment.

Demonstration of compliance

Safety criteria determine the requirements with which the safety assessment results must comply. Whatever the detailed criteria might be, the assessment work that has to be done remains to a large extent the same. A key issue is how to demonstrate and judge compliance with the safety criteria. This is a much more complex issue than just comparing the end results of an assessment with the safety criteria to see if they are formally met. It has to do with the level of understanding of the disposal system provided by the assessment and the quality of the data and models used in predictive modelling.

Three general observations were made at the workshop, finally revealing a great deal of common elements in the various national approaches:

- In a practical sense, safety is provided by the combination of the waste forms, the engineered barriers, and the design and siting of the repository. Thus, an important part of providing safety through the use of regulatory requirements is to make sure that sufficiently high quality and "good engineering practice" prevails throughout the process of designing, siting, constructing, operating and closing a radioactive waste repository.

- A detailed and quantitative safety assessment using predictive modelling based on adequate scientific understanding of all important phenomena and processes and using site-specific data is the key instrument to gain an understanding of the long-term performance of a repository. The scientific basis of and the methods and tools used for performance assessments are continuously being improved and refined, often within international co-operation. A "code of good practice" concerning, for instance, scenario selection, model validation and uncertainty analysis, has emerged and has been reported in recent NEA publications. Guidance regarding the requirements on safety assessment methods, models and data used, does exist or is under development in many countries.

- The quantitative detailed safety assessments will always need to be complemented by qualitative evidence and human judgements concerning different aspects of the long-term safety of radioactive waste repositories.

An important element in judging compliance will be the assurance that assessment results are derived from a rigorous and systematic process, leading to a good understanding of the long-term behaviour of the disposal system. In this respect, it should be stressed that the licensing process has to be seen in a broad perspective, radiation protection and safety criteria for the disposal of high-level and long-lived waste being only one of the many elements of this process.

OTHER ISSUES

Human Intrusion

It was suggested that human-intrusion issues might deserve a separate consideration compared to other disruptive scenarios, and require specific safety and radiological protection criteria. It was noted that, for deep repositories for high-level waste, human intrusion might be characterised by low probabilities (although very difficult to estimate with precision) and potentially high consequences. Such low-probability high-consequence scenarios would be difficult to treat within the normal regulatory guidelines and might, therefore, need separate consideration, keeping in mind that a certain residual risk will always exist for all ways of disposing of radioactive wastes even with adequate siting and conservative repository design. The development of some kind of international consensus regarding how to treat and judge human intrusion risks would be very useful to Member countries. These issues will be treated within the NEA Working Group on Assessment of Future Human Actions at Radioactive Waste Disposal Sites.

Use of Collective Dose/Risk

As already noted, there is only limited use made of collective dose or risk in safety criteria and assessements. The reasons are that use of collective dose/risk requires assumptions about - not only future critical groups of human beings and their habits - but the whole society (number of people and their living conditions and habits). Collective dose calculations will, therefore, be associated with large uncertainties, and differences between disposal options will often be masked by the uncertainty ranges affecting such calculations. It was noted, however, that for certain scenarios it might be appropriate to consider not only individual doses/risks, but also the number of individuals involved and the duration of the exposure. In particular, a low-probability high-consequence scenario might be judged differently depending on whether the consequences are likely to concern only a few individuals, or a larger group.

In conclusion, individual dose or risk limits were generally regarded as more appropriate for determination of the long-term acceptability of high-level waste disposal practices than collective dose or risk limits, which should be used mainly as a comparison tool for the discussion of repository design alternatives.

INTRODUCTORY PAPERS

PREDICTING AND JUDGING LONG-TERM SAFETY OF HIGH-LEVEL WASTE DISPOSAL: MAIN APPROACHES AND KEY ISSUES

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ABSTRACT

This paper consists essentially of a sequence of statements (based upon generally accepted findings as presented eg. at the "Symposium on Safety Assessment of Radioactive Waste Repositories, Paris, October, 1989" and upon specific experience from the Swiss programme) which are of direct relevance to the topic "Radiation protection and safety criteria for the disposal of HLW". The following areas will be touched upon:

- Existing performance assessment studies: principle features of relevance
- Current status of performance assessment methodology
- Role of performance assessment studies
- Uncertainty in performance assessment and confidence in the model predictions
- Judgment on the acceptability of performance assessment results

It is hoped that these statements can provoke some interesting discussion during the workshop.

This paper is not aimed at presenting a specific point of view on performance assessement, nor at summarizing completely the state-of-the-art in that area; it consists rather of a sequence of statements (based upon generally accepted findings as presented eg. at the "Symposium on Safety Assessment of Radioactive Waste Repositories, Paris, October, 1989" and upon specific experience from the Swiss programme) which are of direct relevance to the topic of this meeting. It is hoped that these statements can provoke some interesting discussions during the workshop.

1 Existing Performance Assessment Studies: Principle Features of Relevance

- During the last few years many *integrated performance assessment studies* for HLW have been performed for different purposes:
  - formal demonstration of feasibility of safe disposal such as KBS-3 (Sweden) and Project Gewähr (Switzerland), etc.
  - concept assessments such as PSE (FRG), OPLA (Netherlands), SAFIR (Belgium), PAGIS (CEC), etc.
  - and other studies eg. in context of developing performance assessment tools (eg. BURKHOLDER et al., 1976; HILL and GRIMWOOD, 1978; DORMUTH and SHERMAN, 1981)

  The above mentioned performance assessment studies for HLW repositories generally include considerations of the following *three topics*
  - scenario analysis
  - consequence analysis
  - assessment of results

  As a result of all these studies experience has been gained in all three topics mentioned and the practicability of performing assessments whose results can be compared with safety criteria has been illustrated.

- All above mentioned studies show that for deep geological disposal of HLW *sufficient safety* as measured against any reasonable safety criteria for risk or safety is in principle achievable; however, because of the sparsity of site-specific data no final confirmation of site- and design-suitability has yet been completed.
  Furthermore, no formal license application has yet been made for a HLW repository in any country.

- As measure of detriment (or safety) *dose to the individual* (or risk to the individual) is today generally accepted; in some countries a cut-off time has been defined for the analyses. The estimates on dose rely on more or less detailed biosphere transport calculations. The dose calculations and the judgment on the acceptability of calculated doses rely on *radiation protection principles*. Population doses have been used as additional measures of detriment, nuclide releases to the environment also (in particular in the USA)

- *Scenario analysis* (conceptualisation of (different alternative) futures) is an important element in performance assessment. The most important issues are
  - completeness of scenarios (FEP's)
  - selection of scenarios to be considered
  - the likelihood of occurence of specific scenarios

  Safety assessments criteria must take into account the *uncertainties* in each of these points. Recently much attention has been given eg. to the issue of *human intrusion* (a low probability event with high consequences for a small number of individuals); from this example it becomes more and more clear that the judgment on the acceptability of such scenarios is not a purely technical question.
- *Biosphere transport calculations* (over long time scales) is provoking much discussion. Because of the expected *large changes in the biosphere* for the long time scales considered, the accuracy of biosphere calculations will be very limited. Therefore, the meaningfulness of these calculations are sometimes questioned.
  In many studies the different possibilities of alternative future evolutions of the biosphere are explicitely acknowledged and a broad range of different realistically conceivable future representative situations of the biosphere (taking into account possible changes in environmental conditions etc.) are analysed. However, all studies assume that the basic nutritional requirements and the lifestyle are for all times the same as those of people today.

2 The Current Status of Performance Assessment Methodology

- For performance assessment purposes there exists general agreement that the *prediction* of the evolution of a repository system
  - can not be directly based on observations,
  - relies on models,
  - must be quantitative, and
  - needs a broad data base (partially site-specific).

- The current *status of performance assessment methodology* has recently been assessed at the "Symposium on Safety Assessment of Radioactive Waste Repositories, Paris, October 3-19, 1989" and, based upon the findings of this conference, the NEA Radioactive Waste Management Committee (NEA-RWMC) will publish its collective opinion on the evaluation of long term safety. In this collective opinion the following major conclusions are recorded:

The NEA-RWMC confirms that

- "safety assessment *methods are available* today to evaluate adequately the potential long-term radiological impacts of a carefully designed radioactive waste disposal system on man and his environment."

and considers that

- "appropriate use of safety assessment methods, coupled with sufficient information from potential disposal sites, can *provide the technical basis* to decide whether specific disposal systems would offer to society a satisfactory level of safety for both current and future generations."

These important, broad conclusions are qualified by the following remarks:

The NEA-RWMC

- "recognises that a correct and *sufficient understanding* of proposed disposal systems is a basic prerequisite for conducting meaningful safety assessments,
- notes that the collection and evaluation of *data from proposed disposal sites* are the major tasks on which further progress is needed,
- notes that safety assessment methods can and will be further developed as a result of ongoing *research work*, and
- acknowledges that quantitative safety assessments will always be complemented by *qualitative evidence*".

3 The Role of Performance Assessment Studies

- The ultimate role of performance assessment is to provide quantitative predictions of potential repository consequences in order that these can be compared with safety criteria. There are also further important applications; performance assessment studies are carried out during all phases of repository system planning and implementation and *provide input* to:
  - concept development
  - development of site selection criteria
  - repository design
  - planning of site characterisation programmes
  - setting of research priorities
  - system optimisation
  - the licensing process

- A straight comparison of calculated and regulated numbers will never suffice for judging repository safety. It will also be necessary that implementer and regulator are convinced that they understand the system behaviour sufficiently well. Accordingly it is important to note that performance assessment is *more than just a calculational framework*; it essentially consists of the following elements:

- development of sufficient *system understanding* (development of conceptual models);
- *quantification* of the expected or maximum consequences based on sufficient system understanding (development of calculational models);
- indication on the *certainty of the results* and assessment of the impact of false assumptions (sensitivity and uncertainty analysis);
- *convincing of all relevant groups* (implementer, regulator, public) of the adequacy of the performance assessment study (validation with the help of experiments and analogues).

4 How much confidence can we place in the quantitative results of performance assessment?

The comparison of model predictions with (quantitative) criteria is one of the most important parts to derive a *decision basis* to decide on the acceptability of a repository. Therefore, the available levels of confidence in the model predictions are of key importance and uncertainties must explicitely be considered.

4.1 Uncertainties and Their Treatment

- *Sources of uncertainty* are:
  - uncertainty in *scenarios* (completeness of scenarios, uncertainty in conceptualisation of future evolution, uncertainty in estimating the liklihood of occurence of the different scenarios, etc.),
  - uncertainty in *conceptual models* (incomplete understanding, uncertainty in the choice between different alternative conceptual models, etc.),
  - parameter *uncertainty*,
  - parameter *variability*.

  All these uncertainties result in *uncertainty in the predictions*.

- For the *quantification of uncertainty*, performance assessment tools can be used:
  - For uncertainties on scenarios, several alternative future evolutions must be analysed.
  - For conceptual uncertainties, several alternative conceptualisations must be considered.

- For parameter uncertainty both probabilistic (propagation of pdf's through the model chain in a closed computational form) as well as deterministic models (sufficiently broad parameter variations) can be used.

- *Tolerable uncertainties* should explicitly be acknowledged and accepted both in the models and the data; eg. for small consequences large uncertainties may well be acceptable.

4.2 Validity of Models

- The ease of proving that the predictions are sufficiently "close to the truth" (i.e. are valid) depends upon
  - the *complexity* of the system modelled,
  - the temporal and spatial *extrapolations* made by the model,
  - the *current understanding* of the system modelled (eg.: dependence on fundamental laws of science, evidence from experimental/analogue observations etc.),
  - the *sensitivity* of overall performance to the specific processes modelled.

  However, in a strict sense, rigorous and complete proof of matching "the truth" is not possible because
  - only few systems are available that allow direct comparisons with modelling results (because of the large temporal and spatial scales of prediction),
  - models can only be disproven (invalidated), and
  - positive evidence of the ability to model similar systems is not a rigorous proof of the general applicability of models to predicting the future behaviour of repositories.

- Rigorous and complete proof of matching "the truth" is not needed however; confidence in predicted safety only requires that predictions of a model are *correct* (a sufficiently close representation of "the truth") *or* the *model overpredicts detriment* (errs on the side of conservatism).

4.3 Robustness - one way to reduce validation requirements

- A *robust model* for safety analysis (the model chain and its database) has the following general characteristics:
  - it relies on *credible application* of generally accepted scientific principles and well validated models;
  - it considers *all potentially negative processes*;
  - *simplifications* (made wherever justifiable) result into demonstrably conservative models;

- *impact-reducing processes* are only considered when they are certain to operate (i.e. are sufficiently validated)
- the results derived by a robust model are, within established ranges, *insensitive* to changes in conceptualisation and parameters;
- there exists sufficient confidence in the *database* used.

- In this sense, a robust model does not require to match "the truth" in all details; simplifications are acceptable and will reduce validation requirements.

- The steps in *developing a robust assessment model* are
  - all key processes occurring must be described;
  - all *potentially detrimental processes* are quantitatively considered;
  - those *impact-reducing processes* which are needed to provide sufficient safety and which are certain to operate, are quantitatively evaluated.

Robustness doesn't necessarily mean "primitive" models. In fact models of varying sophistication will be applied.

4.4 Models to be used in performance assessment

The use of the following 2 types of models will provide (parts of) a decision base which allows repository implementation with sufficient confidence:

- *research models* (realistic, detailed, process-orientated) describe parts of the system:
  - they provide the theoretical framework to demonstrate system understanding,
  - they allow interpretation of experiments (laboratory and field),
  - they are the tool for validation,
  - their results provide the basis for decisions on simplifications of assessment models.

- *assessment models* (complete model chain, simplified) are used to assess the overall performance of the repository system. Two types of assessment models are used:
  - *realistic, "best guess"* assessment models (relying on best estimate models and parameters)
    - they are an important element in the licensing procedures,
    - they are the tool for optimisation (eg. to determine the point of diminishing returns in adding additional barriers to the system),
    - they are needed for sensitivity analysis,
    - they allow the estimation of uncertainty,

- they are needed for the development of sufficient understanding of overall system behaviour,
- they are the tool for demonstrating sufficient repository optimisation.

- *robust* assessment models are used to convincingly demonstrate clear compliance with criteria.

This then requires a *well-balanced judgement* on all available results including also other available quantitative and qualitative evidence (eg. from analogues)!

4.5 Repository Siting and Design - important aspects with respect to uncertainty

- The *ease of demonstration* of sufficient safety and the *treatment of uncertainty* (and inherent variability) are key issues to be considered already in the early phases of repository planning. Key elements in this respect are thus:
  - the *explorability* of the geological environment (spatial predictability)
  - the *predictability* of the evolution of the geological environment with time
  - a *robust lay-out* of the whole system
  - the development of *robust models* for performance assessment; the robust models are complemented by "best guess" models

- For a "robust" repository system in an adequate geological environment and with adequate engineered barriers it should be possible to demonstrate convincingly that the *"hazard potential"* (bounding value of performance) of the repository is within acceptable levels.

  Such a *robust repository system* has the following characteristics:
  - it is *simple* with respect to its physical and chemistal properties as well as in its design,
  - for such a system *large safety margins* are available,
  - such a system provides *maximum redundance* in its barrier functions.

  Both the engineered barriers as well as the geological environment can exhibit robust properties.

- The remaining levels of (with reasonable technical efforts non-reducible) uncertainty will determine the successfulness of performance assessment with respect to
  - reliable predictability (such as setting *upper bounds*),
  - accurate predictability (best guess of *expected behaviour*),
  - achievable levels of "reasonable assurance" in correctness of model predictions (easiness of *validation*).

5 Judgment on the Acceptability of Performance Assessment Results

The judgment on the acceptability of performance assessment results is a key performance assessment issue related to the task of setting criteria; a few thoughts from a performance assessor's point of view are given below.

- When demonstrating compliance with criteria the following questions must be asked:
  - Are the specific *criteria* to be met clear and *understandable* to all groups involved (implementer, regulator, public)?
  - Is our *methodology good enough* for quantitative analyses?
  - Do we have an *adequate data set* in terms of both accuracy and completeness?
  - Where are the largest *uncertainties* in analysing repository behaviour?
  - How can we handle the non-reducible uncertainties?

- To assess the model *predictions* we must give answers to the following questions:
  - Is the repository *sufficiently safe?*
    - are the model predictions below regulatory limits?
    - are future effects (not covered by the criteria) within acceptable levels?
  - Are the analyses *understandable and convincing?*
    - are both the public and the experts convinced?
    - can adequate validation be achieved?
    - are the assessment models sufficiently robust?
    - can the research models partially be validated?
  - What *reserves of safety* are available?
    - do the "best guess" models give negligible effects?
    - are the robust predictions below regulatory limits?

- It is important to note that the judgment on the *acceptability* of an option is equivalent to the choice between *available alternatives* (in a very broad sense):
  - alternatives in energy production (pro/contra nuclear energy: do we want to sacrifice nuclear energy production because discussions on final disposal are losing context?).
  - alternatives to deep geological disposal: today, no serious alternatives are under discussion (except sub-seabed disposal?). The choice not to implement disposal means the choice to retain hazardous materials in engineered structures in our environment.
  - the choice between different host rock options and design options.

- The assessment of the results produced requires *(informed) expert judgment* considering both the levels of conservatism used (best guess vs robust) and remaining uncertainties. Expert judgment is especially needed for events with small likelihood of occurence but significant consequences (eg. human intrusion etc.).

The following issues should be clearly distinguished when judging on the acceptability of performance assessment results:

- risk vs uncertainty:
  . uncertainty = a range of possible results
  . risk = {probability} x {consequence}
- risk vs individual dose:
  . dose and risk limits should be equivalent for events with stochastic effects
  . risk is an adequate measure for "low probability, high consequence"-events (such as human intrusion, unlikely disruptive events).
  . consistency on judgement of acceptability of dose and risk must be maintained also for events with
    - a small number of people being affected by the event
    - a short duration of the event (and its effects)

- Technical experts on implementer and regulatory sides should be able to reach a consensus on the level of risks presented by a disposal facility. The judgement of the acceptability of these risks is a matter for society. Regulators and implementors can, however, both help to provide a proper framework for these judgements in that they set the risks in proper context by comparing them with other hazards faced by men.

6 Conclusions

- The levels of safety offered by geological repositories can be adequately analysed.

- Deep geological repositories can provide the necessary protection for man and his environment - also for HLW.

- The level of safety of a repository system is in principle not dependent on the formal safety criteria. However, if criteria are poorly formulated, they divert attention to inappropriate designs or even directly affect efficiency of design (eg. too specific design requirements).

- For demonstrating compliance, the following aspects of safety criteria are important
  . the type of radiological safety criteria (individual dose, collective dose, risk, release limits),
  . the level of detail of criteria (overall system criteria, criteria for components),
  . the time scales to be considered for institutional control, complete containment, and for predicting release (100 - 10^6 y!),
  . the values chosen for numerical limits,
  . requirements on treating uncertainties in models and in data.

- The details of criteria are in principle not very important for developing and assuring safe systems.

- However, criteria strongly affect the procedure of repository development and implementation. It is for example important that
  . the collection of field data is possible without significant delays,
  . the criteria allow for "the unexpected" and maintain sufficient flexibility for changes in design ("design as you go").

- Criteria also strongly affect the licensing procedure and consequently the acceptability of HLW disposal. The explicit acknowledgment of levels of conservatism used in the assessment is important; discussions otherwise lose easily context!

- Formal performance assessment will be the backbone of all licensing procedures but qualitative, "soft" evidence must also be used.

- The first goal in licensing is achieving a technical *consensus* (between implementer and regulator) based on analytical assessment complemented by sound human judgement. This goal is prerequisite for consensus with, or acceptance by, the public. Consensus with the public requires trust based on open information.

- The feasibility of radiological optimisation (ALARA) for the post-operational phase of a HLW repository seems questionable; the implemented ambitious (radiological) design criteria assure already an optimal design.

7 References

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CRITERIA AND BASIC OBJECTIVES FOR RADIOLOGICAL PROTECTION : AN OVERALL VIEW OF EXISTING INTERNATIONAL CRITERIA AND RECOMMENDATIONS TO EVALUATE HIGH ACTIVITY WASTES.

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RESUME

A la différence des autres étapes du cycle du combustible nucléaire, le stockage des déchets de haute activité se heurte à un problème de durée qui nécessite l'établissement d'objectifs et de critères de protection radiologique spécifiques à ce type d'opération. Ceux-ci peuvent résulter d'une adaptation des critères et principes généraux existants notamment des principes d'optimisation du niveau de protection et de limitation des doses individuelles.

En ce qui concerne la limitation des doses individuelles, il est suggéré de la remplacer par une limitation du risque individuel, afin de pouvoir notamment prendre en compte le caractère probabiliste d'évènements qui, dans un futur très lointain, pourraient être à l'origine d'une exposition de la population.

Par ailleurs, les incertitudes inhérentes à l'évaluation du détriment collectif, élément essentiel du processus d'optimisation, et l'introduction d'une approche probabiliste dans cette évaluation, limitent sensiblement la portée et les conditions d'utilisation de ce principe.

INTRODUCTION

Although nuclear activities do not lead to greater amounts of waste than other industrial activities, and although some of the elements composing these wastes may have relatively short lifetimes, and even in cases where relatively long lifetimes are involved, they are obviously shorter than the unlimited lifetimes of stable elements, public suspicion is much more aroused by nuclear activities.

It is true, that generally speaking, public opinion is very sensitive to problems involving the disposal of wastes of any origin. However, when the adjective "radioactive" precedes the word "waste" and one bears in mind the way in which nuclear opposition focuses attention on accidents, it is easy to understand the consequences.

This public image has made the nuclear industry even more aware of the absolute necessity of paying enormous attention to safety considerations when making decisions concerning waste management, and in particular, high activity waste management.

1. WASTE MANAGEMENT: A PARTICULARLY IMPORTANT STAGE OF THE FUEL CYCLE

No fundamental difference should exist between waste management and other stages of the fuel cycle.

Waste management involves operations in which radioactive material is handled, processed and put into repositories; in spite of all the precautions taken to confine this material, a certain fraction of it could conceivably find its way into the environment, resulting in the public being exposed, or at least to the risk of being exposed. Confinement failure may result from a slow deterioration due to an unavoidable aging or may be due to an external phenomenon of natural or human origin. This is just what happens with a nuclear facility, e.g. reactor. It is the job of safety and radiation protection authorities to make sure that the confinement i.e. the isolation of radioactive matter from the environment, suitably resists climatic and other external aggressions, and that even when this resistance cannot be asssured, the consequences for individuals remain acceptable.

It is therefore logical that safety and radiation protection for waste management objectives should be identical to that applied to nuclear facilities : the same concepts should be adopted for acceptability, limitations and choices dictated by technical, economic and social considerations.

This is what might be concluded from a superficial analysis of the problems involved ; however, when these problems are examined in greater detail, the situation reveals itself to be of greater complexity than one might have first thought.

Waste management operations are rather special as they are situated at the tail end of the cycle, and therefore depend on operations and decisions involved in the earlier part of the cycle. Waste management is an essentially passive part of the cycle for which time is the most important factor.

2. TIME: THE ESSENTIAL FACTOR IN HIGH ACTIVITY WASTE MANAGEMENT

Time is a particularly important factor in the management of high-level wastes containing long half-life radionuclides. When low or intermediate level wastes containing short or intermediate half-life radionuclides are encountered, time is not a handicap ; in fact, in such cases, time can significantly contribute to the solution of radiological protection problems. In the case of high-level wastes the time factor has multiple ramifications.

2.1. Confinement integrity

As already mentioned, failures in confinement integrity may arise from aging effects on waste conditioning and/or on the physical barriers interposed between the waste and the environment. External effects of natural (seismic activity, tectonic movements...) or human (intrusion) origin may also occur.

A very high degree of confinement can be assured with techniques and materials available today ; a medium can be chosen for the repository from which any transfer of any released radioelements to the environment would be highly improbable. Finally, a repository, to which human access is very difficult, could be employed.

Such guarantees cannot, however, be assured over periods of time as long as ten thousand, one hundred thousand or even one million years. As we advance in time so does the certainty or probablity of such events occurring coupled with the uncertainty of the conditions under which they might take place.

2.2. Evaluating consequences

Establishing safety objectives for waste disposal and taking appropriate steps to ensure that they are respected implies that it is possible to evaluate the consequences of possible events. In order to do this, it is necessary to have knowledge on environmental factors (hydrogeology, pedology, meterology...), the exploitation of this environment by Man and on the characteristics of the population (population distribution, way of life, dietary habits...).

Although it may be acceptable to extrapolate current conditions over a period of one hundred or even several hundred years, it would be unrealistic to extrapolate over much longer periods of time. However, we do not have any choice in the matter, and are obliged to consider very futuristic scenarios. It is, nevertheless, necessary to bear in mind the increasingly artificial nature of the conclusions reached and the uncertainties involved as we advance into the distant future.

It is reasonable to express doubts as to the significance of the corresponding radiation exposures in comparison with those from future unknown sources, and also, as to the validity of evaluating risks under such circumstances.

It is also possible to imagine that Man may no longer exist or that the Earth will have disappeared.

2.3. Lack of knowledge about exposure

In the other stages of the nuclear fuel cycle, knowledge available on planned or unplanned potential risks and on existing risks (post accident) allows the implementation of measures to ensure the respect of radiological protection objectives : the relatively short lifetimes of nuclear facilities is consistent with such requirements, which even apply to low-level and intermediate- level radioactive wastes, for which radiological implications become negligible during the span of human memory.

This is not true for high-level radioactive wastes: a knowledge of the existence of repositories for such wastes and perhaps their surveillance cannot be guaranteed for more than over a maximum period of a few centuries.

This situation must be taken into consideration when defining radiological protection objectives. This implies that an individual exposed to radiation resulting from such wastes will not be aware of it, and, in consequence, will not be subject to any radiation protection measures.

2.4. Social and economic aspects

The problem is extremely complex because it is necessary to consider the effects of current practices on populations living (or perhaps living !) some thousands of years in the future.

A society is morally bound not to leave future generations with the misdeeds of its practices: it is in the name of this generous principle that the intention exists of assuring future generations a degree of protection at least as high as that of the current generation.

It is questionable whether this principle has been respected in fields of human activity concerned with things other than nuclear wastes ; the benefits of exploiting nuclear energy also concern future generations: without recourse to nuclear energy the heritage of future generations could be bleak!

Finally, it is exact to say that, generally, an individual is concerned by the wellbeing of his descendants ; this concern certainly diminishes with time and eventually disappears. It can be questioned up until what future generation will an individual be prepared to make sacrifices. The subconscious existence of an attenuation factor separating the beneficiary from future generations may intervene: this factor may tend to zero when periods as long as ten thousand, one hundred thousand, or even one million years are involved: such questions should be posed even if they do not, in themselves, suggest a reply.

3. OBJECTIVES AND PRINCIPLES OF RADIOLOGICAL PROTECTION

Radiological protection objectives and the principles enabling them to be satisfied are well known and are defined in the recommendations of the International Commission for Radiological Protection (mainly in publication No.26) and have been restated by other International Organizations, and notably, by the Nuclear Energy Agency of the O.E.C.D.

The following objectives must to be fulfilled :

- prevention of non-stochastic effects,
- limitation of the probability of the occurrence of stochastic effects to an acceptable level.

The three fundamental principles upon which radiological protection is based are :

justification meaning that any activity resulting in an exposure to radiation must be justified by the net benefits to society.

optimization implying that the doses received are reduced to levels, which are as low as reasonably possible, economical and social aspects being taken into account; in order to do this, the best compromise possible is made between antagonistic constraints ; this compromise leads to a level of protection considered to be the optimum, and is often referred to as the ALARA principle (as low as reasonably achievable).

limitation of individual doses implying that even when the level of protection has been optimized by a collective approach, it is still necessary to ensure that individuals are not exposed to inacceptable risks: exposures should always be less than those corresponding to inacceptable risks.

The relation between exposure and the corresponding risk, established in a prudent manner from available knowledge, leads to a risk of the order of 0.01 per Sv for the onset of serious stochastic effects (fatal cancers) ; the annual dose limit recommended for members of the public exposed to radiation over long periods of time is 1 mSv and corresponds to a risk of 1 in one hundred thousand.

It should be noted that in the revised version of the ICRP recommendations, currently being prepared, this limit of 1 mSv per year is retained.

These three principles together constitute what is currently referred to as the system of dose limitation.

In the past the Commission has asserted that the system only totally applies to situations involving controlled sources.

In the opposite situation, for example, in the case of an accident, dose limits cannot be applied, exposed persons being subjected to intervention criteria based on on intervention levels.

For a few years now, the case of potential exposures i.e. exposures associated with a certain probability of occurrence (which can be low) and not with any certainty of occurrence has been taken into consideration : the resulting detriment depends simultaneously on the probability of such an event occurring and on the probability of serious health problems arising once it has occurred. This approach has been developed in order to solve the problem of defining long-term radiological protection objectives for the disposal of radioactive wastes. This is not surprising as it is one of the main aspects of future exposure scenarios : individuals or populations ignoring the exsistence of waste disposal sites will be exposed without realizing it, and will not therefore, be able to apply any radiation protection measures.

It should be noted that in the revised version of the recommendations, the ICRP intends to develop this approach to cover all so-called "potential" exposures.

4. HOW RADIOLOGICAL PROTECTION OBJECTIVES AND CRITERIA SHOULD BE DEFINED : INTERNATIONAL RECOMMENDATIONS

Many texts cover this problem. A few, examples, but not, of course, an exhaustive list, are cited :

- IAEA: Safety series No.63, 1983.
  "Criteria for underground waste disposal of solid radioactive wastes."
- OECD/NEA, 1984.
  "Long-term radiation protection objectives for radioactive waste disposal."
- ICRP publication No.46, 1985.
  "Radiation protection principles for the disposal of solid radioactive waste."

The following points can be retained from the various arguments put forward :

4.1. General principles

A generally accepted principle implied in these texts is that future generations should, without any limitation of time, benefit from a level of radiation protection at least as good as that of the present generation.

It is also unanimously accepted that the objectives and criteria proposed are based on the current system of dose limitation, while at the same time recognizing the necessity of adapting this system to take specific aspects of long-term waste management into account.

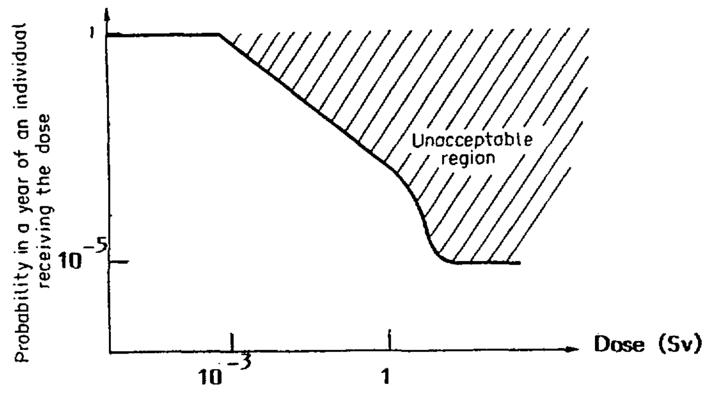
However, it appears that limitation of doses to individuals can be considered to be of greater importance than the optimization principle even though this tendency is not expressed explicitly.

4.2. Individual limitations

Establishing protection criteria in terms of limitation for doses received at some time in the distant future does not have a lot of meaning. This is so, because on the one hand, a dose limit can only be defined for a given situation and a known context, while on the other hand, events that could result in exposures are conceivable but not inevitable. It has therefore been recommended that an individual risk limitation be taken into consideration enabling a clearer concept of the degree of radiation protection sought for future generations, an attempt being made to include both the probability of an exposure taking place (probability of the initiating event occurring) and the probability of serious health effects once it has taken place.

The present annual dose limit recommended for the public is 1 mSv and corresponds to a probability of 1 in one hundred thousand of stochastic effects occurring, assuming that the corresponding exposures are certain to occur i.e. their probability of occurrence is 1. If an exposure, having a probability of occurrence of only 1 in one hundred is considered, then an objective of 1 in one thousand can be fixed for the probability of serious health effects occurring i.e. corresponding to an annual dose of 100 mSv if the same relation is retained. However, when the dose reaches a level where non-stochastic effects occur (about 1 Sv) the probability of serious health hazards becomes equal to unity: it is therefore necessary to limit the probability of such an event occurring to 1 in one hundred thousand.

This system can be represented graphically by a curve defining the boundary between the acceptability and non acceptability regions of risk as a function of this double probability :



However, national authorities can assign the source with only a fraction of the limit established for individuals: this is the "upper bound" concept which is equally well defined in terms of dose or risk. One can pass from one of these terms to the other by shifting the curve and reducing the acceptability zone.

The choice of risk limits for future generations (including those of the very distant future) must conform with the principle according to which the level of protection remains unchanged and must therefore be situated in the 1 in one hundred thousand region as this is the value accepted for the current generation.

In practice, it is more difficult to apply this system than it would appear at first sight: the hypothesis made is that it is possible to assign probabilities to events that could occur at some time in the distant future, perhaps as a result of human actions (for example, intrusion into a disposal site whose existence is not known) ; it is very difficult to predict such events. It is necessary, in this case, to employ systems based on evaluating "subjective probabilities" ; however, reserves must be made about the use of results obtained from this sort of evaluation.

4.3. Optimization (or the ALARA principle)

The ALARA principle should allow decision makers to arrive at the most suitable solution(s) taking into account the different intervening criteria. Even though it may be difficult to put the ALARA principle into practice because of the very long-term effects associated with the disposal of high-level radioactive wastes, rational decisions must, nevertheless be made; no matter how imperfect such decisions are, it is preferable to act in this, rather than a totally arbitrary way. The ALARA tool should therefore be employed in the best manner possible.

ALARA can be applied at different levels :
- in the global management of effluents and wastes from the moment they are produced.
- in determining, which, of the available options, should be used for given types of wastes
- in optimizing the procedures adopted once a given option has been taken, so as to ensure the highest degree of protection possible (geological formations, depth).

The latitude that can be admitted in the final options taken is very limited, as in addition to constraints of a radiological nature, it is necessary to also consider other constraints, and, in particular political and psycho-social constraints.

Because of the many parameters that have to be taken into consideration, it is not possible to aid decision making by employing simple techniques such as cost-benifit analysis.

Recourse to more probing techniques such as multi-attribute analysis becomes inevitable.

The crucial problem, however, remains that of taking uncertainties and the probabilistic nature of events into consideration.

In opposition to the concept of individual limits, which can, without too much difficulty lead to the solution of uncertainty problems by maximizing, a minimum of realism must accompany ALARA techniques, otherwise decisions based on the corresponding evaluations may be erroneous.

In order to make correct decisions it is essential to appreciate the magnitudes of these uncertainties, and either, to integrate them into the evaluations or to treat them as being concomittant.

As uncertainties increase with time, it is tempting to reduce their impact. Several solutions have been envisaged: application of an "attenuation factor" giving less weight to evaluations for the more distant future, introduction of a cut-off when integrating doses less than certain given values or when periods greater than ten thousand years are involved.

From a formal point of view, these solutions might appear to be derogations from the equity principle in protecting current and future generations. However, the necessity of being realistic inevitably leads to modulating the application of this principle. A quantitative approach can nevertheless be reasonably envisaged for periods not exceeding some tens of thousands of years without neglecting the very long-term. This approach then becomes semi- quantitative, and, finally qualitative.

It is finally necessary to verify that the very long-term consequences of the various measures that could be envisaged for a given option lead to the same result, and that the decisions taken are only effective over the short-term.

CONCLUSION

It is always very easy to present an apparently logical and indisputable line of reasoning when one is not confronted with realities. Dogmatic positions can only lead to a totally sterile solution. This is the problem we are confronted with when establishing radiation protection criteria and objectives for the long-term management of high-level radioactive wastes.

In order to overcome such difficulties, practical constraints must be taken into consideration even at the expense of limiting ambitions.

This state of mind must prevail when establishing radiation protection principles and criteria; if realities are not sufficiently considered, it will be impossible to demonstrate that adequate safety measures have been taken. An iterative process will establish a reasonable balance between the obligation of protecting future generations and the demands made on the present generation.

PRESENTATIONS OF NATIONAL CRITERIA / SITUATION

Regulatory Document

Texte de réglementation

Atomic Energy Control Board

Commission de contrôle de l'énergie atomique

REGULATORY DOCUMENT R-104

Regulatory Policy Statement

REGULATORY OBJECTIVES, REQUIREMENTS AND GUIDELINES FOR THE DISPOSAL OF RADIOACTIVE WASTES - LONG-TERM ASPECTS

Effective date:

June 5, 1987

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(The Canadian Regulatory Policy Statement was presented at the Workshop, by Mr. K. Bragg, Atomic Energy Control Board)

REGULATORY OBJECTIVES, REQUIREMENTS AND GUIDELINES FOR THE DISPOSAL OF RADIOACTIVE WASTES - LONG-TERM ASPECTS

1. PURPOSE AND SCOPE

It is the purpose of this document to present the regulatory basis for judging the long-term acceptability of radioactive waste disposal options, assuming that the operational aspects of waste emplacement and facility closure satisfy the existing regulatory framework of requirements. Basic objectives of radioactive waste disposal are given, as are the regulatory requirements which must be satisfied in order to achieve these objectives. In addition, guidelines are given on the application of the radiological requirements to assist proponents in the preparation of submissions to the Atomic Energy Control Board (AECB).

The primary focus of the requirements is on radiation protection, although environmental protection and institutional controls are also addressed in a more general way since these factors stem directly from the overall objectives for radioactive waste disposal. Other types of regulatory requirements such as might concern other aspects of conceptual assessments, siting, design, construction, operation and decommissioning of facilities for the management of particular waste types are, or will be, addressed in separate regulatory documents. Examples of these documents are Regulatory Document R-71 on the concept for deep geological disposal of nuclear fuel waste and Consultative Document C-36 on the management of uranium and thorium mine and mill tailings.

2. INTRODUCTION

In Canada, a wide variety of radioactive wastes are generated at all steps in the nuclear fuel cycle from uranium mining and milling to reactor operations for electricity production, and from the use of radioisotopes in industry, research and hospitals. The bulk of these wastes are managed in a manner based on the principles of containment and isolation from people and the environment. However, the techniques employed rely on the continued need for human intervention and surveillance whether this be for monitoring, maintenance, treatment or restriction of public access to assure an acceptable level of radiological safety. The remaining wastes are disposed of either by controlled discharge to the environment as gaseous and liquid effluents, or in the case of small quantities of lightly contaminated material, by treatment as conventional wastes with no requirement for special radiological precautions.

The current operation of radioactive waste management facilities and the routine discharge of radioactive effluents from other nuclear facilities are strictly regulated by the AECB using a comprehensive system of licensing, compliance and enforcement activities. The specific radiological requirements applied by the AECB are derived from the system of dose limitation recommended by the International Commission on Radiological Protection (ICRP). The dose limits recommended by the ICRP are intended to apply to all practices in which radiation exposure of workers and the public can be influenced by active controls but do not apply to exposures from unusual events, medical irradiations and natural background radiation. For exposures from situations such as accidents and other unusual events during nuclear facility operations, the radiological requirements that are applied by the AECB acknowledge the expected frequency of occurrence of the unusual event or process causing the exposure. In summary, for current operations a regulatory framework of radiological requirements is actively applied, such that procedures of various types are reliably maintained for monitoring environmental discharges, conducting remedial actions as necessary, and controlling exposure pathways.

For the long-term management of radioactive wastes, the preferred approach is disposal, a permanent method of management in which there is no intention of retrieval and which, ideally, uses techniques and designs that do not rely for their success on long-term institutional control beyond a reasonable period of time. The practical disposal options presently being studied usually involve containment of the wastes and their isolation from the biosphere for extended time periods. For some waste types, though, such as the large-volume wastes from uranium mining and milling, the ideal type of disposal may sometimes not be practicable. In such instances where there are no practical disposal options for achieving the ideal goal, there may be a long-term need for continued institutional controls to guard against particular exposure scenarios after the facility has ceased receiving waste and has been closed down.

Whichever option is implemented for the long-term containment and isolation of radioactive wastes, exposures after the closure of a disposal facility will be dependent on a range of events and processes with varying probabilities of occurrence and, in some cases, they will be delayed for considerable periods of time. Forecasts of the possible doses to humans are subject to additional uncertainties owing to the range of factors affecting the environmental transport of radionuclides and to changes which might occur in future living habits, lifestyles and population distributions. Also, in the case of disposal with no ongoing requirement for institutional controls, it is not possible to enforce compliance with present-day forecasts since there would be no operator for the facility in the future. There is consequently a need to establish alternative regulatory requirements to ensure the acceptability of waste disposal options for which there are potential long-term radiological impacts in the post-operational period. The basic purpose of this document is to establish these waste management requirements. For reasons of consistency, equity and fairness, the requirements are based upon an extension of the existing regulatory framework and should be broadly applicable to all waste types and disposal options in which long-term containment and isolation are employed.

It is intended that the requirements and guidelines presented here will come into effect immediately for those facilities designed specifically for the disposal of radioactive wastes. Where a facility may change from an operational storage facility to a disposal facility at some time in the future, the requirements and guidelines are intended to apply at the time disposal is considered to begin. This would normally occur as soon as practical after operations at the facility cease and would likely include a period of institutional control determined by waste and site-specific issues.

3. OBJECTIVES OF RADIOACTIVE WASTE DISPOSAL

The objectives of radioactive waste disposal are to:

- *minimize any burden placed on future generations,*
- *protect the environment,*
- *protect human health,*

taking into account social and economic factors.

Many factors must be considered in meeting these objectives in an effective and reliable way over the long term. The disposal of radioactive wastes on the basis of containment and isolation requires safety features to restrict the release of radionuclides into the environment and to reduce the likelihood of inadvertent public access to the waste. These safety features may incorporate a suitable combination of processes, barriers and institutional controls. The processes include radioactive decay, adsorption, chemical precipitation, dilution, dispersion and other phenomena which influence the transport of radionuclides. The barriers may be provided by engineered design or by the natural geological setting of the site. Such a system of passive multiple barriers gives an increased degree of assurance of containment and isolation and of assurance that any release of radioactive material to the environment will occur at an acceptably low rate. Institutional controls on the other hand are active mechanisms established by society to ensure the continued implementation and achievement of a desired course of action. These controls could include the monitoring and treatment of contaminated releases, the keeping of records, and the imposition of land-use restrictions registered in property deeds and by-laws.

4. BASIC REGULATORY REQUIREMENTS

4.1 Burden on Future Generations

The burden on future generations shall be minimized by:

(a) selecting disposal options for radioactive wastes which to the extent reasonably achievable do not rely on long-term institutional controls as a necessary safety feature;

(b) implementing these disposal options at an appropriate time, technical, social and economic factors being taken into account; and

(c) ensuring that there are no predicted future risks to human health and the environment that would not be currently accepted.

The requirement to minimize the burdens on future generations is based on three matters of principle. The first reflects a pessimistic view of the longevity of institutional controls and concern for the possible consequences should they lapse. Where reasonable disposal alternatives clearly exist, those options which rely on monitoring, surveillance or other institutional controls as a primary safety feature for very long periods are not recommended. This is not because of concern that future generations will be technologically incompetent, but rather because methods of ensuring the continuity of controls are not considered very reliable beyond a few hundred years. Similarly, it is not meant to imply that means to preserve the identity and location of waste disposal facilities or to monitor their performance should not be attempted. It is expected that records will be kept and that in some cases monitoring will be carried out, but, where reasonably possible, safety should not rely on these measures.

The second principle concerns the responsibility of the present generation, as the primary beneficiary of the current exploitation of nuclear energy, to bear the financial burden associated with the implementation of waste disposal options. It has also been argued, however, that it should be recognized that the current use of nuclear energy contributes to an improved standard of living that will benefit future generations. In any case, the timing of the implementation of waste disposal options will depend on a number of technical, social and economic factors. These include the availability and development of suitable sites and technology, the technical advantages to be gained from interim storage of short-lived wastes and, in the case of used nuclear fuel, the desire not to discard prematurely various constituents that are of potential value to future generations.

The third principle concerns the level of risk that may be imposed on future generations since it is not possible to ensure total containment and isolation and absolute safety. On ethical grounds, and in keeping with the recommendations of the ICRP, the radiological risks to future individuals should be limited on the same basis as are the risks to individuals living now. Moreover, the judgement is made that the level of protection to be afforded to future individuals shall not be less than that which is currently provided.

4.2 Protection of the Environment

> *Radioactive waste disposal options shall be implemented in a manner such that there are no predicted future impacts on the environment that would not be currently accepted and such that the future use of natural resources is not prevented by either radioactive or non-radioactive contaminants.*

One of the primary goals of environmental protection is to ensure appropriately safe conditions for human activities. This includes the impacts on human health arising from non-radioactive substances which may also be released from waste disposal facilities. It is thought likely that the level of radiation protection afforded all human individuals ensures adequate protection of other living species in the environment, although not necessarily individual members of those species. It follows then that by establishing the requirements found in this document concerning the radiation health burden on future generations, an appropriate requirement for environmental radiation protection is also formulated.

However, there is also a need to provide adequate protection for the general environment from the impacts that might arise from either radioactive or non-radioactive contaminants. The disposal of radioactive wastes must therefore comply with the appropriate requirements governing land-use and the protection of natural resources, such as water, wildlife, fish, soil, forests, minerals and other economically viable commodities. This basic requirement applies both to the environment surrounding a waste disposal facility and to the materials consumed in its construction and operation.

4.3 Protection of Human Health

The primary focus in this section is on radiological aspects of human health. It must however be recognized that some non-radioactive substances also may have detrimental effects on health. These effects have already been addressed in Section 4.2.

4.3.1 General Requirement

The predicted radiological risk to individuals from a waste disposal facility shall not exceed 10^{-6} fatal cancers and serious genetic effects in a year, calculated without taking advantage of long-term institutional controls as a safety feature.

In judging the acceptability of a disposal facility for which forecasts of hypothetical exposures of individuals in the future are made, it is not appropriate to apply dose limits in the manner practised today for the current operation of nuclear facilities. This is because it will not generally be possible in the long term to enforce compliance with any preselected dose limits. There is also considerable uncertainty as to whether the doses forecast will actually be received. This is due to the assumptions and uncertainties in predictive assessments concerning, for example, the location of the exposed individuals. It is also clear that waste disposal facilities may be subject to unlikely events and processes which could cause doses in excess of an individual dose limit. For example, seismic or tectonic phenomena can modify groundwater flow characteristics, and flooding and erosion may have a disruptive effect on near-surface facilities. Similarly, future human activities such as well-drilling, mineral exploitation, building and farming could give rise to immediate radiation impacts and could modify the characteristics of existing environmental pathways as well as introduce new pathways.

In order to take into account the hypothetical exposures committed in a year from both highly probable and less probable events and processes, the appropriate expression of the requirement is in terms of risk, where risk is defined as the probability that a fatal cancer or serious genetic effect will occur to an individual or his or her descendants. Risk, when defined in this way, is the sum over all significant scenarios of the products of the probability of the scenario, the magnitude of the resultant dose and the probability of the health effect per unit dose. Where it is reasonable to assume that the probability of the scenario approximates unity, the risk is simply the product of the dose and the probability of the health effect per unit dose. This is often assumed to be the case for groundwater transport of radionuclides to the human environment in the long term from a waste disposal facility.

For lifelong continuous exposures, the present view of the ICRP is that the principal limit on effective dose equivalent to members of the public should be 1 millisievert (1 mSv) in a year, taking into account exposures from all sources and facilities excluding medical irradiations and natural background radiation. Since the probability of fatal cancers and serious genetic effects is approximately 2×10^{-2} per sievert, the probability of these health effects associated with a dose of 1 mSv is 2×10^{-5}.

In the case of a single waste disposal facility, there is a need to ensure that the predicted radiological risks associated with it are sufficiently low so as to allow for uncertainties in exposure scenarios and their consequences, and also to allow for future nuclear activities which might impact on the same individuals. An appropriate and prudent risk level for individuals must therefore be chosen in keeping with the objective concerning the radiological health burden on future generations. The level of risk selected, 1×10^{-6}, or 1 in a million, in a year, is a level of risk from other activities that is considered to be insignificant by individuals in their daily lives.

To put the foregoing into perspective, a risk of 10^{-6} in a year is the risk associated with a dose of 0.05 mSv in a year. Individual doses of 0.05 mSv in a year are a small fraction (approximately 2.5%) of the annual dose received by the general population in Canada from natural background radiation and are also of the same order of magnitude as the doses to critical groups predicted from the routine release of radioactive effluents from nuclear power reactors in Canada.

4.3.2 Variance From the General Requirement

> *If there is no practicable method of fully meeting the requirements of Section 4.3.1, an optimization study shall be performed in order to determine the preferred option. A disposal facility, under these circumstances, shall be:*
>
> *(a) compatible with the results of such a study, and*
>
> *(b) such that the predicted risk to individuals does not exceed that which is presently accepted from current operations involving the same wastes.*

It is clearly the intent of this document to have the general requirement used as the basis for judging the acceptability of human health protection to the greatest extent practicable. However, for some waste types in a site-specific situation, there may be no realistic alternative to their disposal in a manner which requires long-term institutional controls as a safety feature. Uranium mill tailings are a general class of wastes which are generated in large volumes and which, in most practicable disposal options, require some form of long-term institutional control to guard against the occurrence of particular exposure scenarios. This need arises since the tailings disposal options usually involve some variation of surface or near-surface containment. In this case, measures must be implemented to deter inadvertent public access to or misuse of the waste material. Moreover, monitoring, surveillance and maintenance may be needed to ensure satisfactory long-term performance. The existence of institutional controls may also permit future societies to take remedial action if that is considered desirable. However, in keeping with the requirement concerning the burden on future generations, the need for such controls must be minimized to the extent reasonably achievable. The process of determining what is reasonably achievable is called optimization and is discussed in greater detail in Section 5.5. The stipulation that the predicted risk to individuals not exceed that which is presently accepted from current operations involving the same wastes follows from the requirement concerning the burden on future generations. It should be ensured that when the long-term risk predicted to arise from a waste disposal facility is compared to presently-accepted risks, a similar set of scenarios, critical groups and overall assumptions are used, so that artificial differences between predictions of consequences for today's practices and those in the future are avoided.

5. GUIDELINES FOR APPLICATION OF THE BASIC RADIOLOGICAL REQUIREMENTS

5.1 Identifying the Individual of Concern

> *The individual risk requirements in the long term should be applied to a group of people that is assumed to be located at a time and place where the risks are likely to be the greatest, irrespective of national boundaries.*

The concept of the critical group is commonly employed when applying individual dose limits to members of the public affected by existing nuclear facilities. This concept involves the identification of a relatively homogeneous group of people that is expected to receive the greatest exposure because of its location, age, habits and diet. Owing to the conservative assumptions usually made in selecting critical groups and in defining their lifestyles, the doses actually received by members of the group will in most cases be lower than the estimated mean dose of the critical group. It follows that doses to individuals outside the critical group are even lower.

When considering potential exposures in the future, the precise identification of critical groups and their lifestyles is not possible because of uncertainties about population distributions, living habits, climate and other aspects of the environment. In these circumstances, the individual risk requirements in the long term should be applied to a critical group of people that is assumed to be located at a time and place where the risks are likely to be the greatest regardless of national boundaries. This ensures that individuals beyond the national border are afforded a level of radiation protection at least as stringent as the level afforded residents of Canada.

Definition of the lifestyle of the hypothetical group of people should be based on present human behaviour using conservative, yet reasonable, assumptions. Similarly, the diet and metabolic characteristics of the group should be based on present knowledge, making the assumption that the basic dietary requirements of future individuals will be the same as those of people at present.

5.2 Probabilities of Exposure Scenarios

> *The probabilities of exposure scenarios should be assigned numerical values either on the basis of relative frequency of occurrence or through best estimates and engineering judgements.*

In order to apply the risk requirements it is necessary to express the probabilities of exposure scenarios quantitatively. While the term "probability" is usually defined in terms of relative frequency of occurrence, the conventional system for assigning probabilities breaks down as the frequency of occurrence decreases, since little information exists on which to base predictions. Low probability exposure scenarios should therefore be assigned values through best estimates and engineering judgements. These values can be determined using a subjective probability approach in which a number is assigned to the likelihood of an event occurring in a defined period of time, as a measure of the degree of belief that the event will actually occur during that time. The assignment should be made using quantitative analytical techniques to assess as broad a base of expert opinion as reasonably possible. The use of subjective probability is appropriate as long as the quantitative values assigned through best estimates and engineering judgements are consistent with the quantitative values of the actual relative frequencies in situations where more information is available. The uncertainty of the probability assigned should also be estimated.

5.3 Timescale of Concern

> *The period for demonstrating compliance with the individual risk requirements using predictive mathematical models need not exceed 10,000 years. Where predicted risks do not peak before 10,000 years, there must be reasoned arguments that beyond 10,000 years the rate of radionuclide release to the environment will not suddenly and dramatically increase, and acute radiological risks will not be encountered by individuals.*

Demonstration that a radioactive waste disposal facility complies with the individual risk requirements can only be done by forecasting future impacts using predictive mathematical modelling techniques. In any assessment of the performance of waste disposal options there are several general sources of uncertainty associated with parameter values, the mathematical models and the specification of environmental pathways and exposure scenarios. In general, these uncertainties will increase as the period of prediction increases. On the other hand, the uncertainties are partially offset in that the potential hazard associated with radioactive wastes usually decreases with time owing to radioactive decay of the source, unlike the potential hazard from many types of toxic chemical wastes which do not decay.

In view of the increasingly speculative and uncertain environmental conditions that might exist in the future, estimates of individual risk in the far future may be subject to considerable error, given that environmental modelling is a key part of risk assessment. For example, if severe changes in global climate were to occur, the human environment would also drastically change from that which exists today. It is therefore considered appropriate for regulatory decision-making purposes to establish an upper bound on the timespan for individual risk calculations.

Selection of an upper bound, however, is a matter of judgement since there does not appear to be any objective way of limiting the assessments in a scientifically satisfying manner. Taking into account the characteristics of radioactive wastes, the options for their disposal, and the uncertainties in long-term predictions, it is considered that 10,000 years after the time of waste emplacement is a reasonable maximum period for assessments of individual risk.

For some waste types and disposal options, shorter time periods than 10,000 years for predictive modelling are all that are necessary. This is particularly true where radioactive decay or radionuclide release and dispersion are predicted to occur to the extent that risks to individuals are clearly on the decline. For other situations, assessments may show that the predicted risks to individuals do not peak before 10,000 years. This might occur where long-lived wastes are contained and isolated in geological formations that are relatively unaffected by natural surface phenomena and that are likely to remain stable over extended timescales. In these cases, there must be reasoned argument leading to the conclusion that beyond 10,000 years sudden and dramatic increases in the rate of release to the environment will not occur, acute doses will not be encountered by individuals and that major impacts will not be imposed on the biosphere.

To put the maximum period of 10,000 years for assessment into perspective, it should be recognized that a number of experts believe that the next glacial episode will commence as early as several to tens of thousands of years from now. In the event of glaciation, it can be expected that near-surface wastes in Canada will be dispersed and diluted in the environment by the movement of ice sheets. It is also reasonable to assume that humans would avoid a heavily glaciated region during an ice age although they would likely repopulate the region when glaciers recede many thousands of years later. Wastes at greater depth will be less affected by glaciation, depending on their depth below the surface and the nature of the geological host formation. For example, the evidence suggests that a deep geological repository for nuclear fuel wastes in hard crystalline rock would not be breached by the erosional effects of glaciation, although the regional groundwater flow system would likely be modified.

5.4 Output From Predictive Modelling

Calculations of individual risks should be made by using the risk conversion factor of 2 x 10^{-2} per sievert and the probability of the exposure scenario with either:

(a) the annual individual dose calculated as the output from deterministic pathways analysis; or*

(b) the arithmetic mean value of annual individual dose from the distribution of individual doses in a year calculated as the output from probabilistic analysis.

There are two general approaches to mathematically modelling the long-term performance of waste disposal facilities, but it must be recognized that in either the deterministic or the probabilistic approach the results can only represent an approximation of the consequences, were releases of radionuclides to occur. Confidence in the modelling output must then derive from a thorough examination of the assumptions, input data and mathematical models constructed to represent the release and transport of radionuclides and the subsequent exposure of individuals. Such an examination can be accomplished by a combination of several complementary methods. These include:

(a) the use of an appropriate quality assurance program in the development, application and maintenance of computer models and in the gathering, interpretation and incorporation of data;

(b) the use of experimental laboratory and field techniques for the validation of models and parameter values to the extent possible;

*dose means the effective dose equivalent committed per year of exposure

(c) peer review by independent experts; and

(d) intercomparison of various modelling approaches.

In the traditional deterministic approach, a single value for each of the model parameters is selected from a range of input values to produce a single value of model output, usually in terms of annual individual dose which is the consequence of primary interest. When using this technique, conservative assumptions are usually made to compensate for the uncertainty in modelling and to ensure that the calculations overestimate the potential doses from possible releases from a facility. Excessive conservatism however is not to be used and a balanced choice of assumptions is to be made to ensure that the overall assessment describes reasonable situations encompassing the full spectrum of exposure pathways, and assesses their impacts in a rational manner. Where complex systems are being modelled, sensitivity analyses should be conducted to investigate the effect of changes in the values of model parameters on the magnitude of the dose estimate, particularly when the estimated dose is judged to be significant. Comparisons with the risk requirements are then straightforward provided that the probabilities of exposure scenarios have been properly assigned.

Another approach now available involves probabilistic assessment techniques in which each parameter value is randomly selected from its probability distribution for input to the model. By repeating the analysis many times, a distribution of consequences is obtained which represents the spread and variation of outcomes as a result of variability and uncertainty in input parameter values for a particular scenario. This approach has certain advantages over the traditional deterministic approach by providing more information. A frequency distribution of individual dose will usually display a most probable dose value and a maximum dose value in the high-tail extremity of the distribution and thus it is necessary to specify a means of comparing the output to the risk requirement. In this case, the arithmetic mean value of the distribution should be calculated and should be taken as being representative of the consequences predicted for an exposure scenario, such as that involving groundwater transport of radionuclides to the environment. In the same way as for deterministic assessments, sensitivity analyses should also be conducted to investigate the effect of changes in input assumptions and model parameters on the mean value of dose. The latter should then be combined with both the probability of the exposure scenario and the risk conversion factor for comparison with the individual risk requirements.

By calculating the arithmetic mean value of the frequency distribution of dose, the significance of the extreme values may be overlooked. Since some of these could conceivably result from combinations of reasonable parameter values, this would clearly be undesirable even though the fact that such combinations generate consequences in the tail-end of the distribution is indicative that their relative frequency of occurrence is low. Nonetheless, the relative frequencies of occurrence of high consequences may differ significantly between frequency distributions having the same mean value. An additional criterion appears to be needed to help judge the acceptability of an option for which probabilistic environmental pathways analysis calculates high doses, albeit with a low relative frequency. It is judged acceptable to allow 5% of the estimated doses to exceed a dose of 1 mSv per year to take account of normal statistical variations which are inherent in the probabilistic assessment process. However the choice of the general risk requirement takes account of this since a 5% occurrence of a dose of 1 mSv corresponds to an average dose of 0.05 mSv. If more than a 5% level of occurrence is predicted at 1 mSv or higher doses, then the criterion for the arithmetic average itself cannot be met. Thus for the numbers chosen in this regulatory policy statement a secondary requirement is not specifically needed but is implied and needs to be specifically addressed in proposals.

5.5 Optimization

> *When an optimization study is required in accordance with Section 4.3.2, it should take account of all relevant radiological and non-radiological factors.*

The ICRP principle that all exposures should be as low as reasonably achievable, taking social and economic factors into account, may be regarded as being generally applicable. However, for the purposes of this regulatory document it is to be applied only to the disposal of radioactive wastes where the general risk requirement is not likely to be met and thus where continuing long-term institutional controls are necessary. In other cases, the risk limit is sufficiently low to be the primary requirement with optimization playing at most a secondary role to help guide broader choices between options. Application of the optimization principle is intended to ensure that all reasonable or practical opportunities to reduce doses are explored in a broad way. The factors to be considered may include both radiological and non-radiological aspects, human health and environmental protection, as well as a broad range of social and economic issues. For example, it is appropriate to consider both public and worker risks associated with each step of the sequence of activities involved in waste disposal and not simply the risks to individuals in the long term. Also it may be necessary to weight some factors to take account of preferences such as might apply to spatial and temporal distributions of risk and other radiological parameters. Some non-radiological factors include, but are not limited to, conventional safety, environmental impacts, transportation, the nature and length of any institutional controls and the susceptibility of disposal options to naturally occurring disruptive events and to human intrusion. Some of these factors will not be amenable to rigorous quantification and thus a full optimization study will require the use of considered judgement. There are various techniques which can help structure this type of analysis so that the choices which need to be made are clear and the rationale for each choice can be fully documented. Generally, optimization in this broad sense does not result in clear or unambiguous choices between disposal options in the long term. It is for this reason, and the fact that the general risk requirement is so low, that optimzation has not been given a prominent role in this document.

CRITERES DE SURETE POUR LE STOCKAGE DE DECHETS RADIOACTIFS EN FORMATION GEOLOGIQUE PROFONDE

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RESUME : La France a engagé un programme de travaux en vue de disposer vers l'an 2010 d'un centre de stockage de déchets radioactifs en formation géologique profonde. Parallèlement au déroulement des études de conception, il est nécessaire de préciser les critères de sûreté qui permettront d'évaluer la sûreté du stockage. Cette communication présente un projet de réglementation précisant les critères de sûreté après fermeture du stockage. Après le rappel d'un certain nombre de principe de base (par exemple : défense en profondeur), elle présente les objectifs de radioprotection, puis des considérations concernant les différentes barrières et les principes relatifs à la démonstration de sûreté.

ABSTRACT : France has engaged a process to select a site and to build a deep geological repository for the high level and the transuranic radioactive wastes. Before licensing, it is necessary to establish safety criteria from which a judgement on the selected site and on the repository concept can be done. This paper presents safety criteria in the post closure phase. After recalling some basic principles (like defense in depth), it explains radiological criteria, then some safety related basic design of barriers, and principles dealing with safety assessment.

1 - Le contexte français

Dès le début des années 1980, la France a engagé un programme de sélection de sites favorables à l'implantation d'un stockage de déchets radioactifs en formation géologique profonde. Il a débuté par un inventaire des régions françaises susceptibles de présenter des structures géologiques intéressantes par élimination successive, compte-tenu des données disponibles, des zones pouvant présenter une possibilité d'instabilité à long terme et en recherchant les formations géologiques les plus homogènes et les plus imperméables.

En 1987, le Gouvernement a autorisé l'ANDRA (Agence nationale pour la gestion des déchets radioactifs) à effectuer des études plus approfondies sur quatre zones correspondant chacune à un matériau différent : l'argile (Aisne), le granite (Deux-Sèvres), le schiste (Maine et Loire) et le sel (Ain). Les travaux à effectuer comprennent des mesures géophysiques destinées à établir la cartographie structurale (profondeur, épaisseur et limites des couches de terrain, discontinuités éventuelles...) et des forages destinés, d'une part à reconnaître les conditions hydrogéologiques du milieu (études des écoulements d'eaux souterraines), d'autre part, à recueillir des échantillons et à confirmer les mesures géophysiques . Ils devront être poursuivis par une phase de qualification du site et par des expérimentations poussées dans un laboratoire souterrain situé à l'emplacement du futur stockage.

Toutefois, devant la forte opposition locale soulevée sur les sites, le Gouvernement a décidé en février 1990 de suspendre tous travaux sur le terrain pendant un an, ce délai étant mis à profit pour consulter deux commissions : le collège de la prévention des risques technologiques (Commission de "sages" placée auprès du Premier Ministre)et l'Office Parlementaire d'évaluation des choix scientifiques et techniques.

Seul le collège a rendu un premier avis dans lequel il confirme la nécessité du stockage en formation géologique profonde . En outre, il insiste sur la nécessité de rendre public les critères de sûreté applicables à ces installations, ce qui nécessite que le service central de sûreté des installations nucléaires (SCSIN) formalise l'ensemble des réflexions en cours dans une première règlementation.

Ces réflexions portent, en particulier, sur la méthodologie de l'analyse de sûreté appliquée au stockage profond et, compte tenu du rôle essentiel joué par le site, sur les critères de choix applicables. Pour ce dernier sujet, il faut rappeler les travaux du groupe présidé par le Pr Goguel qui ont permis de dégager et de hiérarchiser ces critères.

Pour ce faire, le SCSIN dispose d'un outil réglementaire qui s'appelle règle fondamentale de sûreté. Une règle fondamentale de sûreté définie dans un domaine technique donné, les objectifs de sûreté et les pratiques jugées satisfaisantes pour respecter ces objectifs.

Toutefois, un exploitant peut toujours ne pas utiliser les dispositions d'une règle fondamentale de sûreté, sous réserve d'apporter la preuve que les objectifs de sûreté visés par la règle sont atteints grâce à des moyens alternatifs qu'il lui appartient de proposer.

Cette forme de texte est particulièrement souple pour permettre de faire évoluer autant que nécessaire les dispositions qu'il contient pour tenir compte du progrès des connaissances.

Habituellement, une régle fondamentale de sûreté permet de formaliser le retour d'expérience dans un domaine particulier. Ainsi les RFS I.2 et III.2.e relatives aux critères de sûreté et aux conditions d'agrément des colis de déchets destinés au stockage en centre de surface ont été établis après qu'une expérience d'exploitation significative ait été acquise à partir du centre de stockage de la Manche, qui a été ouvert en 1969.

Par contre, on ne dispose pas encore d'une expérience significative de la sûreté d'un centre de stockage de déchets radioactifs en formation géologique profonde. Aussi, la règle en cours d'élaboration se doit d'être à la fois assez précise sur les principes et les bases de conception liés à sûreté et assez souple pour intégrer le progrès des connaissances concernant les propriétés et le comportement des éléments constitutifs du stockage.

2 - <u>Le contenu de la règle en projet</u>

La règle fondamentale de sûreté en cours d'élaboration contiendra :

a) <u>un certain nombre d'objectifs et de principes de base</u> en particulier les suivants :

a1 - La protection des personnes et de l'environnement constitue l'objectif fondamental assigné au centre de stockage de déchets en formation géologique profonde.

Elle doit être assurée envers les risques liés à la dissémination de substances radioactives dans toutes les situations considérées comme plausibles, sans dépendre d'un contrôle institutionnel au-delà d'une période limitée.

a2 - Le système de confinement de la radioactivité est constitué des trois barrières suivantes :

- <u>les colis de déchets</u>. Ils sont constitués en général d'une matrice dans laquelle les déchets sont incorporés, l'ensemble étant disposé dans un conteneur.

Pendant une période de temps limitée, le colis assure une rétention des radionucléides vis à vis de leur lixiviation par l'eau, dans certaines situations plausibles où l'efficacité des barrières ouvragées ou bien de la barrière géologique se trouverait localement affectée.

- les barrières ouvragées. Elles sont constituées des matériaux de rebouchage des cavités de stockage et des forages, de remblayage des galeries et de scellement des puits d'accès.

Elles sont destinées à combler les vides après mise en place des colis afin de réduire les pertubations du milieu aux plans mécanique et hydraulique et d'assurer un rétablissement approprié de l'isolement entre le stockage et la surface.

- la barrière géologique. Elle comprend les formations géologiques constitutives du site. Elle assure trois rôles essentiels :

. la protection du stockage à l'égard des agressions qui peuvent affecter la surface du sol,

. la protection des colis vis à vis des circulations éventuelles d'eaux souterraines,

. un confinement des radionucléides éventuellement relâchés par les colis de déchets et traversant les barrières ouvragées, soit en cas de défauts affectant précocement l'une ou l'autre de ces barrières, soit à l'issue de la période maximale durant laquelle les performances de ces barrières peuvent être garanties.

L'ensemble des barrières du système de confinement joue des rôles complémentaires, la barrière géologique assurant un rôle essentiel, en particulier à long terme.

a3 - Le concept retenu pour le centre de stockage devra permettre, par un choix et une qualification adéquats des barrières, de limiter l'impact radiologique à des niveaux aussi faibles qu'on puisse raisonnablement atteindre, compte tenu des facteurs économiques et sociaux.

La bonne qualité du choix ou de la conception et de la réalisation des barrières de confinement constitue le fondement de la sûreté du stockage.

a4 - Le concept multi-barrières a pour mérite de ne pas faire reposer la sûreté du stockage sur une barrière unique, dont la défaillance pourrait, à elle seule, compromettre gravement les deux rôles assignés au stockage :

- protéger les déchets en s'opposant à la fois aux circulations de l'eau au contact des déchets et à toute action humaine intrusive,

- limiter et retarder, pendant le délai nécessaire à une décroissance radioactive suffisante des radionucléides concernés, le transfert vers la biosphère des substances radioactives éventuellement relâchées par les déchets.

Toutefois, il serait complètement arbitraire de fixer a priori, pour des raisons de sûreté du stockage, des objectifs quantitatifs pour les performances de confinement des différentes barrières. De tels objectifs élémentaires ne pourront valablement être fixés qu'à l'issue d'un processus itératif, supposant une expérience suffisante de l'étude de la sûreté des stockages. L'histoire de la sûreté des stockages n'en étant qu'à la phase initiale de ce processus, une approche prudente s'impose, consistant à choisir ou concevoir chacune des barrières aussi efficace que raisonnablement possible compte tenu, d'une part de son rôle dans la sûreté globale du stockage, d'autre part de l'état des connaissances et des techniques disponibles.

La justification du bien fondé des choix et des bases de conception sera progressivement établie puis confortée, notamment en terme de performance des barrières, au fur et à mesure de l'acquisition des connaissances et de l'élaboration de la démonstration de sûreté du stockage. Des modifications et des compléments pourront d'ailleurs être apportés, à cette occasion, à certaines dispositions de sûreté si le besoin s'en fait sentir ou dans le cadre d'une meilleure optimisation des performances des barrières.

a5 - Au regard de la démonstration de la sûreté, il convient de s'assurer de la qualité des barrières. Des évaluations de l'impact radiologique seront effectuées pour s'assurer qu'il reste acceptable dans toutes les situations plausibles compte tenu de l'évolution normale du stockage et de l'éventualité d'occurence d'évènements aléatoires pertubateurs.

b) <u>Des objectifs de radioprotection</u>

Ceux-ci sont présentés et commentés dans le paragraphe 3 ci-dessous.

c) <u>Un certain nombre de bases de conception liées à la sûreté</u>

Ces bases de conception portent sur :

c1 - le colis

En particulier, il est considéré que la connaissance des caractéristiques des colis de déchets en cours de fabrication ou dont la fabrication est prévue est nécessaire pour que l'on puisse apprécier leur qualité, disposer de données pour la conception du stockage et la démonstration de sa sûreté et adapter éventuellement l'architecture du stockage et des barrières ouvragées aux caractéristiques des colis concernés.

Tout producteur de colis de déchets destinés à un stockage en formation géologique profonde doit donc réaliser, d'une part des essais de caractérisation, d'autre part des mesures ou évaluations sur les colis produits. Ces essais, mesures et évaluations ont pour but :

- de déterminer les caractéristiques radioactives des colis de déchets, en particulier leur contenu radioactif,

- de connaître le contenu chimique des colis de déchets,

- de connaître les quantités de gaz produits,

- d'évaluer les caractéristiques physiques des colis de déchets,

- de connaître les propriétés des colis, notamment celles associées à leur capacité initiale de confinement de la radioactivité, et la pérennité de celles-ci :

  . taux de lixiviation par les eaux souterraines,
  . taux de dégazage,
  . tenue mécanique dans des conditions de pression représentatives des stockages,
  . effets d'interactions chimiques (déchets/matrice, déchets ou matrice/matériaux des barrières ouvragées...),
  . effets thermiques (températures maximales admissibles, gradients de température maximaux admissibles),
  . irradiation alpha ou bêta-gamma,
  . micro-organismes.

Par ailleurs, des études de comportement à long terme des déchets en présence des différentes agressions susceptibles de les affecter (interactions notamment avec les matériaux des barrières ouvragées et avec la roche, effets de rayonnements ou des micro-organismes) doivent être effectuées.

c2 - Les barrières ouvragées, dont le rôle principal et les objectifs complémentaires seront précisés.

En particulier, on distingue deux types de barrières ouvragées :

- les barrières dites de voisinage ont pour rôle d'assurer le comblement des vides entre les colis et la roche d'accueil.

- les barrières dites de remplissage ont pour rôle de rétablir au mieux l'isolement entre la zone de stockage et la surface.

Dans le choix des barrières ouvragées de voisinage, il conviendra de tenir compte des caractéristiques au regard des fonctions suivantes :

- évacuation de la chaleur dégagée par les déchets ,
- amortissement des contraintes mécaniques initiales ,
- comportement physico-chimique au regard de la corrosion des conteneurs et de la migration des radionucléides.

Les barrières ouvragées de remplissage devront avoir une qualité et une longévité en rapport avec celles de la barrière qu'elles sont censées restaurer et fonction des conséquences sur la circulation de l'eau dans le stockage que leur défaillance engendrerait.

Par ailleurs, il convient de tenir compte, dans les études de conception du stockage du devenir et de l'influence des volumes d'air et de gaz enfermés dans les ouvrages, notamment l'air contenu dans le matériau de remplissage ainsi que les gaz produits par radiolyse, corrosion et effets des micro-organismes.

c3 - La barrière géologique

Les critères de choix de site proposés par le rapport Goguel seront rappelés.

c4 - Le concept de stockage

Il est en particulier considéré que :

- dans les milieux cristallins, l'implantation devra se situer au sein d'un bloc-hôte exempt de grandes failles, celles-ci pouvant constituer des secteurs de circulation hydraulique privilégiée. Les modules de stockage devront se faire à l'abri de la fracturation moyenne, celle-ci pouvant être traversée par les ouvrages d'accès.

- dans les milieux sédimentaires, l'implantation du stockage doit se situer au sein d'une couche exempte de grandes hétérogénéités, à une distance suffisante des aquifères sus et sous-jacents.

- la présence des déchets et des matériaux de remplissage ne doivent pas affecter significativement les propriétés des barrières de confinement.

- les pertubations résultant du creusement des ouvrages doivent être réduites au minimum, la conception et l'implantation des puits d'accès devront permettre de limiter le risque de circulation artificielle des eaux.

d) Des principes relatifs à la démonstration de la sûreté

L'évaluation de la sûreté post-fermeture doit notamment porter sur les trois aspects complémentaires suivants :

- justification du niveau de qualité de chacune des barrières de confinement, c'est-à-dire des caractéristiques favorables, et du concept de stockage vis-à-vis de la sûreté globale du stockage,

- évaluation déterministe des pertubations apportées par la création du stockage et vérification que ces perturbations restent acceptables vis à vis du niveau de qualité choisi pour chacunes des barrières, en particulier de la barrière géologique,

- évaluation du comportement futur du stockage et vérification que le risque radiologique associé est acceptable. L'approche retenue est déterministe. Cela conduit à étudier un nombre limité de scénarios représentatifs des différentes familles d'évènements ou séquences d'évènements et tels que les conséquences associés soient les plus élevées parmi celles des situations de la même famille. Cette approche enveloppe repose sur une sélection d'évènements considérés comme envisageables dans l'ensemble des évènements a priori possibles.

Les scénarios à considérer seront présentés, en distinguant :

- le scénario de référence, "normal" ou "central", constitué des évènements ou processus certains (ou quasi-certains), qui traduit la situation évolutive "normale" du système,

- les scénarios à évènements aléatoires, "altérés", faisant intervenir des évènements ou des processus dont la date d'occurence, l'intensité ou même la loi de fréquence sont beaucoup plus incertaines.

Certains principes seront définis relatifs :

- au choix des modèles : il est important que les représentations simplifiées ne laissent pas de côté des phénomènes importants, et que les simplifications des phénomènes aient un caractère suffisamment conservatif. L'ensemble des simplifications effectuées devra être justifié.

- à la validation des modèles : un soin particulier devra être porté à la validité des modèles et des données. Pour cela, il sera en particulier nécessaire de participer à des exercices d'intercomparaison de modèles.

e) **des considérations relatives à l'assurance de la qualité**

3 - Objectifs de radioprotection

- Pour les besoins de la conception du stockage, la règle prévoit de se référer aux recommandations de la CIPR 46 en ce qui concerne les limites de radio-exposition.

On distinguera pour apprécier le caractère acceptable des conséquences radiologiques l'évolution normale du stockage des situations engendrées par des évènements pertubateurs aléatoires.

a) Situation de référence : Evolution normale du stockage

- La CIPR 46 recommande que les équivalents de dose individuels soient limités à 1 mSv/an pour des expositions prolongées liées à des évènements certains ou quasi-certains.

- Les prévisions d'impact radiologique peuvent se fonder sur une modélisation de l'évolution du stockage, en particulier des barrières et sur une simulation de la circulation des eaux souterraines. Toutefois, les incertitudes des prévisions vont croître avec le temps, et notamment lorsqu'on ne pourra plus considérer l'état de la barrière géologique comme invariant.

- Pour la période durant laquelle la stabilité de la barrière géologique peut être assurée moyennant une marge d'évolution acceptable (période qui doit être au moins égale à 10 000 ans*), on peut raisonnablement estimer que la valeur des résultats des prévisions pourra être attestée de façon objective, notamment sur la base d'études d'incertitudes explicites. La limite précédemment citée sera retenue pour juger du caractère acceptable des conséquences radiologiques.

- Au delà de cette période, les incertitudes sur l'évolution normale du stockage croissent ; l'activité des déchets aura notablement décru. Des estimations quantifiées des conséquences radiologiques seront faites dans toute la mesure du possible, et seront éventuellement complétées, par des appréciations plus qualitatives des résultats de ces estimations, au regard des facteurs d'évolution de la barrière géologique, de façon à vérifier que le relâchement des radionucléides ne conduit pas à un impact radiologique inacceptable. Dans cette vérification, la limite précedemment citée sera conservée comme référence mais l'appréciation du caractère acceptable des conséquences radiologiques reposera dans une large mesure sur la pertinence des appréciations précitées.

*Voir rapport Goguel. En tout état de cause la période de stabilité de la barrière géologique devra être estimée sur la base des résultats des études géologiques menées sur le site.

b) Situations engendrées par des évènements pertubateurs aléatoires

Certains évènements aléatoires peuvent pertuber l'évolution du stockage et éventuellement conduire à des conséquences radiologiques plus élevées que celles associées à l'évolution normale du stockage.

Dans la prise en compte de ces évènements, il peut être envisagé de faire appel, comme préconisé par la CIPR, au principe d'un niveau de risque acceptable en faisant intervenir la valeur des conséquences radiologiques et la probabilité des évènements qui y conduisent, lorsqu'il est possible de l'évaluer.

En tout état de cause, le caractère acceptable des conséquences radiologiques associées à des scénarios à évènements aléatoires sera apprécié en tenant compte du choix des scénarios (exhaustivité, caractère majorant, durée et nature des relâchements de substances radioactives dans la biosphère, caractéristiques des voies d'atteinte de l'homme).

OBJECTIVES AND CRITERIA FOR THE DISPOSAL OF HEAT-GENERATING RADIOACTIVE WASTE IN THE FEDERAL REPUBLIC OF GERMANY

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ABSTRACT

In the Federal Republic of Germany heat-generating radioactive waste is intended for disposal in the Gorleben repository. The planning and construction of this facility as well as its operational and post-operational phase must reckon with safety issues. The existing Safety Criteria for the Disposal of Radioactive Wastes in a Mine are outlined. Emphasis is given on radiation protection and safety criteria regarding the post-closure phase of the planned Gorleben repository. The respective criteria and approaches to their practical application are discussed.

1. INTRODUCTION

In the Federal Republic of Germany two repository projects are planned. In the abandoned Konrad iron ore mine it is intended to dispose of such radioactive waste which has a negligible thermal influence upon the host rock, i. e. the host rock temperature must not be increased by the waste packages by 3 K on average [1]. The Gorleben salt dome is at present investigated for its suitability for the disposal of all kinds of solid and solidified radioactive waste including especially the emplacement of heat-generating waste, i. e. high level radioactive waste such as fission products solutions, hulls and ends, and fines [2]. Beyond this, the disposal of non-reprocessed spent fuel elements must be taken into consideration.

The Bundesminister für Umwelt, Naturschutz und Reaktorsicherheit (BMU - Federal Minister of Environment, Nature Protection and Nuclear Safety) is the competent authority for all aspects of radioactive waste management, and is the supervisory body for the licensing authorities in the federal states. Acting on behalf of the Federal Government, the Bundesamt für Strahlenschutz (BfS - Federal Office for Radiation Protection) has been charged by law as the competent authority for construction and operation of federal installations for the long-term storage and disposal of radioactive waste [3]. In this respect, the BfS is supervised by the BMU.

2. LEGAL PRINCIPLES

The disposal of radioactive waste in deep geological formations is in particular governed by the following specific acts and regulations:

- Atomgesetz (Atomic Energy Act) of 1976,
- Strahlenschutzverordnung (Radiation Protection Ordinance) of 1989,
- Bundesberggesetz (Federal Mining Act) of 1980,
- Sicherheitskriterien (Safety Criteria) of 1983.

The protection objectives of radioactive waste disposal in a repository are prescribed by the Atomic Energy Act and the Radiation Protection Ordinance. The Federal Mining Act regulates all aspects concerning the operation of a disposal mine. The Safety Criteria specify the measures to be taken in order to achieve the objective of disposal.

The legal competences for the licensing of the construction and operation of a repository are regulated in such a way that two procedures must be performed: the procedure under atomic law on the one hand and the procedure under mining law on the other. For the establishment of a repository, pursuant to article 9b of the

Atomic Energy Act, the initiation of a plan-approval procedure, i. e. a special kind of a licensing procedure, has to be applied to the respective licensing authority of the federal state [4]. The BfS is the authorized applicant.

3. SAFETY CRITERIA

The objective of radioactive waste disposal in repositories is to ensure that wastes are handled and stored in such a way that the protection of man and environment from harm caused by the ionizing radiation of these wastes is guaranteed. The basic aspects which must be taken into account to achieve the protection objective for disposal are compiled in the Sicherheitskriterien für die Endlagerung radioaktiver Abfälle in einem Bergwerk (Safety Criteria for the Disposal of Radioactive Wastes in a Mine) announced by the Bundesminister des Innern (BMI - Federal Minister of the Interior) in 1983 [5] due to a recommendation of the Reaktor-Sicherheitskommission (Reactor Safety Commission) in 1982 (Note: The Federal Minister of the Interior was responsible for nuclear safety in the Federal Republic of Germany at that time). Their scope implies all kinds of radioactive waste to be disposed of.

The safety criteria qualitatively specify the measures to be taken in order to achieve the protection objective of disposal and define the principles by which it must be demonstrated that this objective has been reached. The importance of the site selection, the system consisting of geology/repository/waste packages, the multibarrier concept, and the use of state-of-the-art technology are emphasized. In detail, the safety criteria comprise the following items:

- introduction,
- protection objectives,
- measures to achieve the protection objectives,
- site requirements,
- prerequisites for construction and operation of a repository,
- site exploration,
- construction and operation,
- radioactive wastes,
- decommissioning,
- post-operational phase.

Of this, three criteria are considered to be the most important ones:

- The required safety of a repository constructed in a geological formation must be demonstrated by a site-specific safety assessment which includes the respective total geological situation, the technical design of the disposal mine including its anticipated mode of operation and the waste packages intended to be disposed of.

- The protection objectives for the operation of a repository are prescribed by the Atomic Energy Act and the Radiation Protection Ordinance. Beyond these all other pertinent regulations are to be reckoned with.

- In the post-operational phase, the radionuclides which might reach the biosphere via the water path as a result of transport processes not completely excludable must not lead to individual dose rates which exceed the limiting values specified in section 45 para. 1 of the Radiation Protection Ordinance (0.3 mSv/a concept).

The safety criteria permit a certain latitude of judgement. Such margins gradually diminish in the realization of a repository project. This process is predominantly determined by a site-specific safety assessment within the scope of which the required safety of a repository must quantitatively be demonstrated including the derivation of requirements on the design of the facility as well as on the waste packages to be disposed of.

Nevertheless, the protection objective can only be achieved by an iterative process drawing together more and more detailed information obtained as the respective repository project progresses through its various phases of investigation, planning, detailed design and performance assessment, thus assuming more and more concrete forms.

4. THE GORLEBEN REPOSITORY PROJECT

4.1 The disposal concept

Since the early sixties, the radioactive waste disposal policy in the Federal Republic of Germany has been based on the decision that all kinds of radioactive waste are to be disposed of in deep geological formations. In particular, this includes heat-generating waste from reprocessing and spent fuel elements (if declared as a waste). Such a decision is only realistically acceptable if a barrier to radionuclide migration exists which remains effective over very long periods of time radionuclides need to decay significantly.

4.2 Site selection

In February 1977, the State Government of Lower Saxony designated Gorleben as a provisional site of the formerly waste management centre including a disposal mine. The selection of this site for the construction and operation of a repository was especially based on screening investigations using the knowledge on salt domes at that time.

According to the safety criteria [5], host rock and overburden must contribute to the delay or the hindering of inadmissible radionuclide releases getting into the biosphere. Hence, a high sorption capacity for radionuclides is favorable to fulfill the barrier function of host rock and overburden.

4.3 Preliminary design of the repository

As the underground exploration of the Gorleben salt dome is still to be carried out, the existing conceptual design of the repository depends on model assumptions [2]. Thus, it will be necessary to adapt the final layout of this facility at the end of the underground investigations.

The planned Gorleben repository is designed according to general salt mining experiences. The driving of drifts, galleries and disposal rooms is to be performed with techniques identical to those currently used in salt mining operations. According to the safety criteria [5] only well-tried and proven mining methods as well as state-of-the-art technology are to be used. The main objective is to optimize safety aspects versus other repository requirements.

At present, a disposal mine at a depth of about 870 m has been planned. A possible second emplacement level (disposal rooms) is intended at a depth of about 900 m [2]. According to the safety criteria [5] the number of shafts is to be kept to a minimum, although at least two shafts are necessary for transport, ventilation and safety reasons. The shafts are located in the centre of the underground facilities still to be mined. Their distance is about 500 m; no waste packages will be disposed of within a safety pillar of 300 m around them. The underground exploration of the salt dome's interior will be performed about 30 m above the later emplacement level; later on the exploration drifts are intended to be used for ventilation purposes (return air).

Radioactive waste with negligible heat generation is planned to be emplaced in disposal rooms with a cross-section of about 40 m^2 and a length of about 200 m using the stacking technique. The heat-generating radioactive waste is planned to be disposed of in vertical boreholes about 300 m to 600 m deep. This emplacement technique makes use of the probably more vertical extension of the Halite body in the salt dome and the fact that small boreholes will converge in relatively short times due to the heat generation of the respective waste packages. Furthermore, besides handling problems, the emplacement of heat-generating waste packages in disposal rooms or drifts would cause a probably inadmissible thermal impact upon the host rock.

The thermal layout of the repository is based on a maximum temperature of 200°C at the surface of the vitrified fission product solution and 100°C for cemented hulls and ends as well as fines [6]. This limitation resulted from the chemical resistance of glass in brines and the cement properties, respectively.

In the case of direct disposal of spent fuel, two possibilities are discussed at present. On the one hand spent fuel elements in thick-walled self-shielding casks are intended to be emplaced in galleries. On the other hand spent fuel elements in specially designed packagings are intended to be emplaced in vertical boreholes.

With regard to the planned transport, handling and emplacement concept for the Gorleben repository, a standardization of packagings for radioactive waste and spent fuel was performed [6]. It covers the external dimensions of the packagings and the fittings for attachment.

In consideration of safety requirements, the emplacement of waste packages will be done in retreat work from the boundaries of the emplacement fields in direction to the shafts. Backfilling, plugging and sealing of disposal rooms, boreholes and emplacement fields as well as of both shafts is considered as one of the most important engineered safety measures.

4.4 Site-specific safety assessments

Pursuant to the safety criteria [5], the safety of the planned Gorleben repository must be proved within the scope of a site-specific safety assessment. On the basis of such an assessment covering the total geological and hydrogeological situation, the technical design of this facility including its anticipated mode of operation and the waste packages intended to be disposed of, the safety of the Gorleben repository in the operational and post-operational phase has to be demonstrated. The site-specific safety assessment to be carried out comprises the normal operation of the planned facility, assumed incidents, the thermal influence upon the host rock, the criticality safety and the long-term safety in the post-operational phase.

The results of the safety assessment will have to be converted into both the design of the surface and underground facilities of the repository and a system of preliminary waste acceptance requirements. In this connection aspects on a possible limitation of gas generation rates due to corrosion processes and radiolysis and aspects on safeguards will have to be considered. Final waste acceptance requirements will be formulated at the end of the plan-approval procedure.

The aboveground investigation of the Gorleben site is finished. In March 1986 the underground exploration of the salt dome's interior was started by sinking two shafts. The termination of the underground investigations and an evaluation of the Gorleben salt dome's suitability for disposal of all kinds of radioactive waste may be expected at the end of the nineties.

Thus, all existing assessments of the Gorleben site are based on model data and assumptions on the geology, the design of the repository and the radioactive wastes to be disposed of [6]. Only the calculations of the long-term safety, to some extent, include results of the hydrogeological investigations. Therefore nothing but weak points could be identified at this preliminary stage. All these assessments will have to be updated after the termination of the underground exploration.

5. RADIATION PROTECTION AND SAFETY CRITERIA IN THE POST-OPERATIONAL PHASE

5.1 Legal background

The radiation protection objectives for a repository are prescribed and quantified in the Strahlenschutzverordnung (Radiation Protection Ordinance). According to the revised ordinance of 1989 [7],

- section 28 para. 1 states that the radiation exposure has to be kept as low as possible,

- section 45 para. 1 states that the radiation exposure for individuals arising from the respective facility under consideration is to be limited, i. e, to 0.3 mSv/a (effective dose rate) and to 0.9 mSv/a (organ dose rate), being the sum of all relevant exposure pathways, respectively.

Thus, regulatory dose limits have been set which must be complied with. Evidence of this protection objective, according to the safety criteria [5], must be demonstrated within the long-term safety assessment. By this means, possible radiation exposures to individuals will be kept within the variability of normal dose rates. Nevertheless, such a procedure is only reasonable for periods of time for which changes in the geological barriers and in man's environment can still be forecast with sufficient reliability.

5.2 Time periods for long-term safety assessment

According to the common statement of the Reaktor-Sicherheitskommission (Reactor Safety Commission) and the Strahlenschutzkommission (Radiation Protection Commission), given on behalf of the BMU within the scope of the plan-approval procedure for the Konrad repository, the long-term safety assessment covering the calculation of individual doses is limited to time periods in the order of 10000 years [8]. Beyond this time period, i. e. up to 1000000 years, the isolation potential of the geological system of the chosen site may be assessed. This allows adequate safety margins.

5.3 Approach to practical application

To ensure the long-term safety of the planned Gorleben repository including the prove that, i. e., the individual dose limits of 0.3 mSv/a or 0.9 mSv/a are complied with [7], any possible release of radionuclides via the water path must be assessed and the respective dose rates be calculated. For this purpose it is necessary to determine all the relevant basic data required for the performance of the long-term safety assessment.

Within the scope of such an investigation, the release and transfer of radionuclides from the waste packages to the biosphere have to be treated in model calculations and basically be carried out in the following steps:

- determination of the boundary conditions,
- identification of a model scenario including the determination of the model area,
- modelling the migration of radionuclides,
- calculation of radiation exposure rates.

This procedure is in agreement with the safety criteria [5] according to which the release of radionuclides has to be dealt with.

5.4 Preliminary long-term safety assessment

Detailed knowledge of the interior of the Gorleben salt dome will only be available after its underground exploration. Possible incidents are therefore conservatively considered in theory for the long-term safety assessment. It is assumed that thermomechanical effects caused by heat-generating radioactive wastes can produce new pathways for waters in the anhydrite horizons in the post-operational phase of the repository (especially in the Hauptanhydrid). As a result of this, water from the ground-water-bearing overlying strata could intrude into the repository area. Contaminated brines could be released back into the overlying strata in the same way, due to the convergence of the rock salt [9].

In the overlying strata of tertiary, especially quaternary geological age, the sorption of radionuclides will then influence the migration of the radionuclides in the flow of ground-water. The intrusion of waters into the repository area, the release of contaminated water and the calculation of dose rates from these releases were investigated in a R+D study on the consequence of such a scenario [10]. Some of the main results of this investigation are

- that the intruding waters do not reach the disposal area for the vitrified fission products solutions because of the repository's thermal design,
- that the calculated dose rates in the environment are dominated by Np and Tc,
- that the highest dose rates occur about 10000 years after disposal,
- that the safety criteria [5] are fulfilled.

Recent results of the investigation into the sorption behaviour of radionuclides in Gorleben samples [11] have shown that the sorption data for Np and Tc in some of the natural systems, especially those with a low redox potential, are considerably higher than assumed in [10]. The dose rates of these radionuclides will therefore be of less importance.

6. DECOMMISSIONING AND POST-CLOSURE

6.1 Decommissioning

The planned Gorleben repository will be decommissioned after the operational phase. Parts of the underground facility, e. g. disposal rooms and boreholes filled with waste packages, will already be shut down during the operational phase. The decommissioning will be completed with the filling and sealing of both shafts.

Filling and closing off the mine openings have as a goal the increased stability by means of reduction of remaining voids, thereby delaying or hindering the access of transport media (e. g. water or brines) to the radioactive wastes, and minimizing an eventually possible radionuclide release to a permissible level. As to the safety criteria [5], these measures are the final contribution to the long-term safety of this repository.

6.2 Post-closure: monitoring the environment, documentation and marking

The safety criteria [5] require that construction, operation, and decommissioning of the repository are to be performed and monitored such that no particular control or monitoring programme is necessary in the post-operational phase.

Routinely performed, general environmental measurements as well as topographic measurements will give information on the radiology and the long-term thermo-mechanical behaviour of, e. g., the host rock and the overburden.

Data on the repository, the waste packages disposed of, and the essential technical measures taken during construction, operation and decommissioning should be documented. Complete documentation should be maintained at suitably separate locations.

A surface marker for the planned Gorleben repository is not necessary taking the normal environmental protection and topographical measurements into consideration. Knowledge of the site's location should be guaranteed sufficiently by the documentation.

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DEVELOPMENT ON CRITERIA FOR GEOLOGICAL WASTE DISPOSAL IN THE NETHERLANDS

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ABSTRACT

In the beginning of 1990 a project was started in the Netherlands to determine the position of the government on the question of whether and, if so, under what conditions, the deep underground may and can be used for waste disposal. This project is not restricted to radioactive waste. It also comprises other kinds of waste, like toxic and hazardous waste ("chemical waste"). According to the schedule of the project, the results will be available by the end of 1991.
This paper gives a global description of the state of the art. It deals with the history and the procedure of the project. Some aspects that seem to be more in discussion in the Netherlands than in other countries are also mentioned.
A description is given of Risk Management Policy in the Netherlands and its relation to geological waste disposal.

Development on criteria for geological waste disposal in the Netherlands.

o Introduction

In the beginning of 1990 a project was started in the Netherlands to determine the position of the government on the question of whether and, if so, under what conditions, the deep underground may and can be used for waste disposal. This project is not restricted to radioactive waste. It also comprises other kinds of waste, like toxic and hazardous waste ("chemical waste"). According to the schedule of the project, the results will be available by the end of 1991.

This paper deals under paragraph 1 with the history and the procedure of the project. Some Specific Aspects are dealt with under paragraph 2, followed by Risk Management in the Netherlands in paragraph 3.
The development of the governmental position is not yet completed. Consequently, the description of the aspects in paragraphs 2 and 3.2 must be seen as the state of the art of the discussions on these aspects.
The choice of aspects is restricted to some aspects that seem to be more in discussion in the Netherlands than in many other countries.

1.1 The History

Deep underground disposal of (radioactive) waste has been in discussion in the Netherlands for some decades. Untill now these discussions did not lead to a governmental position on the subject, nor to the setting of standards, criteria, etc. What did happen was that different bodies like interdepartmental advisory groups, research institutes and advisory bodies on environment and environmental research made recommendations to the government.

In 1984/1985 the government debated with Parliament on whether or not research should be carried out on the possibilities for deep underground disposal of radioactive waste in the Netherlands salt formations (the OPLA research programme). As a result the first phase of the OPLA-programme was carried out in 1985/1989. The results of this first phase were reviewed by a team of experts under the auspices of OECD/NEA and EC.

At the parliamentary debate of 1984/1985 it was decided to develop, independently of the OPLA-research, a set of criteria for deep underground disposal of radioactive waste.

In 1987 a public participation campaign was started to afford full possibilities for the public and organizations to have a say in the development of these criteria. The campaign was started with the publication of an Introductory Document, describing the problem, the different possibilities for the disposal of radioactive waste and related items. Scenario's and models for the prediction of risks were also dealt with, albeit only globally, together with different kinds of criteria and questions such as how to cope with uncertainties.

In practice, the campaign was not very satisfactory. The document appeared to be difficult to read, for many people access was not easy.
This led to an outcome of the procedure that was rather disappointing. There also were some causes of a political nature which should not be dealt with here, however.
The primary decision - as a first reaction on this result - to revise the document in consultation with different institutes, among which environmental groups, was recalled and ultimately it was decided to start an entirely new project.

1.2 The Procedure

In the beginning of 1989 the Netherlands government published the National Environmental Policy Plan (NEPP)[1].
The NEPP explicitly described concrete measures to be taken in the period 1990-1994, but it emphatically focused on the long term. It set the course to be followed by environmental policy until 2010.
At the same time and as one of the elaborations of the NEPP the document "Premises for Risk Management, risk limits in the context of environmental policy" was published.

One of the points of action of the NEPP is this project to reach at a governmental position on the question of whether and, if so, under what conditions, the deep underground may and can be used for waste disposal. The project will be related to the policy outlined in the document "Premises for Risk Management" as closely as possible.

As contrasted with the previous procedure, there will be no public participation campaign this time.
Instead four organizations are invited to participate and to give their points of view on specific questions that were pointed out and elucidated in a short Consultative Document.

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[1] "Kiezen of Verliezen" (to Choose or to Lose); Second Chamber of the State General, 1988-1989, session 21137, nos. 1-2.

These organizations are:

- o the Association for Nature and Environment
- o the Society for Environmental Sciences
- o the Society of the Dutch Chemical Industry
- o the Association of Co-operating Electricity Producers

They are supposed to represent the views of respectively:
nature and environment protection organizations,
the scientific aspects of environmental protection,
manufacturers of chemicals ("chemical waste"), and
the electricity-producing industry ("radioactive waste").

According to the time-schedule of the procedure the points of view of these organizations will be available in the beginning of 1991. After that, discussion-meetings will be held between the the organizations and the ministry. Based on that a concept of the governmental position will be drafted, which will be sent to the National Council for Environmental Protection to ask for their advice. After reception of this advice the governmental position will be sent to Parliament by the end of 1991.

2 Some Specific Aspects

2.1 The Consultative Document

In the consultative document, the question to be dealt with in this project has been placed in the framework of today's waste situation and waste policy in the Netherlands. The first premise in waste policy is prevention. Recycling comes next, followed by waste-processing and the last option in the sequence is final disposal.
The consultative document starts from the point that even when prevention, recycling and processing are stimulated as far as possible, there still will remain a considerable amount of waste that has to be disposed of.

The conventional methods for disposal of non-processable, non-radioactive waste in the Netherlands are incineration and land burial.(For radioactive waste a final disposal option has not been chosen yet, this waste goes to long term interim storage for a period of 50-100 years.)
Land burial is practised near the earth's surface, that is to say in shallow land burial; the technical conditions for preventing environmental pollution are determined by the nature of the waste.
Land burial in the Netherlands has to meet the requirements laid down in the so-called ICM-criteria:
Isolate, Control and Monitor.

2.2 The ICM-criteria

These criteria mean:

- o Isolate: diffusion of potential soil-polluting substances needs to be prevented by isolation measures

- o Control: the situation in which potential soil-polluting substances have been stored in the soil must be manageble and remain so in the future, even in the case where isolating measures should fail

- o Monitor: the situation in which potential soil-polluting substances have been stored in the soil must be controllable and remain so in the future.
  The situation and the effectiveness of the measures taken must be monitored with regularity.

Operating under these criteria leads to the consequence of the burden of after-care, also for future generations.

2.3 Future Generations: Perpetual after-care?

One cannot be sure that future generations will be ready and able to practice the after-care just mentioned.
Not only that, one should also take into account that in the NEPP it is stated that in the case of final disposal " future generations must be burdened with as little perpetual after-care as possible.".
This point has to be elucidated in the current procedure: the (seeming) contradiction between the requirements of the ICM-criteria with respect to Control and Monitor on the one hand and the wish to unburden future generations on the other hand. In this context one should realize that the ICM-criteria are not a purpose in themselves, but rather instruments for environmental protection. Is it possible to refrain from the criteria Control and Monitor in the case that Isolate is supposed to be sufficient to protect the environment?
Moreover, these criteria were developed in a period when there was only a practice of surface-disposal: they were not intrinsically developed for deep underground disposal.

2.4 Retrievability

This item is getting more and more attention in the discussions on deep underground waste disposal. That does however not mean at the same time that it is clearly defined. What seems to be clear is that retrievability should be defined as an option for a time period of at least several decades. A shorter period seems to be less usefull: in the case that retrievability should be a possibility for only ten or twenty years, after which period the waste has to be retrieved, the waste should not be disposed of in the deep underground; in that case it would be better to store the waste in surface-built facilities like vaults.

If, at least for making discussions more easy, retrievability is defined as an option for one hundred years or more, different questions have to be answered.

The first question could be the question of the burden on future generations: are they ready and able to maintain the retrievability? And: may we burden them?
The second question is how retrievability can be brought into agreement with the safety-requirements. The purpose of deep underground disposal is, inter alia, to isolate the waste in question from the biosphere.
Measures to facilitate retrievability seem on the other hand to keep open in one way or another, the pathway from the waste to the biosphere.
A third question can be related to the purpose of retrievability. One intention could be to keep open the possibility of retrieving with regard to a possible future scarceness of certain substances. In that case an estimation has to be made concerning the amounts of these substances present in the waste and the world's stock of these substances at the moment of eventual disposal.

3. Risk Management in the Netherlands

3.1 General

The following is abstracted from the memorandum "Premises for Risk Management, risk limits in the context of environmental policy":

"It has long be recognised that people are prepared to take high risks on the basis of their own decisions. For instance, they tend to let the perceived advantages (a nice skiing holiday) prevail over the disadvantages (risk of broken bones), because they feel confident about controlling the associated hazards. In many circumstances, however, the nature and extent of the associated risks are insufficiently known, as the inherent dangers only become apparent in the longer term (consequences of an unbalanced diet, lung cancer due to smoking). Moreover, the risks which environmental policies seek to control are largely of an involuntary nature and cannot normally be observed or controlled. As a result, hazards of this type are often regarded as being more serious. The hazards involved may also have an unusually serious undesirable effect. The purpose of an activity may be unclear or there may be alternatives.

Sustainable development is a premis for environmental policy, still meanwhile survival of man, animals, plants, ecosystems and property should be safeguarded. To achieve these objectives, two lines of policy are being followed: the introduction of measures to deal specifically with known sources of pollution as well as initiatives to address the effect of contaminants. The source-oriented approach aims to prevent unnecessary environmental pollution, whereas effect-oriented policies are directed towards ensuring that the chance of deleterious effects on man, animals, plants, ecosystems, environmental functions and property is negigible. This memorandom details the methods used in risk assessment.

The concept of risk assessment does not replace the source-oriented approach but is fundamental to effect-oriented policies. It provides a numerical means of defining "non-detrimental conditions" for each agent. Adoption of this approach allows guidelines to be established for quantifying the harmful consequences of pollution in relation to estimated risks and threshold values.

In defining effect-oriented policies, the government is responsible for identifying the risks involved, for indicating the limits above which the risks become unacceptable (maximum permissible levels) and for establishing levels below which the risks are negligible.

The maximum acceptable mortality risk to human beings from major accidents, exposure to substances and radiation has been defined such that the combined probability of mortality for each of these three hazards should not exceed 10^{-5}*/year. For each activity or substance, the maximum acceptable level has been set at* 10^{-6}*/year. Comparable values have been defined for diseases (effects with threshold levels) as well as for nuisance caused by noise or unpleasant odours.*

The risks to ecosystems are generally assessed using predictive models. By employing standard tests and extrapolating the results obtained, maximum permissible levels can be defined after applying suitable safety factors. In this context, the function of the ecosystem is for the time being assumed to be sufficiently protected when 95% of the species are unaffected by the threat in question. Risk assessments for ecosystems are currently being directed towards preserving the general quality of the environment and are not concerned with specific quality aspects.

The levels below which the risk to man as well as to ecosystems can be regarded as negligible have been defined in principle as 1% of the maximum permissible values wherever possible.

This approach has been adopted to take account of factors such as multiple exposures (additivity of risks and synergism), uncertainties in the estimates (limited testing and specific sensitivity) and to leave a sufficient margin to distinguish between maximum permissible levels and the values below which the risks involved become negligible.

When comparing perceived risks whith the limits set, a distinction is generally made between existing and new activities.In the case of existing activities that give rise to situations in which the specified limits are exceeded, social considerations are often of importance when determining the period over which these hazards should be curbed. New activities, however, must comply with the specified limits immediately. In continuing to develop such policies, the government intends to further assess the risks posed to ecosystems over the coming decade as well as to investigate the financial consequences of imparing the economic functions of the environment particularly in terms of damage to agricultural land or groundwater used for drinking water supplies."

The above described policy is a general environmental risk management policy. It gives general risk levels, taking into account the difference between existing and new situations.

The most relevant[2] levels in the context of this paper are:

o For major accidents in new situations:

with regard to the **individual risk per activity** (mortality, man):
The maximum permissible level is defined as 10^{-6}/year
The negligible level is defined as 10^{-8}/year

with regard to the **group risk per activity** (death all at once, n or more people):
An increase in the number of deaths by a factor n in a given situation is only acceptable if the probability of this event occurring is a factor n-squared lower for both types of level;
The maximum permissible risk levels for disasters are defined as 10^{-5}/year for n=10 or more deaths and 10^{-7}/year for n=100 or more deaths etc.
The corresponding negligible levels are defined as 10^{-7}/year for n=10 ore more deaths and 10^{-9}/year for n=100 ore more deaths etc.

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[2]For full information see "Premises for Risk Management", Annex to the NEPP (see footnote 1).

with regard to the **individual risk for combined activities** in new situations regarding external safety (mortality, man):
The maximum permissible level is defined as 10^{-5}/year
The negligible level is defined as 10^{-7}/year.

o For existing substances:

without threshold values:
with regard to the **individual risk per substance** (mortality, man):
The maximum permissible level is defined as 10^{-6}/year
The negligible level is defined as 10^{-8}/year
For **all substances combined:** 10^{-5}/year, resp. 10^{-7}/year

with threshold values:
with regard to the **individual risk per substance** (effects with threshold levels, man):
The maximum permissible level is reached if the concentration of a substance equals the no-effect-concentration determined in accordance with the recommendations made by the Dutch Health Coucil.
The negligible level is defined as 1% of the upper limit.

o For radiation:
Radiation hazards to man are generally expressed in terms of the cumulative individual risk, for which the following upper limit has been adopted:
with regard to the **individual risk for all radiation** (mortality, man):
The maximum permissible level is defined as 10^{-5}/year.

The risks associated with large disasters, known as external safety risks, are established by means of quantitative risk analysis techniques. Detrimental effects can be expressed in mortality terms, taking account of the fact that lethal accidents will also result in a number of less seriously injured casualties. The parameters incorporated in such analyses refer specifically to individual and group risks.

Existing substances can be subdivided into priority substances, pesticides, black substances and other compounds. With regard to a description of the different assessment methodologies for these, reference is made to page 18-21 of "Premises for Risk Management".

Radiation protection: the risk levels have to be "translated" into radiation doses of activities or substances and into the probabilities of occurrence of these doses. In the Netherlands governments policy on this matter an individual dose of 1 milliSievert/year equals a risk of 2,5 * 10^{-5}/year.

3.2 Risk Management and Deep Underground Disposal

When waste is concerned, the risk management policy may deal with many kinds of waste, radioactive or not.
In the case of deep underground disposal of waste, a special problem to deal with is the very long time scale.
In this context (and perhaps also more generally) it is not clear yet if it will be possible to use without restrictions or without modifications the concepts of individual risk and of group risk, as defined in "Premises for Risk Management". Some concepts may turn out to be still valid, but also irrelevant.

Untill now these aspects were not worked out yet. Nevertheless it seems to be worthwhile to deal with these aspects in the context of a general environmental risk management policy. The dominant advantage of that context is its uniformity in respect to all substances, radioactive or not.
With regard to waste disposal this may lead to an uniform approach to all kinds of waste to be disposed of. This is of great importance when one realizes that in most countries with deep-underground-disposal-research-programmes, the main emphasis is on radioactive waste. Taking into account (parts of) a general risk approach may make it possible to "translate" radioactive waste research techniques and -results into useful information for disposal of other kinds of waste. In other words: radioactive waste research may be a pilot for solving other waste problems.

oo Concluding Remarks

The above described risk management policy is rather new in the Netherlands (the parliamentary debate on it was just held in october 1990). It is not yet worked out completely. For the moment we have nothing better than we have.
Yet it is to be expected that it will offer a suitable framework for developing safety criteria for deep underground waste disposal.

THE SPANISH SAFETY CRITERIA FOR HLW DISPOSAL. THE EXISTING ONES AND THE ENVISAGED FURTHER DEVELOPMENTS

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ABSTRACT

The Spanish legal basis for the development of nuclear activities is not specific for waste disposal aspects but creates a basic framework.

In 1984 ENRESA was created as the national waste management agency.

In 1985 the Nuclear Safety Council (CSN) had stated safety criteria for the site selection of radioactive waste disposal. In the last year also CSN has established radiological acceptance criteria in terms of individual annual risk and dose for the long term of safety assessment of radioactive waste repositories.

PRESENT SITUATION

The Spanish legal basis for the development of nuclear waste-related activities is as follows:

- The Nuclear Energy Act issued in 1964;
- The Decree on Regulation of Nuclear and Radioactive Installations issued in 1972 as a development of the 1964 Act;
- The Act of 1980 creating the Nuclear Safety Council as the only competent body on radiation protection and nuclear safety;
- The Royal Decree for the Regulation of Radiation Protection Matters issued in 1982 as amended in 1987;
- The Decree on the creation of ENRESA as the waste management agency in Spain in 1984.

With the exception of the last one, these regulations are in no way specific for the long-term safety aspects as related to HLW disposal, but constitute a basic framework requiring further development to adequately consider the important and differential aspects of the radioactive waste management.

In the last years, the Nuclear Safety Council has made a statement on the radiological acceptance criteria for the long-term assessment of the waste disposal projects, as "... an individual risk limit of 10^{-6} per year which is equivalent to that with an individual dose rate of 0.1 mSv per year".

Likewise in 1985, the Nuclear Safety Council published the "Safety criteria for the site selection of radioactive waste disposal facilities". The application of these general criteria to each specific site has to be made in order to comply with the established basic radiological protection objective. This basic objective has to be reached by the disposal system as a whole, comprising: the site, the engineered barriers and the waste form and waste container. On the other hand, the necessary degree of isolation (the technical complexity and the time period to be effective) depends directly on the amounts and radiological characteristics of the radioactive wastes to be disposed of.

The above-mentioned criteria are as follows:

Criterion 1: The shape and dimensions of the host rock body should be adequate to allow room for both the repository and also a sufficiently large protection zone around the repository to ensure the waste isolation.

Criterion 2: The repository shall be located in a host rock body having a lithology and depth consistent with the categories and amounts of radioactive wastes to be disposed.

Criterion 3: The site shall be located so that the geological formations setting can be characterized to permit identification and evaluation of conditions that are potentially adverse or favourable to repository location and waste isolation.

Criterion 4: The repository should be located within a tectonically stable geological formation according to the time required for fulfilling the objectives of the repository; therefore, active structures and potential faults must be avoided.

Criterion 5: The site shall be located in a zone of such a nature that any ground motion associated with potential earthquakes, in the mentioned zone, can be shown to have no unacceptable impact on waste isolation.

Criterion 6: In the process of site selection, areas with abnormally high geothermal gradients or with evidence of recent volcanic activity should be avoided.

Criterion 7: The features of the site and its surrounding system should be entirely favourable for the waste isolation.

Criterion 8: The geochemical and physical-chemical features of the geological environment where the site is located should be such as to restrict the mobility of the radionucleides transport to the biosphere.

Criterion 9: The geotechnical characteristics of the sites shall not unfavourably affect the basic objective of disposal. Geotechnical stability shall be ensured, taking into account the mutual influence between facilities, radioactive wastes, ground and potential ground motions.

Criterion 10: The disposal facilities, as shallow ground, as deep ground disposals, should not be affected by any surface process or event that have unacceptable impact for the waste isolation.

Criterion 11: The site shall be located preferentially in areas of low population density with due consideration to urban, industrial and recreational areas, their expected growth and future development, so that the said areas do not prevent the objectives of the repository from being fulfilled.

Criterion 12: The site shall be located to avoid areas having natural resources now or areas of foreseeable future interest, which, if exploited, would result in an unfavourable effect on the waste isolation. The need for the repository, at a specific place and time, should be balanced against the need for, and value of the resources now and in the future.

Criterion 13: The repository should be located in such a way that no significantly adverse alteration will be caused on environmental conditions.

POSSIBLE FUTURE DEVELOPMENTS

Besides other types of initiatives in more preliminary stages, ENRESA have recently started two different projects looking for a conceptual design in two different geological media (granite and salt). As part of these projects, two sets of co-ordinated safety criteria or objectives would be produced. It is the ENRESA's intention to use them as a starting point for further development in this field, taking advantage of other developments at both national and international level.

DISPOSAL OF HIGH LEVEL RADIOACTIVE WASTE CONSIDERATION OF SOME BASIC CRITERIA A PROPOSAL FROM THE NORDIC COUNTRIES

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ABSTRACT

The Nordic proposal on criteria for disposal of high level radioactive waste is presented with comments to the criteria. The proposal has been sent out to many national and international organisations and experts and the major criticism and points of view are summarized. At last some follow-up questions and remarks are given for discussions.

INTRODUCTION

In 1987 a working group (1) was convened with members from the Finnish and Swedish radiation protection authorities as well as the nuclear safety authorities with the purpose of producing a joint Nordic document on criteria for disposal of high level waste (HLW). All Nordic Countries have taken part in this work even though the Finnish and Swedish authorities have been most involved because of their nuclear power programme.

In 1989 a consultative document (2) on the subject was published and sent out to national and international organisations etc. for comments. These were received in the first half of 1990 and will be considered and discussed in the follow-up work. A final document will eventually be produced and published in 1991/92 after Nordic and national discussions within and between authorities, with hearings and other consultations.

In the following the Nordic proposal will be briefly presented and the most relevant national and international criticism will be given followed by some consequential and complementary remarks and questions.

THE PROPOSED NORDIC CRITERIA FOR DISPOSAL OF HLW

The document is partly descriptive in chapters on the nuclear fuel cycle and methods for disposal of HLW and partly discussing in chapters on site selection and research. In the main chapter it gives and explains the basic safety principles for disposal of HLW. The criteria are as follows

1. Long-term safety

The predicted risks to human health and the effects on the environment from waste disposal, at any time in the future, shall be low and not greater than would be currently acceptable. The judgement of the acceptability of a disposal option shall be based on radiological impacts to individuals irrespective of any national boundaries.

Comments: protection of man is thought to be enough to protect other species although not necessarily individual members. Currently acceptable risk can be judged against socially regulated risks, acceptable risks by individuals and comparison with natural radiation. The total detriment from the disposal in terms of collective dose is difficult to assess and judge because the practice, that generates the waste, benefits the present generation while the detriments are received in the future. However, if the detriment is insignificant as compared with that of natural radiation it would be acceptable or ignored by future generations.

2. Burden of future generations

The burden on future generations shall be limited by implementing at an appropriate time a safe disposal option which does not rely on long-term institutional controls or remedial actions as a necessary safety factor.

Comments: the burden includes the financial costs, the administrative, research and other resource requirements and the radiological, social and other impacts the society has to withstend due to waste disposal. Appropriate time for disposal and ultimate closure depends on a number of factors. Prolonged interim storage above ground or underground near surface is much more vulnerable to military operations, sabotage and catastrophic events than a deep geological repository. Disposal should not rely on monitoring, surveillance or other institutional controls as a primary radiation protection feature for very long periods of time even though such may be carried out as monitoring or scientific investigations. Passive institutional controls such as keeping public records or archives, controlling land use at the disposal site and placing permanent markers at the disposal may be worth consideration. The concept of final disposal does not include the intention to retrieve the waste and retrievability should not be a prerequisite for the radiation protection and nuclear safety during postclosure phase. If for some non-technical reason it is decided to make the waste retrievable the integrity of the containment system should not be compromised and jeopardized.

3. Individual protection

The predicted radiation dose to any individual, excluding doses from unlikely disruptive events, shall be less than 0.1 mSv per year. In addition, the probabilities and consequences of unlikely disruptive events shall be studied, discussed and presented in qualitative terms and whenever practicable, assessed in quantitative terms in relation to the risk corresponding to a dose of 0.1 mSv per year.

Comments: 0.1 mSv a^{-1} or less as a dose constraint for disposal of HLW leaves a prudent fraction (> 90 %) of current dose limit (1 mSv a^{-1}) for other local sources in the future. Possible overlapping contributions from other distant repositories should also be considered and the dose constraint correspondingly lowered.

Releases due to unlikely disruptive events might contribute significantly to individual risk from waste disposal. Such scenarios shall be discussed rather in a qualitative than quantitative way and the risk constraint should be of the order of 10^{-6} a^{-1} that a serious detrimental health effect will occur.

The assessment of future doses caused by leakage from a repository is uncertain due to uncertainties in source term, in dispersion in geo-, hydro- and biospheres and because of uncertainties in what the future looks like e.g. concerning living species including homo sapiens, their physiology, diet and habits. However, it can not <u>á priori</u> be excluded that future environment including man will be approximately the same as concerns the qualities that influence the dose from a given contamination of the environment. Therefore one requirement should be that the doseconstraints are contained assuming the same environment and man as today with the same basic nutritional needs and the same lifestyles as today.

There are parts of the environment that probably will not change with time e.g. transport mechanism by water and groundwater - drinking water pathway and the uncertainties involved with individual doses from this pathway might not be unreasonable even for very long time periods.

Dose assessments can also be made in relative sense for longer periods using present kind of environment illustrating dose distributions and concentration peaks and how they may vary with time depending on life-times of radionuclides. If the doses are low enough the uncertainties in future environmental conditions may be irrelevant.

4. <u>Total activity inflow</u>

The total activity inflow rate of the disposed radionuclides into the biosphere, averaged over long time periods, shall be less than one thousandth of the repository specific reference value. This is defined as:

$$\frac{\left\{\begin{array}{l}\textit{Amount of waste}\\ \textit{in the repository}\\ \textit{in tons of spent fuel}\end{array}\right\}}{\left\{\begin{array}{l}\textit{Potential amount of waste}\\ \textit{to be disposed of globally,}\\ \textit{in tons of spent fuel}\end{array}\right\}} \times \left\{\begin{array}{l}\textit{Global inflow of long-lived}\\ \textit{natural alpha emitters from}\\ \textit{geosphere to biosphere,}\\ \textit{in Bq/a}\end{array}\right\}$$

Comments: this is a complementory way to judge the acceptability of disposal. The criterion uses the activity inflow of the disposed radionuclides into the environment as compared with the inflow of long-lived natural alpha emitting radionuclides from geosphere to biosphere. Many of the long-lived radionuclides in the HLW (spent fuel) are radiologically similar to those natural alpha emitters.

The long time periods referred to in the criterion mean periods of the order of 10^5 years. The global activity inflow of natural long-lived alpha emitters (from geosphere to human environment to sea and ocean sediments) is estimated to be at least 1000 TBq a^{-1} on an average. Economically exploitable uranium resources are of the order of 1 Mtons spent fuel equivalent at the most.A possible broad breeder reactor programme in the world are not considered. By this criterion the intention is to limit the concentration of radionuclides from the repository, when they appear in the environment, to lower level than that of natural alpha emitting radionuclides and by that the resulting doses will be lower than the natural doses from these radionuclides, about 0.1 mSv a^{-1}.

5. Optimization of radiation protection

The radiation protection of waste disposal shall be optimized. In doing so radiation doses must be compared and balanced against many other factors that could influence the optimized solution.

Comments: it is quite evident that optimization is connected with many great difficulties. One of them is the many factors to be involved in the choice of site and design as e.g. availability of various waste management facilities, costs, social and environmental effects, institutional and political considerations, radiological effects. Another is the great uncertainty of the effects in the very far future, risk of intrusion etc. However, the optimization approach at least lends to a valuable structuring of information as an input to decision.

One way to get confidence in safety is to demonstrate compliance with criteria by safety assessments and quality assurance procedures. In the following the safety assurance principles are given.

6. Safety assessments

Compliance of the overall disposal system with the radiation protection criteria shall be convincingly demonstrated by means of safety assessments which are based on qualitative judgement and quantitative results from models that are validated as far as reasonable.

Comments: the risks or consequences from unlikely processes and disruptive events should be assessed either by using deterministic analyses, that model several alternative evolutions for the disposal system and estimate the consequences, or by using probabilistic analyses that assess the consequences of a range of future events, or by using both methods. Irrespective of what method is used it is extremely important not to use only calculated figures but also to make qualitative judgements of options, choice of scenarios and results of numerical analyses.

In order to demonstrate compliance with dose- and releaselimits conservative assumptions may be used to overestimate the results. However, in comparison of several different disposal systems, realistic scenarios, models and input data should be applied. Analysis of radiological impacts can be truncated at the time when impacts are the same for all alternatives or the great uncertainties make the alternatives inseparable.

7. Quality assurance

A quality assurance programme for the components of the disposal system and for all activities from site confirmation through construction and operation to the closure of the disposal facility shall be established to achieve compliance with the design bases and pertinent regulations.

Besides these basic criteria on radiation protection some derived specific technical and geological criteria are needed. They must frequently be derived by engineering judgement taking due account of the uncertainties.

The following criteria are specific for the disposal of HLW into crystalline bedrock at a depth ranging from a few hundred metres to about one kilometre.

8. The multibarrier principle

The long-term safety of waste disposal should be based on passive multiple barriers so that

a) deficiencies in one of the barriers do not substantially impair the overall performance of the disposal system

b) realistic changes in repository conditions are likely to affect the system of barriers only partly.

Comments: no man-made or automatic post-closure protective actions should be needed to ensure radiation protection and nuclear safety. The safety of the waste disposal should not rest on one single component of barrier but rather on the combined function of several dissimilar barriers.

9. Site geology

The site should provide good natural conditions for the containment and isolation of radioactive substances. Thus an ideal site should

a) *have hydrogeological characteristics that provide low groundwater flow within the repository, long groundwater transit time from the repository to the biosphere and favorable dispersal characteristics*

b) *have geochemical characteristics that contribute to low corrosion rate of the canister material, low dissolution rate of the waste matrix as well as to low solubility and effective retardation of the released radioactive substances*

c) *be located in a region of low tectonic and seismic activity*

d) *be selected to avoid proximity to such natural resources as are not readily available from other sources.*

Comments: There are two reasons for not locating a repository near (potentially) valuable natural resources. Firstly, future generations would exploit natural resources without being affected by undue radiological risks. Secondly, the knowledge of a repository's location might not be available to a future individual and society and there might be a risk of intrusion in seeking to exploit natural resources. Natural resources to be avoided are fossil fuels, metal ores, major groundwater reservoirs, unique deposits of rare material and unique site features such as geothermal potential.

10. Depth and configuration of the repository

The repository should be located

a) *at a sufficient depth to protect the waste packages from external events and processes and render human intrusion difficult*

b) *in a host rock formation large enough to accomodate the repository and a buffer zone*

The configuration of the repository should be such that

c) *the temperature rise due to heat generation from the waste packages remains at an adequately low level* *d) the extent of geochemical disturbances due to the emplaced waste is limited*

e) the increase of fracturing due to the repository construction or the emplaced waste is limited

f) the emplaced waste remains sub-critical with respect to nuclear fission even in the long term.

11. Backfilling and closure of the repository

The backfilling and closure of the repository should contribute favorably to the containment and isolation capability of the disposal system. The backfill material around the waste packages should

a) protect the waste package from minor rock movements

b) further reduce the mass transfer rate of corroding and dissolving agents and released radioactive substances around the waste packages

c) have a sufficient mechanical and chemical long term stability

The closure of the repository should aim at

d) limiting groundwater flow in the repository

e) disconnecting aquifers in the vicinity of the repository

f) maintaining long term structural stability in the repository

g) preventing human intrusion into the repository.

12. Waste packages

The waste packages should provide technical barriers which will effectively contain and isolate radioactive substances. Thus the waste packages should:

a) have such mechanical and chemical stability as to provide a substantially complete isolation of radioactive substances for an adequately long period

b) *limit the average release rate of radioactive substances from the repository to a sufficiently low level*

In the selection of material for the waste packages, consideration should be given to their value as attractive targets for future explorations.

COMMENTS GIVEN ON THE PROPOSED CRITERIA

The comments range from support and general agreement through constructive criticism and proposals for improvements to general negative attitudes and critical views in structure, supporting material and content.

Some of the more essential remarks are summarised as follows

Criterion 1 : How to do if a neighbour country has more stringent requirements than the own country?

Criterion 2 : The criterion should require possibilites for future control.

Criterion 3 : 0.1 mSv a^{-1} and 10^{-6} a^{-1} are arbitrary. Risk and dose criteria should be combined and there should be a risk constraint for a given, relatively short, time e.g. 10 000 years. How to demonstrate compliance with a risk criteria?

Criterion 4 : A good method to put in perspective, but is it a criteria? The limit of inflow is arbitrary, why is a reduction factor of 1/1000 used? Better to compare with natural activity of groundwater.

Criterion 5 : Optimization is questionable.

Criterion 6 : The use of the terms deterministic and probabilistic is not appropriate and useful. The time of interest varies from 1 000 years to 100 000 years.

At last, a given proposal on possible basis for criteria

a) dose or risk based (short term individual),
b) based on natural activity of ground water in vicinity of repository (long-term individual)
c) based on natural global flow rates (population)

SOME FOLLOW-UP QUESTIONS AND REMARKS

1. Is a non closed repository which offers retrievability an acceptable option? It is argued that future generations should have the right to make their own judgement and take their own decision on how to dispose HLW. It is also argued that the techniques for disposal and the knowledge of consequences are expected to be improved over the next 50-100 years and therefore there is a reason to wait with the closure of the repository.

It may be wise not to require an unnecessarily quick decision on the final solution of site selection, design and closure of a repository. All steps should be taken carefully on the best available scientific basis and whith social and political acceptance in mind. However, as a philosophy it does not help to postpone the solution to future generation because that philosophy will never help to decide on the final solution. Furthermore it is questionable from safety point of view.

2. What is the need and practical possibilities to keep markers and records on the disposal? Would it be possible to do so for time periods of the order of 100-1000 years? Should it be some international record for all repositories around the world?

3. One problem with disposal of HLW is the uncertainties associated with the predictions e.g. the uncertainties in the source term, the dispersion from the source and the uptake in the environment and the consequences for man (or whatever it is). The source term includes here the engineered barriers. Another problem is the basis for acceptance of a solution for disposal of HLW. The uncertainties night require large safety margins, that cause extra costs for the society. Weak basis for acceptance causes diversities in opinion on how to handle the problems from the point of view of radiation protection and nuclear safety and from consideration of ethical and political aspects. There are also concerns that there is no balance in the way of thinking in connection with radioactive waste and non-radioactive waste and that too much money is spent on radioactive waste at the expense of non-radioactive.

The following complementary questions can be made:

a) are the costs for disposal of HLW caused by overconservative assumptions made in the safety analysis a good investment to achieve the needed confidence and acceptance of the politicians and the public?

b) for how long time periods is it meaningful to use models and assessments of future consequences of dispersed radionuclides? 100, 1000, 10 000, 100 000 years? For what time periods should we leave the quantitative approach and discuss the problems in qualitative terms? What scientific disciplines would be involved?

c) what conclusions can be drawn from what we know about environmental changes backwards in time up to now and how can they be used in our prognosis forwards in time of future changes of the environment?

d) what environmental factors, relevant for dispersion, uptake and dose, are known in the long time perspective with great confidence, medium confidence and small confidence and how does that grouping of environmental factors help us in structuring the knowledge of future consequences of disposal of HLW.

e) The last point is an idea for discussion but formulated as a provocative statement:

The level of dose- and riskconstraints given in the criteria should apply only for the first thousands of years. For the very long time periods we accept greater uncertainties in safety assessments and less restrictive dose- and riskconstraints in the sense that the assessed doses and risks to critical group within the envelope of most probable scenarios should be less than a dose- and riskconstraint respectively that will increase with time and be one to several orders of magnitude greater than we accept today and for the first thousands of years.

The first approach in safety assessment should be to calculate the radiological consequences with unchanged environment by which the expected doses and risks should be less than 0.1 mSv a^{-1} and 10^{-6} - 10^{-5} a^{-1} respectively and than apply the uncertainty factors associated with unknown future. Events with probabilities less than 10^{-6} a^{-1} as well as doses appearing after 1 million years will be ignored. The radioactive waste will accordingly be considered as a part of the natural environment after 1 million years.

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	E. Ruokola	-"-
Sweden:	J-O Snihs Chairman	Swedish Radiation Protection Institute (SSI)
	R. Boge (secretary)	-"-
	K. Andersson	Swedish Nuclear Power Inspectorate (SKI)
	S. Norrby	-"-

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THE SWISS SAFETY CRITERIA FOR HLW DISPOSAL, EXISTING AND ENVISAGED FUTURE REQUIREMENTS

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ABSTRACT

The existing Swiss regulatory requirements with respect to the disposal of radioactive wastes are broadly reviewed. This is followed by a survey of some issues which might be considered in the envisaged refinement of the regulations.

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1. <u>Present situation</u>

1.1 According to the Swiss law the responsibility to dispose safely any radioactive waste rests with the producers of the wastes. Those founded a private company, NAGRA, to discharge this obligation. NAGRA became responsible to prepare and to implement the disposal of all radioactive wastes generated in Switzerland. Its tasks include the performance of the necessary research, site identification studies and site selection, the design of the facilities, the methods and the means needed for the disposal and the demonstration of compliance with the relevant federal regulations.

The regulations are issued on behalf of the Government by two federal authorities working in coordination, the

- HSK - the Swiss Federal Nuclear Safety Inspectorate and

- KSA - the Federal Commission for the Safety of Nuclear Installations.

Licences are granted by the Government on the basis of the recommendations of these two bodies (for exploratory drilling, site selection, construction, operation).

1.2 The presently applicable requirements are defined in the regulatory document R-21 [ref. 1] and are discussed in [ref. 2].

The existing requirements reflect two basic ideas, first, that the potential hazard from any waste repository shall be very low at any time in the future and second that the burden to resolve the waste problem shall not be transferred from this to future generations. For them, there should be no need to take any action (repair, survey, control) to stay safe.

The safety related part of these ideas have been developed into four guidelines and two protection goals. The guidelines are

- A dose limit must be observed which is small compared to doses from natural radiation and which is smaller than the differences in radiation doses due to individual habits of living.

- The dose limit must only be claimed for the most unfavourable of the expected events; normally the doses caused by a repository should be well below this limit. (The interpretation of the term "reasonably expectable event" is discussed in the followings.)

- The dose calculations have to be based on conservative assumptions which take into account the long-term uncertainties of repository performance.

- The risk due to a repository has to be reduced as far as reasonably achievable within the state of science and technology.

The protection goals are defined as follows:

Protection goal 1

"Radionuclides which subsequent upon reasonably expectable processes and events return from a sealed repository to the biosphere should at no time give rise to individual dose equivalents exceeding 0.1 mSv per year.
If the effects of several repositories overlap, the dose limit shall apply to the sum of all contributions."

This goal does not imply that the safety of a waste repository should be judged solely on its basis. The level of conformity with the above stated guidelines shall also be taken into account.

Protection goal 2:

"A repository has to be designed so that at any time it can be sealed within a few years.
After the sealing of a repository it must be possible to discontinue all safety and surveillance arrangements."

Thus, the safety, i.e. the compliance with the dose limits, must be achieved by the repository's passive features and it should not depend on any activity (surveillance, intervention, etc.) after its closure.

1.3 The protection goals apply to all types of repositories, irrespectively from the type of radioactive wastes for which they are intended to serve. However, the type of the waste and primarily its activity and composition will dictate the technical conditions (siting, isolation, waste matrix, packaging, backfill, etc.) required to comply with the goals.

The goals refer to the so called "realistic" events, which can be expected to occur with reasonable probability sometime in the future due to natural evolutionary processes. They are not intended to apply to the complementary set of events called exceptional, characterized primarily by a low probability of occurrence. It is acknowledged that the regulations are not precise on this issue and that there are certain possible events which are difficult to classify - judgment will be exercized in these cases.

1.4 Possible requirements, which are not solely safety significant, like retrievability, are not referred to in the existing regulation. They might be considered in the future.

2. Possible future developments

2.1 Obviously, the major problem is the safe disposal of HLWs. These consist of vitrified reprocessing wastes (which will be returned from abroad) and possibly, spent fuel. Transuranic, α-bearing wastes, which also represent a very long term hazard, will be disposed together with the HLWs.

We expect that the ongoing work in NAGRA will provide in a short time adequate guarantee that the deep geological disposal option of HLW can be practically implemented in Switzerland, in compliance with the existing regulations. However, the actual implementation of the disposal is not expected before at least 30 to 50 years from now, as before the disposal can take place, the wastes must be sufficiently cooled (in an interim storage facility).

2.2 We anticipate that during this time-interval two types of regulatory developments might occur, namely

(a) the refinement of the existing regulations

(b) the consideration of alternative methods of disposal (including its deferral).

2.3 Possible subjects to be treated in the frame of future refinement of the regulations are:

(a) improved classification regarding realistic vs. exceptional events.

(b) introduction of probabilistic treatment of exceptional events.

(c) differentiation between tolerable consequences according to the expected time of their occurrence.

(d) introduction of quality and quality assurance requirements.

(e) introduction of retrievability requirements, at least with regard to spent fuel.

(f) introduction of specific requirements with regard to the demonstration of compliance with the regulatory requirements (e.g. use of internationally accepted and validated models).

(g) update of the requirements according to the state-of-the-art before a construction licence is granted.

2.4 With respect to point (c) above a differentiation according to three time periods could be considered, namely

(i) about 600 years (500 - 1'000), the decay of fission products to insignificant levels. For this time-span total isolation should be achieved.

(ii) from about 600 to 10 - 20'000 years, the time required for the decay of the activity and the toxicity of vitrified reprocessing wastes to the level of the original ore. During this period dose and/or risk limits should apply.

(iii) for the period beyond the above the risks associated with the repository shall not be greater than those from an uranium ore deposit.

We have also some thoughts on the possibility of differing appraisal of the possible deleterious effects from the repository in the different time periods described above, which can be expressed by attributing decreasing importance with time to a dose [Ref. 3].

2.5 There are many valid arguments favoring the deferral of the implementation of the final disposal of HLWs, especially when a monitored engineered storage facility, as used for interim storage, is available [Ref. 4]. Besides the clear economic advantage of reduced and postponed investments, the retrievability problem is resolved, the option to consider possible technical advances (especially the possibility of the emergence and the ripening of alternative disposal methods, advances in medical treatments, etc.) is preserved. Perceptions, which played a decisive role in the evolution of the present trends, might change. The disposal can be deferred without any compromise on safety.

The counterargument is that the deferral of the disposal violates the ethical principle according to which no burden shall be imposed on future generations. However, the examination of ethics leads to the conclusion that this ethical principle is a relatively low level one and probing into real life situations reveals that there is no other field of human endeavor to which it is applied. Also, the deferral of the final disposal serves another ethical principle, that of avoiding or postponing irreversible actions to the extent possible.

It seems worthwhile to explore this issue further.

2.6 For the future, all efforts should continue to establish the practical availability of the deep geological disposal option for HLWs, to identify, explore and license adequately safe sites. All the steps should be taken to have this option ready in 30 to 50 years from now. The final decision to use it or to resort to an alternative solution will best be taken by the next generation.

Remark:

It should be noted that the ideas presented in the second part of this paper are not the only ones which may be considered in the future revision of R-21. The others include those which emerged in the Swedish-Swiss Working Group on Waste Disposal. They will also be presented to this forum in an other paper.

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RADIATION PROTECTION AND SAFETY CRITERIA FOR THE DISPOSAL OF HIGH LEVEL RADIOACTIVE WASTE IN THE UNITED KINGDOM

by
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ABSTRACT

In the United Kingdom Government Policy is that high level, heat generating waste be stored for a period of at least 50 years before disposal. No radiation protection or safety criteria specific to the disposal of such wastes have therefore been defined. However the necessary legislation and regulatory procedures and infrastructure are in place to ensure safe disposal of high level wastes. Also assessment principles for disposal of low and intermediate level wastes have been prepared and published by the regulatory authorities, the main features of which would also be applicable to the disposal of high level waste.

INTRODUCTION

In the United Kingdom, Government Policy is that high level, heat generating waste be stored for a period of at least 50 years to allow for decay of radioactivity and the initial thermal transient before disposal. No radiation protection or safety criteria have been prepared specific to the disposal of high level waste. However within the UK a wide range of nuclear fuel cycle facilities, including disposal facilities for low level wastes, have been subject to full regulatory procedures and approval in accordance with prevailing legislation. The necessary legislation and regulatory arrangements and infrastructure are in place to ensure safe disposal of high level wastes.

The regulatory authorities have issued guidance on the principles they will be applying when assessing proposals for disposal facilities for low and intermediate level waste. Although relating specifically to disposal of low and intermediate level waste, their underlying philosophy and main features are equally applicable to high level waste disposal and would be expected to form the basis for assessment of high level waste disposal. This paper briefly reviews the legislation and regulatory framework in the UK and the main features of assessment principles as might apply to high level waste disposal facilities.

LEGISLATION AND REGULATORY FRAMEWORK

The main legislation controlling the selection, design, construction, operation and closure/decommissioning of any nuclear facility distinguishes between the safety of workers and the protection of the general public from accidental release of radioactivity, from that of protection of the public from routine disposals of radioactivity.

Under the Health and Safety Work etc Act 1974 [1,2], the Health and Safety Executive of which the Nuclear Installations Inspectorate forms a part, has responsibility for securing the health, safety and welfare of persons at work and for protecting others against risks to health or safety in connection with the activities of persons at work. The Nuclear Installations Act 1965 [3] is a relevant statutory provision and requires the licensing of nuclear installations. Clearly, since the focus of this legislation is safety of workers, the provisions of this legislation apply only during the institutional management period of a repository and then primarily to the pre-closure operational phase.

The Radioactive Substances Act 1960 [4] under which disposals to and at a repository require appropriate certificates of authorisation from the so-called authorising Departments, ie in England the Department of the Environment (DOE) of which Her Majesty's Inspectorate of Pollution (HMIP) forms a part acting jointly with the Ministry of Agriculture, Fisheries and Food, and/or the Scottish Office, the Welsh Office and the Department of the Environment in Northern Ireland. The authorising Departments are therefore concerned both with the disposal of such emissions, discharges and wastes that may arise during the operational phase of the repository as well as the post-closure safety assessments of the disposal facility.

As with any other major development the requirements of the Town and Country Planning Acts [5,6] must be met. Application for planning permission, to develop a site by constructing a disposal facility, will have to be made to the Local Planning Authority within whose boundaries the site is situated. For the development of a deep disposal facility for low and intermediate level waste the Secretary of State for the Environment has stated his intention to "call in" the planning application to construct a repository for his own determination which will involve a public inquiry. For such a public inquiry the regulatory authorities would give their provisional view on whether the proposed facility would be suitable for authorisation and licensing. Such a public inquiry does not however form part of the formal licensing and authorisation procedures and decisions on whether or not to grant an authorisation or a licence would be taken at later stages of the project. It is to be expected that any application to develop a disposal facility to dispose of high level waste would also be the subject of a public inquiry under the Planning Legislation.

Central to the regulatory approach in the UK is that the onus is firmly placed on the proposer, in this case the disposal facility operator, to address safety in a responsible and comprehensive manner and provide a full justification to support his contention that the facility would be safe. It is for the regulatory authorities to be satisfied the safety case is soundly based and has indeed been justified.

ASSESSMENT PRINCIPLES

The regulatory authorities have prepared and published two documents containing the principles that will be applied by the regulators when assessing proposals for radioactive waste repositories. The first document entitled 'Safety Assessment Principles of a Nuclear Chemical Plant' issued in 1983 [7] will be used by the Nuclear Installations Inspectorate to assess the design and operation of the facility during its institutional management period. The second document entitled 'Disposal Facilities on Land for Low and Intermediate Level Radioactive Wastes' Principles for the Protection of the Human Environment' issued in 1984 [8] will be used by the authorising Departments for assessing the impact of disposal on the environment during both pre and post-closure phases. These documents however do not constitute limits or criteria that must be met - rather they provide a guide on some aspects of the safety case to which the regulatory bodies will be paying particular attention. When the time comes to dispose of high level waste it is to be expected that similar documentation will be produced at that stage.

Focusing on the post-closure phases the latter document identifies a number of aspects relating to the facility and its performance which the regulatory bodies would expect to see addressed in the safety submissions from the applicant, including;

- an analysis of the contribution to radionuclide retention and containment made by each barrier in the system;

- the results from the application of mathematical models, and a full description and justification for those models used to predict radiological impacts;

- comprehensive radiological assessments;

- explanations of how the basic radiological requirements and general principles have been addressed;

- an assessment of the probability that the facility might be disrupted by discrete external events.

Furthermore, the regulatory authorities will expect the applicants safety submissions to demonstrate that;

- in selecting his preferred site the developer has not ignored a clearly better option for limiting radiological risks (although the developer will not be expected to show that his proposals represent the best choice from all conceivably possible sites);

- during the institutional management period, individual and collective doses are as low as is reasonably achievable (ALARA), economic and social factors being taken into account and the average individual effective dose equivalent from all sources of radiation does not exceed 1 mSv a year;

- best practicable means have been employed to ensure that any radioactivity coming from the facility is as low as is reasonably practicable (ALARP). The effect being to ensure that exposures are ALARA;

- individual risk has been compared to a target annual risk to an individual equivalent to that associated with a dose of 0.1 mSv, about one chance in a million;

- future movement of radioactivity from a facility is not leading to a significant increase in the radioactivity naturally occurring in the general vicinity of the facility;

- for the site selected it is unlikely that a future development of natural resources, or of the site, will disturb the facility;

Of particular note is that a risk rather than a dose target for assessing impacts during the post-closure period has been defined where the appropriate target applicable to a single repository at any time is the risk to an individual in a year equivalent to that associated with a dose of 0.1 mSv; about one chance in a million. That risk may be defined as the probability that a given dose will be received multiplied by the probability that such a dose will result in a fatal cancer. In defining a risk target it was recognised that radioactivity may be released into the environment as a result of a range of situations with varying probabilities leading to various radiation doses and there could exist significant uncertainties in predicting the exposures which might occur into the far future whereas existing radiation protection standards apply to situations in which it is reasonable to assume that doses will actually be received.

A further feature of the assessment principles is that no time frame for quantitative assessment is specified. Rather it is for the applicant to justify whatever time frames for quantitative assessments he will be adopting in the context of the overall safety case that will be presented. The risk target however is considered to be the appropriate target at any time in the future.

CONCLUSIONS

Whilst no specific criteria have been defined in the UK for disposal of high level waste the regulatory authorities have published principles they will be adopting in assessing the developers proposals for disposal facilities for low and intermediate level wastel, and it is to be expected that broadly similar principles would be applied to disposal of high level waste. The regulatory arrangements within the UK places the onus firmly on the applicant to develop, present and sustain his safety case demonstrating that the proposed facility affords the necessary level of safety. It is this safety case that the regulators assess but with specific reference to the principles identified above.

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EPA's Development of Environmental Standards for High-Level and Transuranic Wastes

by

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EPA is in the process of developing standards for the disposal of high-level and transuranic wastes. This development process is in response to a Court order that remanded standards that were promulgated in 1985. This paper describes the basic standards that were developed in 1985, the basis of the court's remand, and technical issues that are being pursued as a part of the repromulgation effort.

DESCRIPTION OF 40 CFR PART 191

The Agency promulgated its Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes (40 CFR Part 191) on August 15, 1985. These standards were developed pursuant to the Agency's authorities and responsibilities under the Atomic Energy Act of 1954, as amended; Reorganization Plan No. 3 of 1970; and the Nuclear Waste Policy Act of 1982.

The 1985 Standards consisted of two subparts. One subpart limits the annual radiation exposure of individual members of the public during the management and storage of the subject wastes prior to their disposal. For example, at Department of Energy (DOE) disposal facilities these limits are 25 millirems to the whole body and 75 millirems to any critical organ.

The other subpart established several different types of post-disposal requirements. The primary standards for the period following disposal were long-term containment requirements that limited projected radionuclide releases to the accessible environment for 10,000 years. The Agency estimates that under assumed, generic conditions, these requirements would limit the adverse health impact to no more than ten premature cancer deaths in the first 10,000 years after disposal for each 1,000 metric tons of spent nuclear fuel and HLW or one million curies of alpha-emitting TRU radionuclides. In addition, a set of six qualitative assurance requirements were included to provide added confidence that cautious steps will be taken to reduce problems caused by uncertainties in the quantitative analysis. The third set of requirements limited exposures from all pathways, including drinking water, of individual members of the public for 1,000 years after disposal to 25 millirems per year. Finally, a set of ground-water protection requirements limited, for 1,000 years, radionuclide concentrations in special sources of ground water to the concentrations allowed by EPA's drinking water standards.

LEGAL ACTION CONCERNING 40 CFR PART 191

As you are aware, the disposal requirements have been vacated and remanded to the EPA by the U.S. Court of Appeals for the First Circuit. This is the final outcome of a legal process that began in 1985 when several environmental groups, led by the Natural Resources Defense Council and the States of Maine, Minnesota, Texas, and Vermont filed petitions for review in several Federal courts around the country; these petitions were consolidated in the First Circuit.

The Court rendered its decision in July 1987. That decision vacated and remanded the entirety of the standards even though only the two sections that dealt with individual and ground-water protection requirements, Sections 191.15 and 191.16, respectively, were found defective.

In August 1987, the Justice Department, on behalf of EPA, filed a motion requesting reinstatement of those portions of the Standards which were not found defective. On September 23, 1987, the Court reinstated the management standards, but continued the remand of the disposal standards. The Court thought that all sections of the disposal standards were potentially interconnected and, therefore, changes made on one section could impact another.

Briefly, the Court concluded that:

1. disposal of HLW in mined geologic repositories might be underground injection and that EPA failed to consider the Safe Drinking Water Act's (SDWA) requirements on underground injection by potentially allowing endangerment of ground water by exceeding EPA's own drinking water standards. Therefore, EPA must reconcile the ground-water and individual sections with the SDWA requirements or adequately explain the divergence;

2. EPA must supply an adequate explanation for selecting 1,000 years as the design criterion in the ground-water and individual sections; and,

3. the Ground-Water Protection Requirements were promulgated without proper notice and must be reproposed for public comment.

The Agency has initiated a program to re-promulgate the standards. We will propose a rule for public review and comment, taking into account the issues raised by the Court. Based upon the comments received, we will then proceed to reissue the standards, incorporating any revisions that prove to be appropriate.

SOME REPROMULGATION ISSUES

The last five years have been an interesting period in the regulation and development of the Nation's high-level radioactive waste disposal system in the United States. Recently, long after Congress mandated promulgation of standards, there has been a plethora of guidance and advice from numerous committees and scientific groups. We agree with the great majority of this advice but there are three areas where we have some differences. It is to look at these areas of difference that I will address the remainder of this presentation. First, the need for quantitative probabilistic standards before a repository is developed; second, what level of compliance assurance does EPA believe to be appropriate; and third, why have we chosen to express the probabilistic-related part of our standard in terms of total releases rather than individual annual dose?

The Need For Quantitative Probabilistic Standards

Probabilistic standards are necessary because of the long time period over which one must judge the repository's suitability. Without taking the probability of events into consideration, a standard has no meaning for these types of facilities. If a site has any type of geological integrity at all, and all proposals certainly indicate this will be the case, the releases from undisturbed performance are not expected to be the ones of major concern. As we extend the analysis into the thousands and tens of thousands of years, we realize releases of some kind are indeed possible, despite the geological integrity. The releases that might occur in the longer term are dependent on disturbed performance and, therefore, are not susceptible to the classic type of standard that prescribes limits on "routine releases." Nor can they be brushed aside as of no consequence. The releases of concern for any reasonably considered geology usually result from such things as human intrusion or seismic disturbances. To ignore this reality is to develop standards that have no effect on the releases of concern.

If we take the disturbances into consideration and apply only deterministic standards, we have only two choices for the possible events: we assume they either will or will not occur. If we assume they will occur, it will be difficult to find a repository that can pass the test. If we assume they will never occur, or ignore consideration of these events, we will have abandoned having a meaningful standard. If we do not state these criteria in some type of quantitative terms, we will have no yardstick for decision. This will invite litigation.

Another reason we think that a quantitative standard is necessary is that it provides a criterion against which to measure success or failure. We are very much aware of the potential contentious nature of the forthcoming repository licensing process. Without quantitative standards in place that have gone through a public review and promulgation process, each proposed site will require extensive justification, much of which will be subjective. This could result in an adversarial situation. By having an existing quantitative measure, much of the contention could be avoided since both the licensing board and any subsequent court will have a yardstick against which to judge the arguments.

The final reason for quantitative standards is that we do not believe that the disposal of high-level radioactive waste can be approached on the basis of just doing the best job that we can. Even the most experimental of engineering designers must have in mind some design goal. The country started out on this approach, which resulted with a proposed repository at Lyons, Kansas, that most now agree would not have been adequate. Furthermore, we do not believe that the public is willing to accept a nonquantitative standard as adequately protective of their health and the environment.

Compliance Assurance

The determination of whether a proposed repository complies with the EPA standard will not be made through measurement, monitoring, or inspection. For these facilities, we must depend on mathematical models to carry out the long-term predictions of performance upon which the decisions will be made. Again, we realize that this will be taking place in a rather contentious setting. We are also aware that there is no way to make these types of predictions over such extended time periods and have total certainty as to their correctness. In fact, we would expect that there would be a good deal of uncertainty. We have dealt with this issue by indicating in our standard that we are looking for the analysis to show only a reasonable expectation of the standards being met. We purposefully avoided using the term "reasonable assurance" because it has been extensively used in the licensing of nuclear reactors and has acquired connotations that could complicate the waste repository decision. We have not developed any quantitative definition for "reasonable expectation" because we felt that it was both premature and that it was the responsibility of the NRC to do it in its licensing process.

Although we did not numerically define "reasonable expectation", there were other areas in the 1985 promulgation of the EPA standards in which we gave guidance on how we would handle uncertainty. For instance, in discussing how the implementing agencies might assure compliance where predictions of performance are made, we said:

> Substantial uncertainties are likely to be encountered in making these predictions. In fact, sole reliance on these numerical predictions to determine compliance may not be appropriate; the implementing agencies may choose to supplement such predictions with qualitative judgments as well.

Also, to assure that there is appropriate truncation to the probabilistic analysis, we included the following guidance:

> The Agency assumes that such performance assessments need not consider categories of events or processes that are estimated to have less than one chance in 10,000 of occurring over 10,000 years. Furthermore, the performance assessments need not evaluate in detail the releases from all events and processes estimated to have a greater likelihood of occurrence. Some of these events and processes may be omitted from the performance assessments if there is a reasonable expectation that the remaining probability distribution of cumulative releases would not be significantly changed by such omissions.

Because it was clear that uncertainties were very much a part of the analysis, we included some thoughts on how they might be handled with guidance that:

> When the uncertainties in parameters are considered in a performance assessment, the effects of the uncertainties considered can be incorporated into a single such distribution function for each disposal system considered. The Agency assumes that a disposal system can be considered to be in compliance with 191.13 if this single distribution function meets the requirements of 191.13(a).

And similarly, regarding the analysis of undisturbed performance, we said:

> **When the uncertainties in undisturbed performance of a disposal system are considered, the implementing agencies need not require that a very large percentage of the range of estimated radiation exposures or radionuclide concentrations fall below limits established in 191.15 and 191.16, respectively. The Agency assumes that**

compliance can be determined based upon "best estimate" predictions (e.g., the mean or the median of the appropriate distribution, whichever is higher).

Also, relative to inadvertent intrusion, we wanted to appropriately limit the discussion when we included the following in our guidance:

> The Agency believes that the most productive consideration of inadvertent intrusion concerns those realistic possibilities that may be usefully mitigated by repository design, site selection, or use of passive controls (although passive institutional controls should not be assumed to completely rule out the possibility of intrusion).

As further substantiation that EPA fully understood the uniqueness of the repository venture and the uncertainties that went with it, we provided a mechanism for calling for alternative provisions (section 191.17). In describing the purpose of this provision in the preamble to the rule, EPA wanted to go on record to provide perspective for any future reviewer, such as a licensing board or court. In this context, following are some of the examples of statements we made in the preamble:

> In developing the disposal standards, the Agency has had to make many assumptions about the characteristics of disposal systems that have not been built, about plans for disposal that are only now being formulated, and about the probable adequacy of technical information that will not be collected for many years. Thus, although the Agency believes that the disposal standards being issued today are appropriate based upon current knowledge, we cannot rule out the possibility that future information may indicate needs to modify the standards.
>
> There are several areas of uncertainty the Agency is aware of that might cause suggested modifications of the standards in the future. One of these concerns implementation of the containment requirements for mined geologic repositories. This will require collection of a great deal of data during site characterization, resolution of the inevitable uncertainties in such information, and adaptation of this information into probabilistic risk assessments. Although the Agency is currently confident that this will be successfully accomplished, such projections over thousands of years to determine compliance with an environmental regulation are unprecedented. If--after substantial experience with these analyses is

acquired--disposal systems that clearly provide good isolation cannot reasonably be shown to comply with the containment requirements, the Agency will consider whether modifications to Subpart B were appropriate.

As we have proceeded in repromulgating this standard, the area of guidance for implementation is one that we have given particular attention to. This is especially true where misunderstanding or lack of clarity has been pointed out to us. It should be clear, however, from these references to the 1985 version, that we never intended "absolute proof", as some have contended.

Individual Annual Dose versus Total Release

Probably the area in which we have had the most consistent difference with the various advisories is that of probabilistic-related assessment. Although we have set individual annual exposure levels for the undisturbed performance over a 1,000 year period, we have taken the approach of setting limits on total releases over 10,000-years for the probabilistic-related standards. When we started this standard setting effort, it was our inclination to use individual dose, since that was how radiation standards had always been set. It was only after we examined what it would mean to have to comply with such a provision that we switched to our present approach. We believe that approach is much more appropriate in view of the long time periods and uncertainties involved. The easiest way to show why we came to this decision is through reference to Figure 1.

Figure 1 shows two symbolic spheres representing the boundary line around two repositories and the defined "accessible environment". The sphere on the left represents the compliance case if you have the current structure of the EPA standards for probability related releases. In this instance, the release limits have been determined using fairly simple models related to the overall objective of having no greater than 1,000 health effects in 10,000 years. Under these circumstances, one only needs to estimate the probability and quantities of releases of radioactive material across this boundary at any time during the 10,000-year period. To demonstrate compliance, it is not necessary to identify where on that boundary sphere the release occurs (Location), when the release starts or stops during that 10,000 year period (Year), the time-related frequency of the amounts released (Rate), or how this material might interact with people and how they might be exposed (Pathways).

If we were to pursue the second alternative, annual individual dose, as depicted by the sphere on the right of Figure 1, we have a much more difficult analytical task. It is no longer sufficient to just estimate how much radioactivity is likely to cross the boundary. We now must also estimate where

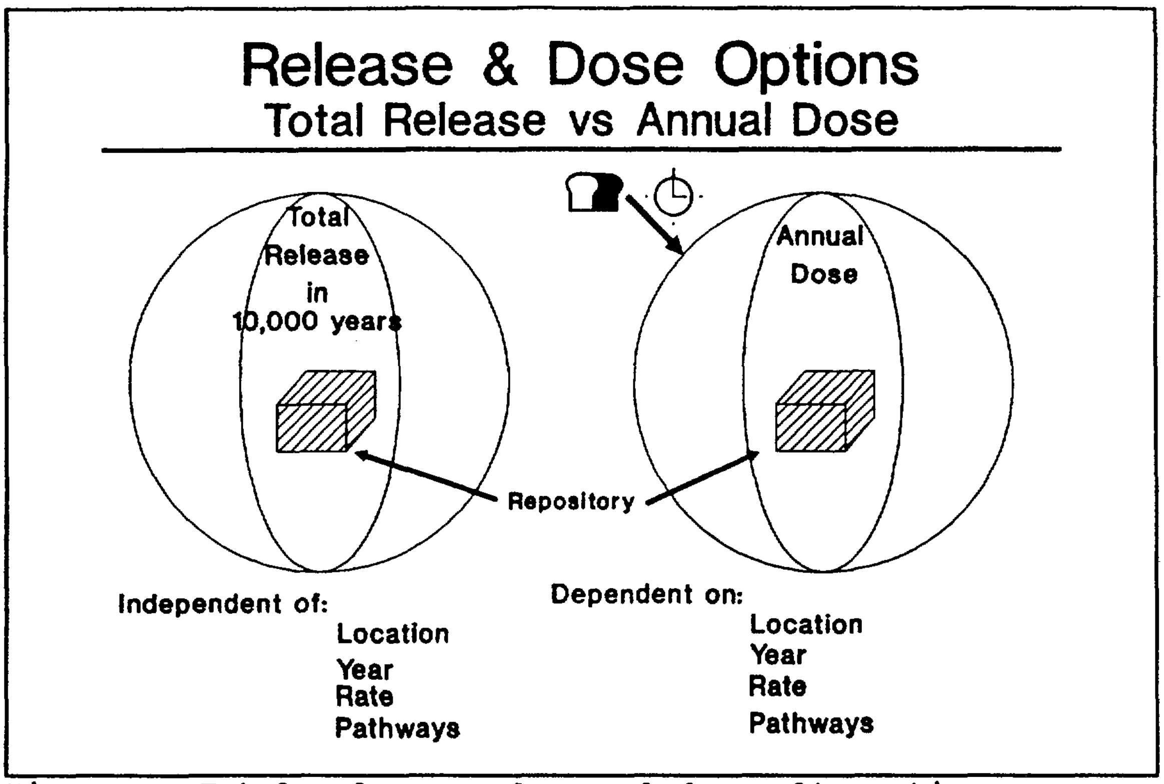

Figure 1: Total release and annual dose alternatives

(arrow) on that boundary it will occur and whether it is close to people. That would be only the beginning of the analytical chore, however. Since we must calculate an annual dose, we must know when the release starts and ends (clock) and how much will be released on an annual basis (time-related factors on an annual basis). While we think all this is more than should be asked of a probabilistic analysis, it would not be sufficient. We would still be required to go on from that point and speculate on how this material might interact with people (pathway-bread?) at this specific location and what the subsequent annual dose might be. These are speculations we believe are feasible for the analysis of the undisturbed repository but that are beyond what should be considered reasonable for the probabilistic analysis,

CONCLUSION

There is no doubt that the country has set itself a considerable challenge in seeking to establish a high-level radioactive waste repository. We believe that the EPA standard has a vital role in setting the basis for the environmental criteria and assuring the public acceptance.

DESCRIPTION OF HLW REPOSITORY REGULATIONS OF THE U.S. NUCLEAR REGULATORY COMMISSION

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ABSTRACT

The high-level waste (HLW) regulations of the U.S. Nuclear Regulatory Commission (NRC) describe both the procedural requirements to be followed for review and approval of a repository and the technical requirements to be used for evaluating repository safety. The fundamental premise underlying the NRC's regulatory approach is that the large uncertainties involved in projecting repository performance make it unwise to rely exclusively on any single barrier to provide waste isolation. Instead, a repository should be designed with multiple barriers of different characteristics, making it less likely that unexpectedly poor performance of any individual barrier will lead to unacceptable releases.

1. INTRODUCTION

In the early 1980's, the U.S. Nuclear Regulatory Commission (NRC) promulgated its regulations for licensing a geologic repository for disposal of high-level waste (HLW), including spent nuclear fuel. These regulations, referred to as 10 CFR Part 60, describe the procedural requirements and the information to be submitted when applying for a license for a repository, as well as the technical criteria to be used for evaluating the safety of a proposed repository. This paper describes the structure of the NRC's repository regulations and the philosophy that led to their formulation.

2. PROCEDURAL AND INFORMATION REQUIREMENTS

The first half of 10 CFR Part 60 contains definitions of terms used in the regulation (Subpart A), lists the procedural requirements to be followed and the information to be submitted in applying for a license to construct and operate a HLW repository (Subpart B), provides for state and Indian Tribe participation in a licensing review (Subpart C) and lists certain requirements for records and reports (Subpart D). Some features of interest include the following.

Multi-step licensing. The licensing process set out in 10 CFR Part 60 consists of (1) site characterization, (2) construction authorization, (3) licensing of operations, (4) approval of permanent closure, and (5) license termination. The first step, site characterization, does not involve a formal licensing action by the NRC. Instead, the NRC participates in an observation and consultation role. The formal licensing process begins after completion of site characterization when an application for construction authorization is submitted to the NRC.

Information requirements. At each step in the licensing process, 10 CFR Part 60 specifies the information to be submitted. For site characterization, the information consists of an initial site characterization plan, to be followed by periodic updates as site characterization progresses. An application for construction authorization is to include a general description of the proposed repository and a safety analysis report demonstrating compliance with the technical criteria of the regulation. At subsequent steps of the licensing process, the application is to be updated to provide additional information acquired during construction, additional test results, revisions to plans for permanent closure, and similar information.

Some of the information requirements of 10 CFR Part 60 will require significant technical efforts by the applicant. For example, 10 CFR Part 60 requires submittal of "a comparative evaluation of alternatives to the major design features that are important to waste isolation, with particular attention to the alternatives that would provide longer radionuclide containment and isolation."

3. TECHNICAL CRITERIA

10 CFR Part 60 explicitly acknowledges the substantial uncertainties that will be involved in any projection of repository performance over long periods of

time. The test of compliance with the technical criteria of the regulation is "reasonable assurance, making allowance for the time period, hazards, and uncertainties involved" rather than complete assurance.

Subpart E of 10 CFR Part 60 contains the technical criteria that must be met at each of the formal repository licensing steps. These criteria are summarized as follows.

Operational period. The radiation protection criteria for the operational period prior to permanent closure of a repository are the same as for operations at other nuclear facilities.

Retrievability. A retrievability criterion is imposed, requiring design so that emplaced waste could be retrieved at any time up to 50 years after waste emplacement operations are initiated. The NRC anticipates that a "performance confirmation" program will be carried out during the period when wastes are being emplaced (see below). If that program should produce information questioning the long-term safety of the repository, it might be necessary to retrieve some or all of the emplaced waste. The retrievability criterion requires that the facility be designed to permit such retrieval.

Overall system performance. The environmental radiation protection criteria for post-closure performance of a repository are the standards developed by the U.S. Environmental Protection Agency, which are incorporated into 10 CFR Part 60 by reference. Those standards limit impacts to populations and to individuals from both likely and unlikely releases for 10,000 years after repository closure.

Subsystem performance. Perhaps the most significant feature of 10 CFR Part 60 is its requirement for use of multiple barriers and its specification of minimum levels of performance to be achieved by three specific barriers. The waste package is to provide "substantially complete" containment of wastes for an initial period of 300 to 1,000 years. Following the containment period, releases of waste from the engineered barrier system to the geologic setting are not to exceed a rate of one part in 100,000 per year. Finally, the geologic setting is to have exhibited a pre-emplacement groundwater travel time of at least 1,000 years between the "disturbed zone" and the environment.

It is the NRC's intent that a repository consist of multiple barriers, both engineered and natural, with each barrier contributing significantly to waste isolation. The subsystem performance criteria were developed to improve confidence that the performance of the overall system would meet its requirement. Supporting technical analyses demonstrated that the subsystem criteria do, indeed, help to achieve compliance with the overall system performance standard, but they are neither necessary nor sufficient to ensure compliance. Therefore, 10 CFR Part 60 explicitly provides for approval of alternative subsystem performance criteria if appropriate. Thus, the subsystem criteria serve as "default" specifications for the level of performance to be achieved. If these "default" criteria prove unsuitable for a specific repository or type of waste, alternative performance criteria may be approved or specified by the NRC.

Siting criteria. A number of "favorable" and "potentially adverse" siting conditions are listed in 10 CFR Part 60. These are not rigid site suitability criteria but, rather, are conditions to be evaluated when determining whether the criteria for overall system and subsystem performance will be achieved. The siting criteria also specify requirements for land ownership and control.

Design criteria. Several criteria are specified for design of the surface and underground portions of a repository. These criteria relate to radiation protection during repository operations, prevention of nuclear criticality, maintenance of retrievability of waste, and enhancement of waste isolation.

Waste package criteria. 10 CFR Part 60 also contains criteria for the waste package. These include requirements for waste solidification, elimination of combustibles, and unique identification of each waste package.

4. ADDITIONAL CRITERIA

Performance confirmation program. A program of monitoring and tests is to be started during site characterization and to be continued until permanent closure of a repository. The purpose of this program is to confirm that repository construction and operation have not caused actual site conditions to deviate from the limits assumed in the licensing review and that the natural and engineered barriers are functioning as intended.

Quality assurance. The requirements for quality assurance for a repository are essentially the same as those previously used by the NRC in nuclear power plant licensing.

5. SUMMARY

In the U.S., the standards for overall system performance of a repository are established by the Environmental Protection Agency. The NRC's regulations implement those standards by use of a multiple barrier approach that specifies "default" levels of performance to be achieved by three specific repository subsystems, and which provides for approval of alternative subsystem criteria if appropriate. The fundamental premise underlying the NRC's regulatory approach is that the large uncertainties involved in projecting repository performance make it unwise to rely exclusively on any single barrier to provide waste isolation. Instead, a repository should be designed with multiple barriers of different characteristics, making it less likely that unexpectedly poor performance of any individual barrier will lead to unacceptable releases.

REGULATORY ASPECTS OF RADIOACTIVE WASTE DISPOSAL IN THE EUROPEAN COMMUNITY: AN OVERVIEW

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1. INTRODUCTION

The Treaty establishing the European Atomic Energy Community provides an equivalent level of nuclear safety throughout the Community by means of uniform basic safety standards, which are to ensure protection of health and safety of workers and the general public against the dangers arising from ionizing radiations.

Disposal activities have to be carried out within an appropriate legal and regulatory framework which is under permanent development at national, Community and international levels.
Some are binding, like the provisions of a nuclear law or a decree, while others are recommendations. Within the European Community they represent a hierarchy of measures, from the general to the specific, and may be conveniently described as a "pyramidal approach", going from general principles at the top over common principles, standards and requirements to basic criteria and their implementation at national and site-specific level.

A review of existing objectives, standards and criteria for radioactive waste disposal in the EC has been published (1).

2. REVIEW OF THE PRESENT SITUATION CONCERNING PRINCIPLES, STANDARDS AND CRITERIA FOR RADIOACTIVE WASTE DISPOSAL IN THE EC

The general principles encompass a much broader field than waste disposal, since they deal with radiation protection, ethical and sociological questions, environment and natural resources protection and nuclear safeguards.
These principles are laid down mainly at international level and constitute an international guidance for implementation at EC and/or national level.

2.1. In radiation protection, the well-known system of dose limitation is expressed in terms of justification, optimisation and individual dose limitation. <u>Justification</u> is given through a net benefit of the whole energy production cycle and is consequently not applicable to waste management and disposal standing alone. <u>Optimisation</u> of protection may be applied to the cycle as a whole, as well as to individual management steps. It reflects the principle that exposure should be kept "as low as reasonably achievable, economic and social factors being taken into account". Its implications in waste disposal are of paramount importance in site selection.

Individual dose limitations for doses presumed to be almost certain to occur, are well established (2). These values are legally binding limits in all Community Member States through the provisions of the EURATOM Basic Safety Standards. These limits are well suited for the operational period of a repository, but do not cover the post-operational phase of a disposal facility where a probabilistic approach is needed. The International Commission on Radiological Protection (ICRP) favours a risk-based approach, with a limit to harm to members of the critical group of 10^{-5}/year from probabilistic events. Individual states may take the risk from a repository to a given critical group as only one of a number of possible risks and specify a fraction as being an acceptable value. The system of control in radiation protection requires that no source or practice involving exposure to man to ionising radiation shall be authorised unless it is subject to control by a system of notification, registration and licensing as established by the competent authorities.

2.2. The principles included under ethical and sociological questions are often expressed in an indirect manner in current legislation. They include, among others, the principles of "care for neighbours" and "care for future generations". Under the EURATOM Treaty, each Member State of the European Community shall provide the Commission with data relating to plans for disposal of radioactive waste in order to enable the determination of whether such a plan is liable to result in the radioactive contamination of the water, soil or air space of another Member State.
The "public involvement" principle is now included in Community legislation, specifying that licensing projects and the supporting information will be made available to the public, and that the public has the opportunity of making known its opinion before the project is started. The "polluter should pay" principle was also formally introduced into European legislation.
The principle of "compensation for damage", or otherwise the civil liability in the field of nuclear energy is being covered by multilateral Conventions ratified by most of the Community Member States defining limits of liability and periods of responsibility after an accident; a particular aspect is that the operator has an absolute liability irrespective of fault.

2.3. In the field of environmental and natural resources protection, three relevant principles may be identified: prevention of damage, rectification of damage, and protection of natural resources. In the European Community legislation, the requirements to preserve, protect and improve the quality of the environment, and to ensure a prudent and rational utilisation of natural resources have been institutionalised, and an environmental impact statement has to be established for new installations.

2.4. Nuclear safeguards are well implemented in the control of fissile material for the prevention of nuclear materials diversion. The Community already has its own safeguards, required since 1957 through the EURATOM-Treaty.

3. MEASURES FOR OPERATIONAL PURPOSES

These sets of principles, regulations and recommendations provide a framework around which more concrete and technical measures can be developed or derived at national level for operational purposes. Their development or derivation and implementation depend in most cases on the geographic and geological situation, on the local environment, on the people concerned, on the political, legal and institutional systems adopted by each country, etc. These are reflected in the national radioactive waste management policies and influence, for instance, the selection of the disposal options. All that makes difficult to attempt at harmonization of this regulation level.

3.1. General approach

However, the methodological approach for setting up these measures for radioactive waste disposal is similar in all EC Countries and is being undertaken in two ways:

- by a careful review of existing knowledge (e.g.: the degree of relevance of seismicity in the site selection process for a waste repository). Usually, groups of experts and scientists are convened and mandated, at governmental or international level, to recommend criteria; this is usually a qualitative procedure, and is not site-specific;

- by a performance assessment of the proposed repository. This is a quantitative procedure performed by highly specialised scientists employing mathematical modelling. Performance assessment is generally linked to a specific project and the results can not be applied, in general, to any disposal system.

Scientific approaches to the radioactive waste disposal problem define the technical choices to be made, without endangering disposal safety. This leads, for example, to the disposal of waste with a high level of radioactivity and/or with a very long life into deep geological formations for radiological protection reasons.

3.2. The role of operators

Within the national regulatory framework, the management of the waste is entrusted to an executive body or national Agency; these waste operators have been in existence for a number of years in the various EC Member States with nuclear programmes.

As far as radioactive waste disposal is concerned, the waste facility operators, or their agents, have to:

- present proposals to the competent national authorities for the siting, design, operation, closure and postclosure of disposal facilities; these proposals must comply with the relevant national and EC regulations, standards and criteria and be in agreement with the national radioactive waste management policy;

they must include a safety case to be submitted to the licensing body as well as radiological and environmental assessments to be submitted to the authorising department(s);

- build and operate the facilities agreed upon by the competent national authorities;

- collect and dispose of the waste generated by the waste producers in the authorised facilities.

To that effect, the operators must provide a number of performance and safety assessments which include site-specific, detailed criteria.

4. CONCLUSIONS

A large number of legal and administrative recommendations and requirements exist at international, European Community and national level. Basic principles established at international level and European Community regulations provide common guidelines and requirements from which a large proportion of national measures are derived.

Policies and strategies for carrying out the management of the radioactive wastes are matters of national competence, as are the ways and means ensuring technological safety. Moreover, choices frequently have a political dimension. As a result differences exist from one EC country to another.

On the other hand, the needs for administrative and legal measures in the field of radioactive waste management are evolving all the time, and this requires adaptation, and even innovation. The very long periods of time during which waste disposed of underground will remain radioactive are a factor to be considered in radiological protection, nuclear safety, and public acceptance.

Recognising that the equivalent level of safety in waste management and disposal is desirable throughout the European Community, harmonisation of national measures or practices would be beneficial in this field, whenever feasible.

In this context the following technical issues have been identified for future consideration by the competent national and Community authorities:

- Efficiency of natural and man-made barriers (the time during which no radioactive release through the barrier under consideration should occur and the retardation effect of the barriers);

- Quantitative figures for maximum alpha content acceptable in waste for near-surface disposal and for maximum heat generation acceptable in waste declared as non-heat emitting waste for disposal;

- General site selection criteria for underground repositories;

- Methodologies for performance assessment and safety evaluation of repositories, in particular for human intrusion scenarios leading to site-specific evaluation.

In addition, study of the following matters, already undertaken at international and/or Community level, should be pursued:

- Exemption of waste and definition of waste being "below regulatory concern" (application of internationally agreed principles to particular waste streams);

- Guiding principles in waste equivalence problems (3);

- Optimisation of radiological protection in waste disposal (the application of the ALARA principle);

- Quality Assurance in waste conditionment.

Finally, the apparent fuzziness in radioactive waste categorisation in Europe, even though the result of differences in national policies, should be looked at with a view to achieving a better public understanding of waste management and to facilitating international cooperation between the waste operators.

Reference

(1) "Objectives, standards and criteria for radioactive waste disposal in the European Community" Euradwaste series N°1 Report EUR 12570 EN

(2) Council Directive 80/836 Euratom of 15.7.80 Laying down the basic safety standards for the health protection of the general public and workers against the dangers of ionizing radiation, as amended on 3.9.84
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(3) "Radioactive Waste Equivalence" Euradwaste series N°3 Report EUR 12879

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