Developing International Safety Standards for the Geological Disposal of Radioactive Waste

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Abstract: In the context of the International Atomic Energy Agency's (IAEA) programme to create a corpus of internationally accepted Radioactive Waste Safety Standards (RADWASS), focus is currently being placed on establishing standards for the "geological disposal of radioactive waste". This is a challenging task and to help the standards development process there is a need to stimulate discussion of some of the associated scientific and technical issues. A number of position papers developed in recent years by a subgroup of the Waste Safety Standards Committee (WASSC), the subgroup on Principles and Criteria for Radioactive Waste Disposal, address many of the relevant issues. These include a common safety based framework for radioactive waste disposal, appropriate timeframes for safety assessment, different possible indicators of long-term safety, the safety implications of reversibility and retrievability, the assessment of possible human intrusion into the repository, the role and limitations of institutional control, establishing reference critical groups and biospheres for long-term assessment, and what is meant by "compliance" with the standards. These papers will be discussed at a Specialists Meeting to be held at the IAEA in June 2001 as a means of establishing the extent to which they enjoy the general support of experts. In order to broaden that consensus, the conclusions reached at the Specialists Meeting on the issues listed above will be presented and discussed with participants at a number of international meetings.

Later this year, a draft safety standard on the geological disposal of radioactive waste which takes account of the consensus positions reached through the various consultations will be submitted for the consideration of Waste Safety Standards Committee (WASSC), the officially approved body within the IAEA for the review and approval of waste safety standards. The Committee is made up of government appointed radioactive waste regulators. Subsequent steps include the provision of formal comments by governments, final approval by WASSC, and by the IAEA's Commission on Safety Standards (CSS) and finally by the IAEA's Board of Governors.

1. INTRODUCTION

As part of its mandate, the International Atomic Energy Agency (IAEA) is required to develop internationally endorsed safety standards for nuclear, radioactive and radioactive waste safety. With respect to the latter, a set of fundamental principles [1] has been developed, and agreed upon at the international level, for the overall management of radioactive waste. These principles have been the subject of technical and inter-governmental debate and form the basis for the suite of international standards currently under development and for the

Joint International Convention on the Safety of Spent Fuel Management and the Safety of Radioactive Waste Management. There are nine principles that have been adopted concerning:

1. Protection of human health

2. Protection of the environment

3. Protection beyond national borders

4. Protection of future generations

5. Prevention of any undue burden on future generations

6. Provision of an appropriate legal framework

7. Minimization of waste generated

8. Consideration of interdependencies between different stages of waste management

9. Safety of waste management facilities

The interpretation of these principles has led to a system for managing radioactive wastes which, at the outset, differentiates those materials comprised of, containing or contaminated with radioactive material which, from a safety perspective, must be managed as radioactive wastes. Materials which do not require to be managed as radioactive waste can be managed and disposed of as normal waste. Radioactive wastes need to be managed in such a way that radiation exposure of people is controlled both now and in the future to levels which are safe and to ensure that the environment is also adequately protected. For solid radioactive wastes the general approach adapted to achieving these objectives is to contain and isolate the waste from the environment but also allowing for the authorised discharge of effluents under controlled conditions. For relatively short lived radioactive materials, the preferred technology is to safely store them in dedicated facilities within buildings for periods of months or a few years until they decay away to insignificant levels. For materials with radioactive half lives up to around thirty years, the preferred option is near surface disposal in dedicated radioactive waste disposal facilities. Low and intermediate level waste arisings from the operation of nuclear reactors fall within this category. The safety of these facilities is provided for by ensuring both engineered containment of the waste and a surrounding natural environment which will also provide a contribution to the isolation of the waste. By limiting the content of these wastes to radionuclides with half lives of less than around thirty years, safety can be assured by ensuring the integrity of waste containment for periods around a few hundred years. In addition to containment of the waste, consideration is given to inadvertent intrusion into such repositories and this is catered for by providing for some form of institutional control over the site and by selecting the site location were intrusion would be unlikely.

Regarding high level waste and more concentrated long lived waste, the preferred disposal option that has evolved is that of deep geological disposal. This option has been adopted taking into account the longer lived nature of the wastes and the need to provide a high level of assurance that inadvertent intrusion will be prevented. Because of the long time scales associated with the management of these wastes, selection and development of appropriate repositories has given rise to a number of challenges both to those involved in designing and in structuring and presenting safety arguments for such repositories and for those parties having to make decisions on their acceptability. These challenges have crystallized into a number of issues regarding which international consensus is presently emerging.

2. MEETING THE FUNDAMENTAL SAFETY PRINCIPLES FOR DEEP GEOLOGICAL REPOSITORIES

The suite of nuclear, radiation and radioactive waste safety standards developed by the IAEA is structured in each of the areas into a set of fundamental principles which are supported by a series of regulatory requirements for different elements of each discipline such as pre-disposal waste management, near surface disposal, mine and milling waste management and geological disposal. These requirements are published in discrete standards documents which are in turn supplemented by a series of safety guides, which provide guidance on meeting the requirements. A series of safety reports provides background information and detailed examples of how the standards have or may be applied.

In view of developments in a number of countries within the past few years related to geological repositories, it has been deemed both prudent and necessary for the international community to now develop a set of requirements representing present day consensus on achieving and demonstrating an acceptable level of safety of these facilities. The initial approach to structuring such requirements has been first to set down the radiological and environmental protection objectives. The safety strategy to be adopted in geological repositories has then been addressed. The strategy incorporates passive safety features and multiple safety barriers in the form of engineered, natural and operational elements for assuring isolation and containment of the waste. The approach to containment and isolation is then addressed and the provision of the necessary level of reliability of the safety features. Finally the protection strategy addresses the protection from human disturbance.

The proposals then consider implementation of the safety strategy. This covers elements ranging from the national legal framework, a staged approach to repository design and development through site selection and engineering design to monitoring and quality assurance. Finally the proposals cover the areas of safety assessment and development of the safety case for the repository.

This overall approach to structuring the safety standards requirements for geological repositories will be subjected to broad international peer review over the forthcoming months. In the process of developing the safety standard, a number of unresolved issues have been under international review for some time now and a process of broad international debate is being undertaken with a view to converging opinion. These include the setting down of a common framework for radioactive waste disposal of all types of radioactive waste, timeframes for safety assessment, different possible indicators of long term safety, the safety implications of reversibility and retrievability, the assessment of possible human intrusion into the repository, the role and limitations of institutional control, establishing reference critical groups and biospheres for long term assessment and how should compliance with the standards be achieved.

3. THE OVERALL SAFETY AND PROTECTION OBJECTIVES FOR GEOLOGICAL REPOSITORIES

The safety requirements for deep geological repositories that are being developed from the agreed fundamental safety principles are addressing radiation protection criteria with a view to meeting the fundamental principle of protecting human health. The recent ICRP recommendations for disposal of radioactive waste, contained in publication 81 [2], suggest an annual individual dose constraint no greater than 300 µSv from normal, as opposed to disruptive processes. Regarding potential exposure situations ICRP recommends that repository designs should avoid any intrusion event that could lead to radiation doses which would warrant intervention. The advice in this regard being that for annual doses below 10 mSv intervention would not be likely to be justified and in excess of 100 mSv intervention would most likely always be justified. Regarding the principles on protection of the environment, protection beyond national borders, protection of future generations, not placing undue burdens on future generations and on the safety of facilities, the prime consideration is to ensure containment of the waste and to isolate it from the environment with a high degree of reliability and assurance.

4. THE SAFETY STRATEGY

The safety strategy indicated considers the approach to designing and developing repositories where a reasonable assurance of safety can provided. Designs should fulfil the overall intent of providing safety in the long term consistent with the safety objectives set down.

The first requirement considered in this regard is that safety should be provided by passive means. This means that the engineered and natural features of the repository should, without further operational or institutional arrangement, provide the levels of safety required. This does not mean that monitoring or institutional control arrangements would not be put in place, but their role would be limited to one of providing reassurance of design adequacy and continuing good performance.

The second feature required is that of defence in depth by providing multiple safety functions. The functions may be in the form of engineered or natural barriers to migration of activity from the repository, or for prevention of fluid ingress or of intrusion in the repository. These physical and chemical barriers will be complemented by elements of quality assurance that will provide a high level of confidence in the performance of individual barriers and of the integral system design. The basic objective here is to ensure that shortcomings in any single barrier will be compensated by a series of other complementary barriers.

Repositories must have containment and isolation features that will ensure the provision of these functional requirements over appropriate timeframes. Consideration must be given to the period during which the heat generated by the waste may impact on the repository integrity - generally hundreds to a thousand years. Similarly consideration will have to be given to the rate of radioactive decay and the time periods were the activity remains such that serious consequences could result from intrusion - typically a few thousand years.

The disposal facilities must be sited, designed, constructed and closed such that the natural and engineered features and characteristics on which the long term safety depends are reliable over suitably long time periods. The key design features should be based on the intrinsic properties of the materials and systems or be of sufficient reliability. The processes on which safety depends should be well understood over the required time scales.

The siting and location, together with the depth of the repository must be such that the likelihood of inadvertent intrusion will be sufficiently low. Additionally, records will have to be maintained of the repository design and content, and mechanisms put in place to pass such information on to subsequent generations.

5. IMPLEMENTING THE SAFETY STRATEGY

The first requirement for implementing the safety strategy is the establishment by government of an appropriate legal framework. This must make provision for a clear allocation of responsibilities, for the necessary technical and financial resources to be available and for an independent and competent regulatory function.

A staged approach to repository design and development and decision making is indicated. The time frames associated with each stage must be sufficient to allow for the necessary collection of data and for the scientific and technical interpretations to be confirmed as well as for dialogue to take place between all interested and affected parties.

Mechanisms will have to be in place to ensure that the characteristics of the waste and its packaging disposed of in the repository conform to the waste acceptance criteria derived from the safety assessment of the repository.

The engineered barriers must be designed so as to be physically and chemically compatible with the geological environment of the repository. The safety functions must be complementary in providing overall integrated barriers to migration of activity from the repository.

The design and implementation of repository closure must be such as to ensure the integrity of the repository following closure. The integrity of the host rock must be assured and any provision in place to facilitate retrieval of the waste must not compromise the repository integrity. Closure arrangements must be established and demonstrated to be adequate long enough before planned repository closure to ensure timely implementation.

An appropriate monitoring programme must be in place during repository development, operation and closure. The programme must be designed to collect and analyse all appropriate parameters necessary to demonstrate the required level of quality assurance in repository design, operation and closure.

Design and operation must be such as to ensure sub criticality throughout operations and following closure.

Nuclear safeguards arrangements should be considered in the design and operation of the repository. Such arrangements must not compromise the integrity of the facility.

All aspects of the design, operation and closure are to be subject to an appropriate quality assurance regime.

6. SAFETY ASSESSMENT AND THE SAFETY CASE

An overall safety case for the design, development, operation and closure of the repository must be prepared. Different elements of the overall safety case may be developed and presented throughout the various stages of repository development, operation and closure. The regulatory requirements for each stage of repository development must be agreed and become preconditions for moving to subsequent stages.

The safety case must, in addition to addressing the long term safety of the repository, demonstrate that operations can and will be conducted in a safe manner and that the workforce and members of the public will be afforded levels of protection set down in the basic safety objectives.

The elements of the safety case dealing with the integrity and safety of the repository throughout its lifetime must provide the intellectual argument behind the safety case and substantiate the argument by way of appropriate systematic assessments supported by appropriate and valid analysis, testing and data.
In line with the quality assurance requirements to be adopted throughout the design, operation and closure of the repository, the safety case and all its supporting assessments, analyses, tests and data must be appropriately documented.

7. ISSUES UNDER CONSIDERATION

7.1. A Common Framework for Radioactive Waste Disposal

Although not related directly to the development of the geological standard, consideration is being given to the development of a common safety based framework or rationale for the management of radioactive waste. As indicated, the currently identified preferred option for disposal of spent nuclear fuel and high level wastes from reprocessing is deep geological disposal. The prime consideration being to provide sufficient isolation and repository integrity over the necessary time scales. Other wastes of a long lived nature but without significant heat generating capacity are also indicated for geological disposal and in some countries intermediate level wastes are also considered for geological disposal. Similarly, proposals are under consideration for the disposal of disused sealed radiation sources of high intensity and of intermediate to long half life in deep boreholes. At the same time, considerable amounts of very long lived mining and minerals processing wastes have been disposed of on the surface but have very long radioactive half lives and display a significant propensity for radiation exposure – albeit not at levels which could give rise to acute overexposures. In order to rationalize the management of all radioactive waste types an overall common framework for radioactive waste management is under development. It is intended to provide a safety rationale for the management of all the various different types of waste. The framework will have common safety objectives and will trace these objectives from waste categorisation to disposal options and provision of reasonable assurance of their safety.

7.2. Timeframes for Safety Assessment

The approach that has been generally adopted has been to extend time frames for safety assessment out to periods where the maximum impact could be calculated by modelling migration from the repository, through the geosphere and into the biosphere. Because of the designs selected at depth in rock matrices of high retention integrity these time frames have had to be extended into hundreds of thousands of years. Whilst such assessments may be indicative of good overall repository performance, the meaning and utility of the results has been subject to considerable debate. It has been suggested more recently that performance assessments should focus on shorter timeframes to avoid the credibility of the assessment being seriously questioned over the attendant uncertainties. Debate in this area is underway.

7.3. Different Possible Indicators of Long Term Safety

The overall objective of any safety evaluation of a repository must be to demonstrate that the associated impact on human health and the environment is acceptable. This involves making estimates of such impact and in order to do this mathematical models are used to simulate any migration of radionuclides from the waste, through the engineered barriers and the geosphere to the biosphere and into the human environment. Uncertainties increase as more processes are taken into account and the greatest uncertainties will, therefore, surround the estimate of health impact. It is possible to take intermediate quantities such as predicted fluxes from the geosphere to the biosphere or environmental concentrations and use these to provide a measure of the safety of the repository. Such indicators are also subject to uncertainty but to a lesser extent as the possibility exists to verify some of the modelling by field measurements. It has therefore been suggested that alternative indicators might be measured which could help to build up confidence in the adequacy of a waste repository. In this regard measurements indicating the migration of existing natural materials in the biosphere my help to build confidence in modelling processes. Alternatively, measuring parameters which provide evidence of the stability of the natural host system or integrity of the host rock medium and its ability to retard movement of groundwater may be of similar utility

7.4.The Safety Implications of Reversibility and Retrievability

It has been suggested in recent years that waste management processes should make provision for reversibility such that if the system does not operate as anticipated or better alternatives become available, or future generations wish to adopt alternative approaches to managing the waste, options would not be foreclosed. A consideration in this regard is that repositories should be designed in such a way that wastes could be retrieved from the repository. The emerging consensus in this regard would suggest the adoption of a stepwise approach to facilitate the option of retrieving waste and provide periodic opportunities to re-evaluate decisions. Of paramount importance would appear to be the need to ensure that any design features adopted to facilitate reversibility or retrievability should not seriously compromise the integrity of the repository. There may be implications in this regard for the need for some form of institutional control to provide assurance that a repository is suitably closed in accordance with its design.

7.5. The Assessment of Possible Human Intrusion into the Repository

The first consideration often raised in respect of assessment of human intrusion in geological repositories is the need for such an assessment. The objective of siting considerations is to avoid locations where it would be likely that human or natural disruptive events that could compromise the integrity of the repository or the waste isolation provisions could occur. In addition, the depth of the repertories should be selected such as to reduce the likelihood of human intrusion into the repository. In
this regard the safety of the repository should not depend on institutional control in order to comply with the standards laid down. Nevertheless, it is still considered that an assessment of the consequences of intrusion should be carried out for the purposes of building confidence in the repository design. The issues under consideration are how to interpret the results of human intrusion into repositories and how to judge the significance of the results. Opinion appears to be that such assessments should make use of stylized scenarios and present the results in terms of both the magnitude of the consequences and the likelihood of their occurrence.

7.6. The Role and Limitations of Institutional Control

As indicated in considering intrusion into geological repositories, the required level of safety should be provided by the engineered, chemical and natural host matrix barriers. As such, any form of institutional control could be seen as a mechanism to build confidence in the repository by providing ongoing assurance of the integrity of the facility. Prevailing opinion is that institutional control should not be seen as a prime barrier. Nevertheless, decisions have to be made as to how much reliance can be placed on such control and for what periods of time if quantitative impact assessment are to be made featuring institutional control. Considerations are being given to whether or not it is reasonable to assume that institutional controls can last for indefinite periods or if more emphasis needs to be placed on mechanisms for passing information between generations rather than predications in the far future on its reliability.

7.7. Establishing Reference Critical Groups and Biospheres for Long Term Assessment

Any assessment of the overall safety of a deep geological repository will entail analysis of radionuclide migration from the repository through the geosphere into the biosphere and into exposure pathways. These will necessarily involve projections into the far future. Such projections raise numerous questions about what conditions will prevail in the far future, however, decisions have to be made about what assumptions such assessment should be based upon. The prevailing consensus in this regard is that such assessment should be made on the basis of reference biospheres and critical groups representative of current conditions. These, however, should make use of conservative but not extreme assumptions.

7.8. Compliance with the Standards

The matter of compliance with the standards laid down is being considered in two dimensions. One is of compliance with technical, derived quantitative criteria and good engineering practice. This entails constructing a logical intellectual argument to support compliance with requirements in terms of good engineering practice such as defence in depth and reliability of isolation, development and validation of performance assessment models and a great deal of data collection, analysis and interpretation. The other dimension that has to be developed is the presentation of the safety argument in the decision making process. In this regard arguments will have to be put forward that are suitable for assuring a variety of stakeholders from different backgrounds of the
safety of the repository. This will require conclusions from the more technical input, considered as aids to the decision making process. It will also require argument, evidence and possibly analogy to provide the necessary confidence to decision makers that a reasonable assurance of safety has been provided. Approaches to the latter dimension are still under development; again the adoption of a stepwise approach appears to be favoured in this regard.

8. CONCLUSION

The process to establish international consensus on safety standards for geological repositories for the disposal of spent nuclear fuel and high level radioactive waste is underway. Concepts and ideas that have been developing for a number of years are being structured into draft standards. A number of issues have been identified on which international debate is being focused by the IAEA. The consensus which emerges from this debate will be reflected in the standards which will then be subjected to the formal review process by the IAEA Commission for Safety Standards and its advisory committees and for formal review and approval by the Member States of the IAEA.

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