The Swedish Radiation Protection Authority's guidelines on the application of the regulations (SSI FS 1998:1) concerning protection of human health and the environment in connection with the final management of spent nuclear fuel and nuclear waste;

decided upon on 5 September 2005.

Guidelines concerning geological disposal of spent nuclear fuel and nuclear waste

On section 1: Area of application

These guidelines are applicable to final geological disposal of spent nuclear fuel and nuclear waste. The guidelines cover measures undertaken with a view to develop, site, construct, operate and close a repository, which can affect the protective capability of the repository and environmental consequences after closure.

The guidelines are also applicable to measures that are to be undertaken with spent nuclear fuel and nuclear waste before final disposal and which can affect the protective capability of the repository and environmental consequences after closure. This includes activities at other installations such as the conditioning of waste that takes place by casting waste in concrete and by encapsulation of spent nuclear fuel, as well as transportation between installations and steering of waste to different repositories, including shallow land burials for low-level nuclear waste that are licenced in accordance with section 19 of the Ordinance (1984:14) on Nuclear Activities. However, the guidelines, like the regulations, are not applicable to the landburial itself.

On section 2: Definitions

Terms used in the Radiation Protection Act (1988:220), the Act (1984:3) on Nuclear Activities and SSI's regulations on protection of human health and the environment in connection with final management of spent nuclear fuel and nuclear waste have the same meaning in these guidelines. In addition, the following definitions are used:

Scenario:	A description of the development of the repository given an initial state and specified conditions in the environment and their development.
Exposure pathway:	The migration of the radioactive substances from a repository to a place where human beings or an organism covered by the environmental protection regulations are present. This includes dispersion in the geological barrier, transport with water and air flows, migration in ecosystems and uptake in human beings or organisms in the environment.
Risk analysis:	An analysis with the aim to clarify the pro-

tective capability of a repository and its consequences with regard to the environmental impact and the risk for human beings.

On sections 4, 8 and 9: Holistic approach etc., intrusion and access

Optimisation and Best Available Technique

The regulations require that optimisation must be performed and that best available technique should be taken into account. Optimisation and best available technique should be applied in parallel with a view to improving the protective capability of the repository.

Measures for optimisation of a repository should be evaluated on the basis of calculated risks.

Application of best available technique in connection with final disposal means that the siting, design, construction, operation and closure of the repository and appurtenant system components should be carried out so as to prevent, limit and delay releases from both engineered and geological barriers as far as is reasonably possible. When striking balances between different measures, an overall assessment should be made of their impact on the protective capability of the repository.

In cases where considerable uncertainty is attached to the calculated risks, for instance, in analyses of the repository a long time after closure, or analyses made at an early stage of the development work with the repository system, greater weight should be placed on best available technique.

In the event of any conflicts between application of optimisation and best available technique, priority should be given to best available technique.

Experiences from recurrent risk analyses and the successive development work with the repository should be used in the application of optimisation and best available technique.

Collective dose

The regulations require an account of the collective dose from releases that take place during the first thousand years after closure. For final disposal the collective dose should also be used in comparisons between alternative repository concepts and sites. The collective dose need not be reported if the repository concept entails a complete isolation of the spent nuclear fuel or the nuclear waste in engineered barriers during the first thousand years after closure.

Occupational radiation protection

An account should be given of measures undertaken for radiation protection of workers that may have a negative impact on the protective capability of the repository or make it more difficult to assess.

Future human action and the preservation of information

When applying best available technique, consideration should also be given to the possibility to reduce the probability and consequences of inadvertent future human impact on the repository, for instance, inadvertent intrusion. Increased repository depth and avoidance of sites with extractable mineral assets may, for instance, be considered to decrease the probability of unintentional human intrusion.

Preservation of knowledge about the repository could reduce the risk of future human impact. A strategy for preservation of information should be produced so that measures can be undertaken before closure of the repository. Examples of information that should be taken into consideration are information about the location of the repository, its content of radioactive substances and design.

On sections 5 – 7: Protection of human health and the environment

Risk for the individual from the general public

The relationship between dose and risk

According to the regulations, the recommendations of the International Committee for Radiation Protection (ICRP) are to be used for calculation of the harmful effects of ionizing radiation. According to ICRP publication no. 60, 1990, the factor for conversion of effective dose to risk is 7.3 per cent per sievert.

The regulation’s criterion for individual risk

According to the regulations, the risk for harmful effects for a representative individual in the group exposed to the greatest risk (the most exposed group) shall not exceed 10^{-6} per year. Since the most exposed group cannot be described in an unambiguous way, the group should be regarded as a way of quantifying the protective capability of the repository.

One way of defining the most exposed group is to include the individuals that receive a risk in the interval from the highest risk down to a tenth of this risk. If a larger number of individuals can be considered to be included in such a group, the arithmetic average of individual risks in the group can be used for demonstrating compliance with the criterion for individual risk in the regulations. One example of such exposure situation is a release of radioactive substances into a large lake that can be used as a source of drinking water and for fishing.

If the exposed group only consists of a few individuals, the criterion of the regulations for individual risk can be considered as being complied with if the highest calculated individual risk does not exceed 10^{-5} per year. An example of a situation of this kind might be if consumption of drinking water from a drilled well is the dominant exposure path. In such a calculation example, the choice of individuals with the highest risk load should be justified by information about the spread in calculated individual risks with respect to assumed living habits and places of stay.

Averaging risk over a lifetime

The individual risk should be calculated as an annual average on the basis of an estimate of the lifetime risk for all relevant exposure pathways for every individual. The lifetime risk can be calculated as the accumulated lifetime dose multiplied by the conversion factor of 7.3 per cent per sievert.

Averaging risk between generations

Deterministic and probabilistic calculations can both be used to illustrate how risk from the repository develops over time. A probabilistic analysis can, however, in certain cases give an insufficient picture of how an individual detrimental event, for instance, a major earthquake, would affect the risk for a particular generation. The probabilistic calculations should in this case be supplemented as specified in Appendix 1.

Selection of scenarios

The assessment of the protective capability of the repository and the environmental consequences should be based on a set of scenarios that together illustrate illustrate the most important courses of development of the repository, its surroundings and the biosphere.

Handling of climate evolution

Taking into consideration the great uncertainties associated with the assumptions on climate evolution in a remote future and to facilitate the interpretation of the risk to be calculated, the risk analysis should be simplified to include a few possible climate evolutions.

A realistic set of biosphere conditions should be associated with each climate evolution. The different climate evolutions should be selected so that they together illustrate the most important and reasonably foreseeable sequences of future climate states and their impact on the protective capability of the repository and the environmental consequences. The choice of the climate evolutions that serve as the basis for the analysis should be based on a combination of sensitivity analyses and expert judgements. Additional guidance is provided in the section with guidelines on sections 10 – 12.

The risk from the repository should be calculated for each assumed climate evolution by summing the risk contributions from a number of scenarios that together illustrate how the more or less probable courses of development in the repository and the surrounding rock affects the repository’s protective capability and environmental consequences. The calculated risk should be reported and evaluated in relation to the criterion of the regulations for individual risk, separately for each climate evolution. The repository should thus be able to be shown to comply with the risk criterion for the alternative climate evolutions. If a lower probability than one (1) is stated for a particular climate evolution, this should be justified, for instance, by expert judgements.

Future human action

A number of scenarios for inadvertent human impact on the repository should be presented. The scenarios should include a case of direct intrusion in connection with drilling in the repository and some examples of other activities that indirectly lead to a deterioration in the protective capability of the repository, for example by changing groundwater chemistry or the hydrological conditions in the repository or its surroundings. The selection of intrusion scenarios should be based on present living habits and technical prerequisites and take into consideration the repository's properties.

The consequences of the disturbance of the repository's protective capability should be illustrated by calculations of the doses for individuals in the most exposed group, and reported separately apart from the risk analysis for the undisturbed repository. The results should be used to illustrate conceivable countermeasures and to provide a basis for the application of best available technique (see guidelines on optimisation and best available technique).

An account need not be given of the direct consequences for the individuals intruding into the repository.

Special scenarios

For repositories primarily based on isolation of the spent nuclear fuel or nuclear waste, an analysis of a conceivable loss, during the first thousand years after closure, of one or more barrier functions of key importance for the protective capability should be made separately from the risk analysis. The intention of this analysis should be to clarify how the different barriers contribute to the protective capability of the repository.

Biosphere conditions and exposure pathways

The future biosphere conditions for calculations of consequences on human beings and the environment should be selected in agreement with the assumed climate state. Unless it is clearly unreasonable, however, today's biosphere conditions at the repository and its surroundings should be evaluated, i.e. agricultural land, forest, wetland (mire), lake, sea or other relevant ecosystems. Furthermore, consideration should be taken to land uplift (or subsidence) and other predictable changes.

The risk analysis can include a limited selection of exposure paths, although the selection of these should be based on an analysis of the diversity of human use of environmental and natural resources which can occur in Sweden today. Consideration should also be taken to the possibility of individuals being exposed to combinations of exposure pathways within and between different ecosystems.

Environmental protection

The description of exposure pathways should also include exposure pathways to certain organisms in the ecosystems that should be included in the risk analysis. The concentration of radioactive substances in soil, sediment and water should be accounted for where this is relevant for the respective ecosystem.

When a biological effect for the identified organisms can be presumed, a valuation should be made of the consequence this may have for the affected ecosystems, with the view to facilitating an assessment of impact on biological diversity and a sustainable use of the environment.

The analysis of consequences for organisms in “today’s biosphere”, carried out as above, should be used for the assessment of environmental consequences in a long-term perspective. For assumed climates, where the present biosphere conditions are evidently unreasonable, for instance, a colder climate with permafrost, it is sufficient to make a survey based on knowledge currently available about applicable ecosystems. Additional guidelines are contained in Appendix 2.

Reporting of uncertainties

Identification and assessment of uncertainties in for instance, site-specific and generic data and models should take place in accordance with the instructions given in general advice from the Swedish Nuclear Power Inspectorate. The different categories of uncertainties, which are specified there, should be evaluated and reported on in a systematic way and evaluated on the basis of their importance for the result of the risk analysis. The report should also include a motivation of the methods selected for handling different types of uncertainties, for instance, in connection with the selection of scenarios, models and data. All calculation steps with appurtenant uncertainties should be reported on.

Peer review and expert panel elicitation can, in the cases where the basic data is insufficient, be used to strengthen the credibility of assessments of uncertainties in matters of great importance for the assessment of the protective capability of the repository.

On sections 10 – 12: Time periods

Two time periods are defined in the regulations: the period up to a thousand years after closure and the subsequent period.

For longer time periods, the result of the risk analysis should be successively regarded more as an illustration of the protective capability of the repository given certain assumptions.

Limitation of the risk analysis in time

The following principles should provide guidance for the limitation of the risk analysis in time:

1. For a repository for spent nuclear fuel, or other long-lived nuclear waste, the risk analysis should at least include approximately one hundred thousand years or the period for a glaciation cycle to illustrate reasonably predictable external strains on the repository. The risk analysis should thereafter be extended in time as long as it provides important information about the possibility of improving the protective capability of the repository, although at the longest for a time period of up to one million years.
2. For other repositories for nuclear waste, than those referred to in point 1, the risk analysis should at least cover the time until the expected maximum con-

sequences in terms of risk and environmental impact have taken place, although at the longest for a period of time up to one hundred thousand years.

The arguments for the selected limitations of the risk analysis should be presented.

Reporting on the first thousand years after closure

The period of time of a thousand years should be regarded as the approximate time period for which a risk analysis can be carried out with high credibility with regard to factors such as climate and biosphere conditions. For this time period, available measurement data and other knowledge about the initial conditions should be used for a detailed analysis and reporting on the development of the protective capability of the repository and its surroundings.

The conditions and processes during the early development of the repository, which can affect its long-term protective capability, should be described in as much detail as possible. Examples of such conditions and processes are the resaturation of the repository, stabilisation of hydrogeological and geochemical conditions, thermal evolution and other transient events.

Biosphere conditions and known trends in the surroundings of the repository should also be described in detail, partly to be able to characterise "today's biosphere" (see guidelines to section 5), and partly to be able to characterise the conditions applicable to a conceivable early release from the repository. Known trends here refer, for instance, to land uplift (or subsidence), any trends in climate evolution and appurtenant changes in use of land and water.

Reporting on very long time periods

Up to one hundred thousand years

Reporting should be based on a quantitative risk analysis in accordance with the guidelines to sections 5-7. Supplementary indicators of the repository's protective capability, such as barrier functions, radionuclide fluxes and concentrations in the environment, should be used to strengthen the confidence in the calculated risks.

The given period of time of one hundred thousand years is approximate and should be selected in such a way that the effect of expected large climate changes, for instance, a glaciation cycle, on the protective capability of the repository and consequences to the surroundings can be illustrated.

Beyond one hundred thousand years

The risk analysis should illustrate the long-term development of the repository's barrier functions and the importance of major external disturbances on the repository such as earthquakes and glaciations. Taking into consideration the increasing uncertainties over time, the calculation of doses to people and the environment should be made in a simplified way with respect to climate development, biosphere conditions and exposure pathways. Climate development can simplified be described as a repetition of identical glaciation cycles.

A strict quantitative comparison of calculated risk in relation to the criterion for individual risk in the regulations is not meaningful. The assessment of the protective capability of the repository should instead be based on reasoning on the calculated risk together with several supplementary indicators of the protective capability of the repository such as barrier functions, radionuclide fluxes and concentrations in the environment. If the calculated risk exceeds the criterion of the regulations for individual risk or if there are other indications of substantial disruptions of the protective capability of the repository, the underlying causes of this should be reported on as well as possible measures to improve the protective capability of the repository.

Summary of arguments for demonstrating compliance with the requirements of the regulations

The reporting should include an account of how the principles for optimisation and the best possible technique have been applied in the siting and design of the repository and appurtenant system components and how quality assurance has been used in the work with the repository and appurtenant risk analyses.

The arguments for the protective capability of a repository should be evaluated and reported on in a systematic way. The reporting should include a logically structured argument for the protective capability of the repository with information on calculated risks, uncertainties in the calculations made and the credibility of the assumptions made. To provide a good understanding of the results of the risk analysis, it should be evident how individual scenarios contribute to the risk from the repository.

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Appendix 1. Guidelines on the averaging of risk between generations

For certain exposure situations an annual risk, calculated as an average of all conceivable outcomes of a probabilistic risk assessment, provides an insufficient picture of how risk is allocated between future generations. This applies in particular to events which:

- can be assessed as leading to doses during a limited period of time in relation to the time period covered by the risk analysis, and
- if they arise, can be assessed as giving rise to a conditional individual risk exceeding the criterion in the regulations for individual risk, and
- can be assessed as having such a high probability of occurring during the time period covered by the risk analysis that the product of this probability and the calculated conditional risk is of the same order of magnitude as, or larger than, the criterion for individual risk in the regulations.

For exposure situations of this kind, a probabilistic calculation of risk should be supplemented by calculating the risk for the individuals who are assumed to live after the event has taken place and who are affected by its calculated maximum consequence. The calculation can be made for instance by illustrating the importance of an event occurring at different times (T_1, T_2 …,T_n), taking into consideration the probability of the event occurring during the respective time interval (T_0 to T_1, T_0 to T_2,…,T_0 to T_n, where T_0 corresponds to the time of closure of the repository). The results from these, or similar calculations, can in this way be expected to provide an illustration of the effects of the spreading of risk between future generations and should, together with other risk calculations, be reported on and evaluated in relation to the regulation's criterion for individual risk.

Annex 2. Guidelines on the evaluation of environmental protection

The organisms included in the analysis of the environmental impact should be selected on the basis of their importance in the ecosystems, but also according to their protection value according to other biological, economic or conservation criteria. Other biological criteria refers, among other things, to genetic distinctiveness and isolation (for example, presently known endemic species), economic criteria refers to the importance of the organisms for different kinds of obtaining a livelihood (for instance, hunting and fishing), and conservation criteria if they are protected by current legislation and local regulations. Other aspects, for instance, cultural history, should also be taken into consideration account in the identification of such organisms.

The assessment of effects of ionising radiation in selected organisms, deriving from radioactive substances from a repository, can be made on the basis of the general guidance provided in the International Committee for Radiation Protection's (ICRP) Publication 91[1]. The applicability of the knowledge and databases used for the analyses of dispersion and transfer of radioactive substances in ecosystems and for analysing the effects of radiation on different organisms should be assessed and reported on.

[1] A Framework for Assessing the Impact of Ionising Radiation on Non-human Species, ICRP Publication 91, Annals of the ICRP 33:3, 2003