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Philosophical and technical/scientific bases

for characterization of future societies and biospheres in assessment of compliance with regulations for long lived radioactive waste

Mikael Jensen, SSI, SE-171 06 Stockholm, mikael.jensen@ssi.se

1 Introduction

1.1 BACKGROUND

This is a position statement to be discussed at the Regulators' Workshop, "The Role of Future Society and Biosphere in Demonstrating Compliance with High-level Radioactive Waste Disposal Standards and Regulations", Stockholm, 11-13 September 2001.

1.2 SCOPE

This work is restricted to the post-closure performance of a deep repository for radioactive waste. The focus is on high-level waste, but some of the principles presented may also be relevant for other types of long-lived solid radioactive wastes. The treatment of the issue is limited to individual dose or risk. Collective dose is not discussed.

1.3 OBJECTIVE

The objective of this document is to provide a basis for discussion, directed towards a common regulatory view on the issues of society and biosphere in judging compliance with regulation. Since the regulatory framework for radioactive waste disposal varies considerably between countries, the suggestions presented relate primarily to judgment of compliance with regulations.

2 Definition of radiation protection and safety for an unknown society and biosphere

2.1 THE PROBLEM OF AN UNKNOWN FUTURE

The is consensus among physicists that the mathematical model for radioactive decay can be described accurately up to millions, and perhaps even billions, of years. Many geological formations have been stable for millions of years, e.g. the Fennoscandian shield.

There is also consensus in the so-called performance assessment community that the processes involved in the description of the long-term safety can modeled and assessed [Ref. 1]. However, even using given models, the calculation is never completely straightforward. In reference 1 from the OECD's Nuclear Energy Agency, NEA, it also recognized that although the necessary models exist, "quantitative safety assessments will always be complemented by qualitative evidence".

Many safety analysis results indicate that an outflow or release from the repository will not occur until after many millennia, and this raises the question of how to model the transport in the biosphere and the uptake by people in a distant future.

The large variation of the biospheric conditions adds to the uncertainty of exposure to man from a hypothetical release, but there is no doubt that the ambiguities in the definition of biosphere and society in the distant future still is a main obstacle to a clear and coherent description of the problem of safety analysis. The descriptions of the development of the engineered barriers and geosphere, in terms of radionuclide transport, are usually put forward as predictions or at least as giving reasonable boundaries for the repository's development. Such a procedure cannot be carried out for the biosphere with the same degree of confidence, and this has led to several suggestions for the treatment of the biosphere in safety assessments.

Engineered and geological barriers delay and dilute releases, the biosphere may dilute only. In this quality the biosphere can still contribute partly to safety, since the biosphere in different sites may have different characteristics. However, the biosphere is usually not seen as contributing to safety. Operators/implementers will not trade positive values from the robust geosphere for elusive qualities of an ever-changing environment. This problem is discussed in the next sections.

2.2 THE BIOSPHERE AND THE GEOSPHERE/BARRIER SYSTEM

In a document from a group within the Performance Assessment Advisory Group, PAAG, of NEA, a case was made for a separate treatment of the biosphere [Ref. 2]. The article gave a "Case for Benchmark Biospheres and De-coupling of Biosphere and EBS Geosphere Analyses", EBS being an acronym for the "Engineered Barrier System".

According to the article,

> *The characteristics of a repository and its environment will change over time, e.g. due to degradation processes, geological and climatic change and human-related developments. The extent to which such changes can be predicted into the future varies between the different elements of the system. In particular, the conditions in the surface environment at times in the far future could vary widely, and it is not possible to predict the patterns of future human behaviour and local resource use that will determine radiation doses received by humans living in the future.*

The advantage of de-coupling EBS/geosphere from the biosphere is that this part does not suffer from the above uncertainties. Is indeed a valid benefit, and this approach has been used extensively in performance assessments, used here as synonymous to safety assessment, internationally. The problem has not been the de-coupling in itself, but rather the highly unbalanced focus on one part of the de-coupled components, the engineered barrier system and the geosphere.

Although there are many reasons to concentrate safety work on barriers and the geology, there can be no doubt that the reluctance to incorporate the biosphere into the performance assessment is, apart from possible cross-discipline territorial friction, to a high degree has originated in the lack of a well-defined system to model, and from the lack of a rationale for choosing one.

2.3 THE COMPLEXITY OF SIMPLICITY

In the beginning of the 90-ties, the performance assessments experts often used, or discussed the value of using, a reference biosphere with relatively arbitrary characteristics. The reference biosphere concept was understood and described as a “simple biosphere”. A simple model of a complex reality may be basically sound, just as we would expect a simple model to give a reasonable description for basic scenarios. The similarity of the reference biosphere to the real world, however, was often an open question.

The use of the word “biosphere” in this context was clearly questionable and invited confusion. A more correct concept, used in some later studies, would have been “an axiomatic biosphere”, that is *if* the biosphere had been as assumed *then* the model would produce the presented results.

The word “biosphere” was poorly explained in its other dimensions as well. The unsolved problem was, and still is, the concept of a “simple” future. The question is what the reference biosphere is a model of. Is it today’s biosphere at a certain site, the biosphere of tomorrow, in need of prediction to be justified, or something else? The term “reference biosphere” implied that some relation to the real biosphere must exist.

Even if the chosen biospheres may not have been scientifically justifiable in the given context, and sometimes completely unrelated to any real biosphere, one might argue that it would still permit assessor a dose for a certain design, and to achieve results for optimization, and that such a procedure would be justifiable, although obviously subject to the condition that the assessment is revisited and recalculated later with more realistic models. There are still several disadvantages to this approach, however. The fundamental problem of the treatment of the biosphere by recurrent evaluation of confidence was postponed and has still not come about. It prevented the iterative process of growing system understanding by interaction between key disciplines and reaching for robustness by recognizing all interactions and uncertainties.

Such a fruitful scientific development has indeed occurred within BIOMOVS and BIOMASS, but it has been restricted to biosphere. It was natural for several reasons in the beginning, but now these reasons are no longer valid.

2.4 SAFETY

A fundamental reason for the disparate role of the biosphere in the performance assessment community was a prevailing feeling in the early 90-ties, and still widely held, that “safety” must be explained as a feature related to the barriers and the geosphere alone, and calculations of hypothetical outflow to the biosphere and to man serve the purpose of illustration, at best.

Sooner or later the question for all programs for radioactive waste disposal will be “is the repository safe or dangerous? ”. The answer depends on what “safety” means. It is sometimes described as a concept that defies description, “a feeling of well-being”.

In advanced programs with pronounced regulatory input, the regulator's view of safety has a more important role than for programs in early stages where the operator/implementer's technical efforts are in focus. The questions from the public in candidate sites adds to the focus on safety and on the movement towards answers in quantifiable terms.

There has been a parallel development in several countries of the safety goal in the 90-ties, although the development was somewhat uneven with countries such as USA, working on rules for waste repositories much earlier.

2.4.1 Safety as such, "completely safe"

In a law passed by the Swedish government 1977, the process of fuelling the newly built reactor Ringhals 3 required the industry to present a "completely safe" solution of the waste problem. A new law, the Swedish Nuclear Activities Act 1984, changed this. According to the new law, draconian compliance to the "completely safe" concept was replaced by traditional authority judgement of compliance.

Although very unsophisticated, the requirement of a "completely safe " disposal method can nevertheless be seen, in an indirect way, as a starting point for quantitative risk assessment for repositories in Sweden. The concept was easily criticized, but alternatives were not presented in a quantitative way. Seen in retrospect, the two alternatives in the discussion were often either i) quantitative and dubious, described by the physical impossible "0"- release, or ii) dubious because of a complete relativism and a lack of quantification.

2.4.2 The preferred endpoint of the 90-ties: dose and risk

The US Environmental Protection Agency's (EPA) standard 40 CFR Part 191 limited both the release and the dose. The regulator, the Nuclear Regulatory Commission, NRC, suggested additional so-called sub-system requirements for the envisaged repository for high-level civilian reactor waste.

The US Congress, in the Energy Policy Act 1992, directed the EPA to promulgate a separate standard for a repository that might be built under Yucca Mountain [Ref. 3] and asked the National Academy of Sciences (NAS) to advice EPA in this matter. The NAS, through its body the National Research Council (NRC) was asked [Ref. 4] to investigate "Whether a health-based standard based upon doses to individual members of the public from releases to the accessible environment . . . will provide a reasonable standard for the protection of the health and safety of the general public", and to investigate two other issues in the field of institutional control and human intrusion. The National Academy of Sciences suggested in reference 3 that human health be the only measure of merit for regulatory purposes and came out against sub-system requirements which in their view – and in the author's – could lead to sub-optimized solution.

During 1995, the same year the NAS study, the author published an essay in collaboration with two scientists with connections to the Institute of Theory of Sciences in Gothenburg, Sweden [Ref. 5]. The authors commented that the whole high-level waste management program in Sweden lacked environmental guidance mechanisms and argued that such principles should be imposed on the program. The NAS study also had an impact on the formulation of radiation protection criteria in Sweden. The Swedish Radiation Protection Institute's, SSI, criteria for long-lived waste [Ref. 6], were promulgated 1998. Risk was chosen as the preferred quantity for the regulation in line with NAS's recommendations, but SSI never saw a fundamental difference between risk and dose, understood as the dose expectation value.

Also in the UK, the Environmental Agency presented a risk criterion or "risk target" around the same time, 1994 [Ref. 7]. Today Canada, USA, UK, Sweden, and Finland all state the endpoint in the form of dose or risk.

In the face of these developments it is obvious that safety in itself, understood as barrier strength and geological siting, cannot be enough, at least not in a country where the program has matured towards a license application. It is now both necessary and urgent that the regulators can define the biosphere.

The concept of safety may still be understood defined in many ways, but one of these must be related to dose or risk.

2.5 THE GOAL AND ITS ACHIEVEMENT

It must be emphasized that none of the above regulators believe that the goal is easily achieved. The emergence of a clear goal for the assessment endpoint was a major step forward, however. Before the mid 90-ties, a view was held by many that the expert's confidence was sufficient, and not only that; the uncertainty were so large that any attempt to calculate them were doomed fail.

Before, the uncertainties were so large that they "extended" to the goal itself to make it unclear and lacking transparency. Now, all uncertainties still exist, but we at least have a goal.

The handling of uncertainties in compliance is explained in various ways. Firstly, no regulator will ever accept a risk value alone as a basis for judging compliance. In the regulatory review it would have to be presented along with all its components, all the assumptions made and the reason for making them. Most regulators would also accept so called multiple lines of reasoning. It is an equivalent to the above statement that "quantitative safety assessments will always be complemented by qualitative evidence" [Ref. 1].

In SSI's comments to its regulations [Ref. 6] the view of risk is explained:

> *In many cases it is not possible to calculate an "exact" risk, on the basis of this formula. Instead, the risk must be assessed from the risk picture which is obtained by weighing together consequences and probabilities for different event sequences. In this context, the concept of the risk scenario refers to calculated, or otherwise assessed, consequences and probabilities for a relevant selection of possible event sequences (scenarios). The consequences must be calculated or estimated so that they include uncertainties in the assumptions and data upon which the calculations or assessments are based. The chosen scenarios must in their entirety give a full picture of the risks attributable to the final repository.*

3 Several solutions needed

If the safety judgment of a repository requires modeling of the biosphere, the question still is “what biosphere? ”. This is synonymous to the question “safety for whom? ”. The regulatory handling of the question requires input from several disciplines: philosophy, jurisprudence, science and technology.

3.1 THE PHILOSOPHICAL SOLUTION

Whatever endpoint a regulator uses in a license procedure, the regulator must, if the procedure is successful, take over some or all responsibility to guarantee that the site is safe and will remain so in the future.

In the particular case of a regulation with a dose or risk endpoint, the regulator may be asked to prove that the criteria used indeed describe a safe situation. The regulator is therefore also faced with the question “safety for whom?”

3.1.1 Sustainable development

Sustainable development, defined by the Brundtland Commission as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” [Ref. 8], relates to a number of issues such as population, health, food, species and ecosystems, energy, industrial development, urbanization, societal issues and economy, and how these global challenges could be met within a long term strategy.

The issue of nuclear waste cannot be separated from the whole issue of electricity production, but some issues are still relevant for waste regulation. The Swedish criteria have used a semi-quantitative interpretation of the above text as a point of departure for the regulations [Ref. 9] and SSI invites regulators to discuss the regulations. However, as a proposal for the international community of regulators, a more general approach is described below.

3.1.2 One philosophical solution

For the purpose of the task in this work, the author recommends a general strategy. The proposed solution is embedded in the term “the ability of future generations to meet their own needs”. If this formulation is taken as the fundamental goal and the basis for regulations it can be expressed as a commitment to regulate in way that does not encroach on future generation’s ability to meet their needs.

The “solution” does not solve the problems of what biosphere to model, but it does set the scene for a structured approach to the problem. It relates directly to the Brundtland Commission, it is not depending on predictions and it is much more easily understood both by experts and laymen. It doesn’t require a particular style of living to be described in the biosphere calculations but it follows from the commitment that a broad number of activities must be available for future generations. The regulator’s responsibility and associated burden of proof must take into account such a range of activities available for future generations.

It is also more intimately connected with the general principles in the international consensus document concerning ethical principles for final management. These principles have been summarized in IAEA's publication "The Principles of Radioactive Waste

Management" [Ref. 10] and in the "Collective Opinion" concerning the environmental and ethical principles of geological final disposal prepared by the Radioactive Waste Management Commission (RWMC) of OECD/NEA [11].

The most important criteria or principles for the post-closure phase of a repository are:

> *<u>Principle 1: Protection of human health.</u>*
> *Radioactive waste shall be managed in such a way as to secure an acceptable level of protection for human health.*
>
> *<u>Principle 2: Protection of the environment</u>. Radioactive waste shall be managed in such a way as to provide an acceptable level of protection of the environment.*
>
> *<u>Principle 4: Protection of future generations.</u> Radioactive waste shall be managed in such a way that predicted impacts on the health of future generations will not be greater than relevant levels of impact that are acceptable today.*

These principles all relate in a natural way to the suggested goal. Just as the idea of sustainable development, they don't require any predictions to be made.

3.2 THE SCIENTIFIC SOLUTION

In 1985, following an initiative from The Swedish Radiation Protection Institute, SSI, the Biosphere Model Validation Study, BIOMOVS, started and was later followed by BIOMOVS II. Theme 1 of the IAEA project on Biosphere Modeling and Assessment Study, BIOMASS, continued the effort with wide international support, with a final report this year. From these projects and other initiatives, the modeling capability and the knowledge is much better today than before BIOMOVS and BIOMASS.

A set of rules has emerged within the BIOMASS co-operation to describe a process of defining a reference biosphere, based on a set of well-defined procedures. It does not solve the problem of predicting an unknown future, but it does give advice to the modeler with a certain biosphere in mind. It also reminds the modeler that the "assessment context" must be recognized as an independent issue from the start.

It should also be mentioned that the project BIOMASS is not reduced to technical issues. Much of the issues presented in this work have been discussed in BIOMASS. BIOMASS has also acknowledged the need to address the assessment context

3.3 JURISPRUDENCE AND THE BIOSPHERE

The legal signification of regulation of releases in thousand of years, and in some cases hundreds of thousands of years, is unclear. Usually, when such extremely long periods are mentioned in regulations, the requirements are limited to a qualitative description, but projections even of thousands of years are unheard of in legal proceedings. This was a major consideration in the formulation of the Swedish radiation protection criteria.

The next section discusses the time periods.

4 The time dimension

4.1 THE SWEDISH CRITERIA

The Swedish radiation protection criteria have no time cut-off, but two time periods after closure are specifically mentioned.

The general requirements are given in **10 §**

> *An assessment of a repository's protective capability shall be reported for two time periods of orders of magnitude specified in 11 -12 §§. The description shall include a case, which is based on the assumption that the biospheric conditions which exist at the time that an application for a licence to operate the repository is submitted will not change. Uncertainties in the assumptions made shall be described and taken into account in the assessment of the protective capability.*

The two time periods are described in the regulations in paragraphs 11 and 12

> *The first thousand years following repository closure*
> **11 §** For the first thousand years following repository closure, the assessment of the repository's protective capability shall be based on quantitative analyses of the impact on human health and the environment.
>
> *The Period after the first thousand years following repository closure*
> **12 §** For the period after the first thousand years following repository closure, the assessment of the repository's protective capability shall be based on various possible sequences for the development of the repository's properties, its environment and the biosphere.

Society
The rationale for the choice of a dividing line was the observations given in previous section. SSI took a humble view of man's ability to predict, and thought that a strict requirement in balance with tradition legal thinking is only possible for a "historical" period. Society, biosphere and the geology all have a particular input to the decision of the time periods necessary in the studies, and SSI chose the societal aspect as a point of departure. SSI argued that the choice of thousand years is a reasonable upper boundary, which distinguishes time-periods that can be associated with existing judicial traditions from time-periods associated with an unknown future.

Biosphere
Some changes in the biosphere of geological origin can be foreseen in this time scale and even longer than 1000 years, such as the land uplift on the Swedish Baltic Sea cost. This is not to say that the society's use of the land created may be predicted, but it natural to question what impact this process may have on the repository, and to require that this process be described in the safety assessment. Such issues as land uplift would require studies to be made in the ten thousand year range.

Geosphere
The above reasons for requiring the land uplift to be described is similar to the question of the impact of a glaciation on the repository. It is unknown when, or perhaps even *if*, this process might set in, but it is reasonable to require that it is described. It is natural to ask questions about glaciation even with limited knowledge of the distant future.

4.2 ADAPTING COMPLIANCE JUDGMENT TO THE TIME PERIODS

Ideas for handling the biosphere for different time periods have been discussed internally in SSI. The Finnish Radiation and Nuclear Safety Authority, STUK, has presented similar ideas in a more definite form [Ref.12]. Reference 12 represents an interesting basis for a discussion on time periods.

4.2.1 The first period

STUK considers the first period, described as "*an assessment period that is adequately predictable with respect to assessments of human exposure but shall be extended to at least several thousand years*". For this period, the operator must meet the annual dose criteria of 0.1 mSv.

4.2.2 Beyond the first period

Beyond this assessment period STUK has taken responsibility for the biosphere definition and has derived constraints for activity release to the biosphere through a scenario screening procedure.

4.3 A COMMON VIEW OF TIME PERIODS

The view presented by STUK can be reconciled with the Swedish regulation periods, if the first thousand-year limit is combined with the longer period where such input to biosphere change as land uplift is expected.

A possible view would be to define this period up to ten thousand years. After this period the regulator might define the biosphere and implicitly also accept the burden of proof that the derived constraints also represent a safe situation.

5 Conclusion

The development in last decade has shown a dramatic change in the regulatory view of the role of society and the biosphere. There is now a growing international understanding between regulators that dose and risk endpoint can be used by operators/implementers and that results can be assessed in compliance judgements. Much of the initial uncertainty is giving way to deeper understanding and regulatory decisions. There are now answers to most of the questions that earlier represented obstacles to a total system assessment.

It is therefore timely that regulators discusses the challenges in judging compliance with dose and risk regulations and the role of society and the biosphere in that effort. The author believes that these topics should have a high priority in the discussions between regulators.

6 References

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