RADIATION PROTECTION BASES FOR REGULATING RADIOACTIVE WASTE REPOSITORIES

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ABSTRACT

The international development of post-closure repository regulations has gone through several phases. In the early days, i.e. the 1980s, some of the regulations have been derived from health effects such as for WIPP. In other countries, like Sweden, more unspecific requirement on safety were given at that time without a clear quantitative goal, except for some subsystem requirement. The Environmental Protection Agency-funded study on Yucca Mountain Standards by the US National Academy of Sciences, USNAS, contains an important systematic reference point for work in other countries.

In the 1990s, most countries embrace the idea of a global single, or at least dominant, assessment endpoint. This endpoint is the expected dose or risk. There is to this day still a significant amount of confusion even within the performance assessment community, about what a risk target implies, in terms of methods for compliance demonstration. Uncertainty can be handled by several methods, including probabilistic calculations and bounding calculations. As the USNAS treats the matter, and as the authors see it, risk is simply a consequence of a radiation dose, however calculated. If and when probabilistic calculations are appropriate in the performance assessment, it is because they are motivated on good scientific grounds, not because the standard is risk based.

The safety assessment also requires a test person or group of persons. The dispute within the USNAS perhaps contributed to EPA's choice of a test person rather than a group of people located in a well-defined biosphere, taken to be the one existing today. The biosphere may be viewed as a critical component on the grounds that no one can possibly know the society thousands of years in the future. The authors suggest that several biospheres are tested, not as predictions but as possible conscious choices for future generations. This repository requirement makes the regulation in accordance with the principle of sustainable development. The derivation of the quantitative risk level can also be done using the same principle assuming continued nuclear power, with many waste repositories, representing a steady state risk burden.

The authors finally want to point out the need to follow up the expected new ICRP recommendations. It is of great value that these are extensively communicated, and that consequences for waste management are derived in a broad international discussion.

INTRODUCTION

The licensing process for a repository for radioactive waste is usually a complex process evolving through many steps, but basically it consists of two components, construction of the repository, and its regulatory assessment. This work is about the second component, and the focus is on human health. Such issues as protection of the environment per se, human intrusion and retrievability are left out, and so is the discussion of regulatory cut-off time periods. Intrusion and institutional control, together with the issue of retrievability, raise a number of philosophical questions about the intruder, about our relation to future societies and their responsibilities, which are avoided in this article for reasons of conciseness.

DEVELOPMENT OF AN ASSESSMENT ENDPOINT

Post-closure disposal requirements for radioactive waste - the Swedish example

In a law, called the Stipulation Act, passed by the Swedish government in 1977, the process of fuelling the newly built reactor Ringhals 3 required the industry to present a "completely safe" solution of the waste problem. The modern Nuclear Activities Act, 1984, replaced the Stipulation Act. In a benevolent interpretation, the notion of a "completely safe " method can be seen as a starting point for quantitative risk assessment. The concept was easily criticized, but alternatives were not presented in a quantitative way.

Global vs. detailed regulatory assessment endpoints?

During the 1980s safety issues for waste disposal were studied internationally, but the concept prevailing today, the dose or risk endpoint, was never the only issue. The idea of a single overall (total system performance) health based standard for a repository was in the future for most countries. In 1985, the US Environmental Protection Agency, EPA, established a regulatory global assessment endpoint in the form of a release standard, and was, therefore, perhaps the most advanced example of a post-closure standard for long-lived radioactive waste at the time, in that it used essentially a single figure of merit, i.e. release, rather than subsystem requirements, to describe the repository.

"Subsystem requirements" were often used to ensure safety for single barrier functions, such as requirements for ground-water travel time. The US Nuclear Regulatory Commission, NRC, in 1983 promulgated a rule [1] which "specified three numerical subsystem performance objectives for repository performance after closure", including the objective that "The pre-emplacement ground-water travel time to the accessible environment (at least 1000 years)". Similarly, the Swedish Nuclear Power Inspectorate at some point stipulated that travel time should be at least 400 years [2].

Although subsystem requirements have the potential to guarantee a minimum quality for individual barrier functions, they do not address the total system performance and the requirements, therefore, have a built-in risk of infringing on the proponent's freedom of making an optimal choice from the proponent's point of view. (We may observe in passing that "optimal" here is used in a different sense than optimization as used by the International Commission on Radiation Protection, ICRP, since only one stakeholder's interest is involved.) It might also be argued – against subsystem requirements – that the regulator, by stipulating detailed technical requirements, takes some responsibility without full information about the final product and therefore without complete knowledge of its consequences.

Risk as the total system endpoint

The concept of risk is often understood to be a general, not necessarily quantitative, aggregation of concepts such as hazard, probability and consequence. However, in technical circles in the field of post-closure standards for repositories, the term "risk" or "health risk" is so well established, that the author prefers to retain it with the following definition: risk is understood as the probability of adverse health effects for an individual, attributable to exposure from radioactive substances from a repository. As does ICRP, the author treats the dose-effect in the low dose region as a linear relation. The non-linear high dose range does not play an important role in this field, which makes the mathematical formulation straightforward, although non-linear effects might readily be incorporated in a formulation as shown in ICRP Publication 55 [3c], section 6.5. The risk for an individual is simply taken to be the product of two probabilities, i) the probability of an individual receiving a dose and ii) the probability of adverse health effects from the dose. In a complex situation, integration should be carried out over all potential doses with their respective probabilities of occurrence.

In the UK in 1992, a guidance document for intermediate level radioactive waste suggested the use of a risk endpoint, [4]. In 1995, the US National Academy of Sciences, NAS, published their findings from a US EPA-funded project [5], initiated by a congressional decision in the Energy Policy Act of 1992. NAS recommended risk as the regulatory assessment endpoint. Today, most countries use dose or risk as a figure of merit for repository safety, although with somewhat different views and interpretations of the requirements for compliance demonstration. Dose and risk refer here to consequences from a hypothetical outflow of radioactive material from the repository to an individual representing a grouping of the public, likely to receive the highest exposure (critical group). In the US, the EPA has developed a substitute for this representative member of the critical group called the Reasonably Maximally Exposed Individual. In either case, the idea is to evaluate a credible case representing those most likely to receive the greater dose because of proximity and lifestyle, but to stay away from an extreme case.

The debate in the US that was being addressed by the NAS report developed from criticism of an earlier standard, still being used for the Waste Isolation Pilot Project, WIPP, but thought to have been inappropriate for a repository located in an unsaturated environment such as Yucca Mountain. A site-specific standard was written for the Yucca Mountain repository, with the existing standard remaining in effect for WIPP and other potential future repositories. The NAS review was probably the most comprehensive and penetrating national contribution to the debate on the endpoint for assessment and regulation. The NAS suggested in the report that risk, calculated from dose, be used and recommended against the use of subsystem requirements, on the ground that they were sub-optimal, as discussed above. The EPA, however, wrote their Yucca Mountain-specific regulation so that compliance is demonstrated by addressing dose probabilistically. The regulatory endpoint is, thus, not risk as defined by the NAS report but dose calculated in such a way that it is related to risk.

Health risk or dose?

A reason to prefer health risk to dose in developing a post-closure standard for radioactive waste disposal is that it is possible to imagine an unlikely scenario resulting in exceptionally high doses to members of the public. In such a case those who may be associated with the highest dose do not have the highest risk from the repository, as the postulated scenario has a low probability and therefore represents a small risk. This paradox can only be reconciled if the probability of the event causing the dose is taken into account. Thus, if the dose is taken to be the expectation value of dose from all conceivable scenarios, the risk and dose standard accomplish essentially the same thing. However, dose is only an intermediate and risk the fundamental quantity, as far as health effects are concerned. Both the NAS and the UK National Radiological Protection Board, NRPB, suggested risk as the preferred endpoint over dose. The NAS study also remarked that because the dose-to-risk factor used might change over time, a risk standard would remain current in the face of such change and thus has an advantage over the expectation value of dose.

There is considerable confusion about the meaning of quantitative risk assessment in connection with radioactive waste disposal. Obviously it implies that a risk is calculated, but since ICRP 60 [3d] presents a risk per dose, all that is required for a risk calculation is a calculated dose. Strictly speaking, a risk regulation does therefore not necessarily imply any particular, e.g. probabilistic, way of assessing data models and scenarios in the description of the radioactive substances potential path from the repository to man. Because the uncertainty may arise in both parameters, within and in the choice between alternative possible models, the arguments must cover a wide range of issues. The use of a broad range of arguments is sometimes referred to as "multiple lines of arguments". The authors takes the view that such arguments performs nothing but a single, but complicated task, i.e. to demonstrate compliance with a risk or dose endpoint, and to promote confidence in the demonstration.

Risk assessment

The development of post-closure risk based regulations must not be seen as a journey from ignorance to wisdom. Some of the reasons that lead to hesitation to accept a risk endpoint in the first place are still a subject of debate. Risk is used differently in other neighboring disciplines. For example, the risk concept in probabilistic safety assessments, PSA, for reactor safety is used in a different way. It is a tool, among others, for safety improvement and precise measures of risk are not the only goal of PSAs. Furthermore, there is still no international consensus around estimation of probabilities for scenarios such as climate change in the safety assessment for repositories. The presentation and the assessment of risk will inevitably be subjective, in that choices are made in the face of uncertainty for a large number of components in the analysis. A more fundamental issue is that probability is a tool for handling uncertainty and that objective probability cannot exist. This is not to say that subjective analysis cannot inspire trust, but trust and confidence will require that uncertainties are carefully addressed, and the reasons behind choices made are given for all the scenarios, models and parameters.

CRITICAL GROUP

ICRP addresses in Publication 81 a number of issues valuable in the development of final disposal plans and strategies. It is probably valuable during the formation of a regulatory framework, but it came at a late time for many countries with major nuclear programs, such as the US, Sweden, the UK and Canada. In Norway, a country with no nuclear power, the national radiation protection authority licensed a disposal facility already in 1999. ICRP 81 was published in1998, the same year as the Swedish regulations about final management were promulgated [6]. In the US, regulations for Yucca Mountain were developed in a series of steps, but the main features of the regulations were depending on the NAS publication in 1995. In a similar process in the UK, the National Radiological Protection Board made recommendations in 1992 [4] as mentioned above, based on ICRP Publication 60, which were later taken into account by the UK Environmental Agency in its regulatory guidance.

The critical group

The critical group is defined in the general recommendations in ICRP 26 [3a]. It may be used in connection with demonstrating compliance with a dose limit and the dose should be taken as the mean dose in a "reasonable homogeneous group" as explained further in ICRP 43 [3b]. ICRP goes on in the same publication (ICRP 43) to say that "in an extreme case, it may be convenient to define the hypothetical group in terms of a single hypothetical individual, for example when dealing with conditions well in the future which cannot be characterised in detail".

The critical group in the far future

In ICRP 81, dealing specifically with long-lived waste, the Commission has not used this idea from Publication 43 but refers to the critical group as if it consisted of a group of persons. In the author's opinion, the notion from Publication 43 is far better, e.g. for educational purposes. The condition of the distant future can easily result in endless speculation, and on top of that the term "group" may invite speculation as to different behavior of different individuals in an already doubtful scenario. It is an indication of the concept's elusiveness that it was the only item on which the National Academy's team could not come to a unanimous agreement [5, Appendices C and D]. Exposure from a source of any group of people living today can be calculated using hypothetical persons, but measurements can be made at any time to verify the calculations. This is not true for persons exposed in the distant future.

The variability within a group existing today can be studied, but it has to be assumed for a group the distant future, in addition to the biosphere and societal conditions.

By taking today's society and biosphere as the regulatory point of departure, the US agencies EPA and NRC have avoided speculation about the distant future. The US EPA in writing its standard for Yucca Mountain focused the regulatory endpoint of an individual as recommended in ICRP 43 whose dose would be near, but not at, the upper end of what would be the critical group for a similar exposure today. Hence the name given to this hypothetical person: the Reasonably Maximally Exposed Individual.

THE PROBLEM OF PREDICTION

When the idea of prediction in the geological domain is transferred to the biosphere, the need for a predicted future gives rise to both confusion and – worse – to the feeling that the lack of credibility of such prediction may "contaminate" the more reliable assessments of geological parameters, as given in Table I below, inspired by a publication from the Organization for Economic Co-operation and Development's, OECD, Nuclear Energy Agency, NEA [7], following the principle that a chain is not stronger that the weakest link.

Table I Years of post-closure predictability for a repository with long-lived waste

Barriers, host rock	Geohydrology	Surface processes	Exposure
100 000 –1000 000	10 000 – 1000 000	100 – 1000	10?

Observe that Table I captures ranges over which different processes are reasonable stable. There may still be large uncertainty over how those processes work even in a period of relative stability.

Understanding the biosphere

The Swedish Radiation Protection Authority, SSI, initiated the international BIOMOVS-project (Biosphere Model Validation Study) in which different models for biosphere modeling were compared and "validated" [validation means here to check that predications comply with observations]. The project's first meeting was held in Basel, Switzerland, October 1985. The project had an international follow-up, BIOMOVS-II, and there have also been recent advances in biosphere modeling as a result of the efforts of the Biosphere Model Assessment (BIOMASS) program, under the auspices of the International Atomic Energy Agency (IAEA). During these projects issues about the future biosphere and society have been debated intensively during several decades, but these groups of environmental experts have only had a limited overlap with the experts working with the total system safety analysis, such as the OECD/NEA working groups, the former Performance Assessment Advisory Group, PAAG, and the present Integration Group for the Safety Case, IGSC. It follows from this that, in addition to building up a technical understanding and modeling capability of radionuclides' behavior in the biosphere, it is necessary that appropriate assumptions be made about future human behavior and biosphere, and that the solutions found can be broadly acceptable. IGSC has recently held topical seminars highlighting the biosphere in order to bring the disciplines closer together.

Human action in the biosphere

The above activities pertain mainly to the mission of understanding nuclide transport in the biosphere. Another more complex issue is what conditions to assume regarding humans in the biosphere, such as their distribution of water and foodstuff that may influence the possible exposure from the repository's radioactive substances.

The performance assessment community has often displayed a certain uneasiness in connection with biosphere issues, and suggested that the biosphere be de-coupled from the performance assessment [7]. The idea of de-coupling doesn't go well together with a total system performance risk endpoint, however.

Looking at the whole system but one component would just constitute another subsystem measure. At the other hand, the authors behind Table I have a point that must be taken into account.

Part of the problem presented by the uncertainty of the future society and biosphere can be avoided by the use of an interpretation of sustainable development as explained below. In this concept, the future biosphere and society are treated as a subjective, rather than an objective, phenomenon.

SUSTAINABLE DEVELOPMENT

ICRP 81 recommends the use of a reference biosphere with today's conditions for demonstration of compliance. There is no justification for this choice given in the recommendations, but it is the same as has been suggested by the NAS and others, e.g. the Swedish Radiation Protection Authority's post-closure regulations. This choice is intuitively sound, in that is refers to a known and consistent society, and it is a natural reference for all other safety work in society. However, the author wishes to take a step further and suggest a philosophical framework for the treatment of the biosphere, which avoids the above problem of predicting the future biosphere and society, simply by referring to the principle of sustainable development. The Brundtland Commission defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [8].

The requirement from the Brundtland Commission, in terms of a repository for long-lived solid waste, is thus that risk from a hypothetical outflow of radioactive substances from a repository must meet the risk limit for a number of scenarios for the biosphere and society, such that they allow future generations to fulfill their needs within a broad spectrum of human activities and environmental conditions. Looking at the future this way excludes any need for prediction. The future conditions are seen as results of conscious choices constrained by consequences, i.e. risks, from the repository's possible releases, which in turn are limited by the regulatory requirements. Observe that there is no easy way to define or limit the "broad spectrum of human activities..". The main difference, introduced by the view of sustainable development, is that decisions about appropriate assumptions is taken out of the realm of predictive science and into that of societal judgment.

The regulator can either prescribe the condition to be assumed for the biosphere and society in the future as a basis for compliance assessments, e.g. assume that the future conditions are as today's conditions, and have the benefit of a strict regulatory assessment, or leave open the future development, i.e. allow for many possible conditions in the future. The latter leads to a broader and more illustrative, but also more subjective regulatory assessment. One alternative may fit better in a country's legal tradition than another, but both aspects need to be addressed.

By using use present-day lifestyle for compliance demonstration, the US bodies EPA and NRC avoid the problem of speculation about future human behavior, but the regulations do not address hypothetical consequences from the repository for people with alternative lifestyles/biospheres. The author assumes that such issues, "what would happen if people lived differently, e.g. in a big city/in a nearby location or further away, etc", can be addressed within the dialogues between the implementer, public and decision-makers.

We note here that this example also illustrates a constraint in the risk integration procedure, namely that the hypothetically highest exposed group must be placed in a consistent biosphere. In the case of the two locations where regulations are in place in the US, the WIPP site in New Mexico and the Yucca Mountain site in Nevada, regulations take into account the likely system and radionuclide pathway changes due to a climate change, and the unlikely pathway changes resulting from a volcanic event, are required to be explicitly taken into account in the compliance calculations. Such changes would not make the current regional lifestyle impossible. In Sweden, a repository, SFR, is located with the disposal facility presently projecting into rock under the sea. People are fishing today near this location, but may be farming in a few thousand years, so that the term "present day activities" if taken literally will have no meaning. Some scenarios may come into conflict with the lifestyle assumed in the exposure assessment. A farmer cannot have a dose in which 50% of the total exposure comes from fish caught over the topsoil.

The principle of sustainable development also offers a way to derive a regulatory risk level for post-closure performance along the following lines. The risk from the repository outflow may have a flat shape, i.e. "radioactive contamination of the biosphere due to releases from the repository is likely to remain relatively constant over periods that are considerably longer than the human life span", to quote ICRP 81. For some repositories planned today, releases during thousands of years may take place from a repository with an inventory from only 50 years of energy production, from the period around 1970 to 2020. Surely, a release with such endurance can only be accepted if it is of negligible size. A view on nuclear power incorporating sustainable development requires that effects of several such repositories ~~of~~ superimposed in some way would still be acceptable, i.e. in the range not exceeding ICRP upper bound of 10^{-5} as a yearly risk. For this reason, large groups should not be subject to risks higher than 10^{-6} per year. If several repositories were placed so that their effects might superimpose, a hypothetical test person or a critical group from one repository will not necessarily belong to the critical group for another. A yearly risk of up to 10^{-5} from a repository might therefore be acceptable if proper assumptions have been made to show that the test person is likely to represent the population group with the highest potential dose.

The assumption above with several repositories should not be taken too literally. It simply represents sustainable development, i.e. a steady state risk load, low enough to allow "future generations to meet their own needs".

SSI takes credit for the idea of sustainable development as a point of departure for regulations, but it is potentially also a merit for nuclear power production, assuming such regulations can be met. It is a major aspect of sustainable development for this energy form, that even indefinite production would not pollute the environment above consequences in the trivial dose range.

INTERNATIONAL HARMONIZATION

Internationally, a large part of the regulatory work for post-closure performance has been made without access to ICRP 81. The general recommendations in ICRP 60 were initially more important for a number of countries in Europe and the US than the other ICRP recommendations on waste existing at that time, which did not address the long-term aspects sufficiently. It is the author's hope and belief that ICRP will have a stronger impact on the waste regulatory activities in the future.

The International Atomic Energy Agency

IAEA is in the process of issuing a Safety Requirement document in its Safety Series, on geological disposal in cooperation with NEA. The final document is likely to reference ICRP 81.

BIOMASS

The report from the BIOMASS project on reference biospheres has recently been published [9] and there are a number of valuable and practical suggestions on practical approaches to describe exposure scenarios.

Swedish guidance document

In Sweden, the Swedish Radiation Protection Authority, SSI, is preparing a guidance document on the post-closure period. In this work, international guidance is of great value.

European Union

In the European Community, decisions will be taken in 2004 on two proposed directives on safety and on waste management, referred to as the "Nuclear Package". The safety directive requires a common safety standard for all Members States in the Community. The debate of the safety directive is focused on reactor safety, but the directive also covers waste installations, i.e. a common waste safety standard is required. In the draft preamble, the Council refers to Article 2[b] of the EURATOM Treaty, implying that the Community must "*establish uniform safety standards to protect the health of workers and of the general public and ensure that they are applied*". If the Council accepts the directive, then a debate may follow about a common post-closure standard for the European Community, and ICRP's recommendations will be important also for that work.

CONCLUSION

The view on sustainable development is the reasoning of SSI in its post-closure regulations for spent nuclear fuel. It does not add or subtract to the numbers given in existing international recommendations such as ICRP's, but is essentially a philosophical framework, both regarding the level of protection and the assessment endpoint. The latter requires the implementer to look at a number of different scenarios not because they are estimated future states, but as freedom of choices for future generations, held open and passed on to them by the present generation.

It is of great value that post-closure standards are discussed internationally. ICRP, IAEA and OECD/NEA have made, or are in the processes of making, important progress on the subject. ICRP is preparing new general recommendations that it plans to issue in 2005. Waste management is not mentioned in the material that has been released to date. It is therefore important that possible consequences for waste management are continuously discussed.

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