SAFETY OF RADIOACTIVE WASTE DISPOSAL -
REGULATORY PRINCIPLES AND ASPECTS IN
THE FEDERAL REPUBLIC OF GERMANY

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ABSTRACT

The Federal Republic of Germany is undertaking a program for disposing of radioactive wastes in deep land based geologic formations. Licensing documents for a repository in the disused iron-ore mine "Konrad" have been submitted to the licensing authority. Safety analyses were carried out both for the operational and post-closure phases. The applicant employed a deterministic approach to demonstrate compliance with regulations and prescribed safety-criteria for a repository in a mine. The risk assessment methodology recommended by ICRP-46 is regarded to be less appropriate due particularly to the uncertainty in determining the likelihood of possible geologic events (disruptive events). Individual doses calculated beyond 10,000 years are regarded only as "orientating" figures. The application documents are being subjected to the current licensing procedure. This paper reports safety related requirements and aspects which have to be considered both in the application documents and the licensing procedure. The outcome of the licensing procedure will indicate whether and if so where and to which extent modifications should be made.

INTRODUCTION

From as early as the 60's the Federal Republic of Germany has been undertaking a program for disposing of radioactive wastes in land based deep geologic formations. In 1965, the disused salt mine Asse II was purchased by the Federal Government in order to develop methods and techniques for the safe disposal of radioactive wastes. From 1967 until 1978 some 126,000 LLW -packages and some 1,300 MLW -packages were emplaced there and valuable experiences gained. The amendment of the Atomic Energy Act in 1976 terminated operational license in 1978. Currently, the Asse salt mine is being used for R&D work for disposal in salt.

In the 1970's, the interest in geologic formations other than salt led to the investigation of the disused iron-ore mine "Konrad" as a repository for wastes with negligible heat generation. The specific need to have a repository for high level wastes for which the Asse salt mine was assessed as being unsuitable resulted in the decision to develop a salt dome like Gorleben. Hence, two schemes are being pursued: the disused iron-ore mine "Konrad" and the salt-dome at Gorleben.

Site characterization of the Gorleben salt dome is currently being performed in order to confirm its suitability as repository for all categories of radioactive wastes. In 1992, a definitive report is expected addressing the suitability of the Gorleben salt-dome.

The disused iron-ore mine "Konrad" is already subject of licensing procedures. The "Konrad" mine is planned for the disposal of radioactive wastes with negligible heat-generation. After a short period of storage at the surface, the waste packages will be lowered to the emplacement level in the repository, transported by road vehicles to the disposal rooms and there emplaced. Remaining interstices will be back-filled and the disposal rooms sealed when full.

Retrievability does not form part of disposal concepts in the Federal Republic of Germany. Disposal in deep formations has the objective of safe isolation from the biosphere. Long term retrievability is, therefore, unnecessary and indeed, to the contrary, compromises the degree of isolation. This isolation should be secured as soon as possible. The licensing documents for the "Konrad" repository have been submitted to the State (Land) of Lower Saxony for approval. Both the competent licensing authority of Lower Saxony and the applicant, the Federal Physical Technical Agency (PTB) in Brunswick, are subject to the supervision of the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety.

In the following, the nuclear safety related requirements in the Federal Republic of Germany and their applications to the operational and post-closure phases will be described. This description is based upon the application documents and the current discussion in the Federal Republic of Germany. Depending on the outcome of the licensing procedure, minor or major modifications may result.

OPERATIONAL SAFETY REQUIREMENTS

General

The basic design requirements for the repository are determined by:

- First, the limitation of thermal loads to the repository; in the case of the "Konrad" repository, its suitability was investigated with the boundary condition that temperature increases at the walls of the repository do not exceed 3^{0} K. This requirement is met by disposing of wastes with negligible heat generation. The content of radionuclides is limited per package and an appropriate emplacement strategy will be chosen.

- Secondly, protection of the repository personnel and the public. This requirement is met by technical and administrative measures. For planning these measures, analysis of operational procedures and conditions has to be carried out. Particularly, radiation exposures arising from transport of the waste packages from the surface to the underground disposal rooms, handling of waste packages, releases of volatile radionuclides from open disposal rooms before being sealed and, at least partly, the release of nuclides from closed disposal rooms into mine air have to be considered as contributions to occupational doses.

From the analyses of operational procedures, including operational incidents, maximum admissible activity limits per package can be derived, properties of the nuclide inventory, waste form and packaging taken into account. The waste package has to comply with the activity limits and the heat limit, for the waste package to be suitable for the emplacement in the repository without additional requirements.

The amount of activity which may be emplaced per year has been determined on the basis of the rates of release from packages, the concentration limits for radioactivity in the mine air and discharged into the environment and the number of packages to be emplaced per year.

Protection of the Personnel During Normal Operation of the Repository

The German radiation protection ordinance limits the whole body dose to 5.10^{-2} Sv/a (5 rem/a). For inhalation, nuclide-specific limits based on 5.10^{-2} Sv/a (5 rem/a) apply. In accordance with the ALARA principle, these limits have been tightened up for the design of the repository. Within the repository, the maximum dose exposure by direct radiation has been limited by PTB to 5.10^{-3} Sv/a (0.5 rem/a) and for inhalation 5.10^{-4} Sv/a (0.05 rem/a). As far as inhalation is concerned, the release of H 3, C 14, Rn 222, I 129 "emanating" from the packages into the mine air are of particular importance.

The technical and administrative measures for reducing the occupational dose are:

- limiting direct exposures by shielding,
- limiting residence times in radiation fields,
- limiting the activity of specific radionuclides by package and by annual disposal rate,
- designing appropriate operational procedures.

Designing appropriate operational procedures for reducing occupational doses are:

- appropriately shielded packages and large volume container (up to about 11 cubic meter) for transport and emplacement,
- separation of repository areas where waste packages will be handled and those free of activity,
- separated air circulation for areas where emplacement and mining occur,
- sealing of emplacement rooms filled with waste packages by construction of sealing walls.

Protection of Members of Public and the Environment During Normal Operation

As for every nuclear facility, the radiation protection ordinance requires that exposures of the public caused by radionuclide discharges from a repository must be "as low as possible" and must not exceed 30 mrem/a for the whole body and 90 mrem/a for the thyroid.

Doses have to be estimated in accordance with a prescribed calculational procedure for radiation exposure resulting from radionuclides in exhausted air and in surface waters. The exposure is to be calculated for the points of maximum impact incorporating all relevant exposure pathways. This includes internal irradiation originating from radionuclides inhaled with air (inhalation) and from consumption of contaminated food (ingestion). Taking into account the number of waste packages to be emplaced annually, the estimated exposure to the public amounts to only millirems per year.

Dose Limits in Case of Operational Incidents

For nuclear power plants, the German radiation protection ordinance requires that the design must accomodate the assumption of incidents, with a dose limit not exceeding 5 rem for the whole body and 15 rem for the thyroid.

In the Federal Republic of Germany, licensed nuclear facilities, not just nuclear power plants, have to meet this requirement. There is no justification for changing these criteria for radioactive waste. Analyses show that for operational incidents, radionuclide releases occur via the air pathway. In principle, the guidelines developed for nuclear power plants have to be applied. Hence, the exposure pathways of:

- external exposure by beta radiation inside the exhaust air plume (beta submersion),
- external exposure by gamma radiation from the exhaust air plume (gamma submersion) and from contaminated ground (ground radiation),
- inhalation and ingestion.

are to be taken into account.

Incident analysis has identified mechanical and thermal events which could lead to radiologic hazards. These are:

- handling-incidents involving falling packages or heavy loads impacting on waste packages,
- collision of transport vehicles with and without fire,
- external effects particularly on surface-installations such as earthquakes, floods, lightning, ice and snow, and fire.

Aircraft crash and pressure waves from explosions have not been accommodated due to the low probability of their occurrence, these events are accepted as "residual-risk".

Depending on the impacts arising in the course of the incidents to be considered, it is distinguished between:

- incidents the consequences of which are limited by the inherent characteristics of the repository, by limitation of the source-term of the waste packages or the waste form and packaging and,
- incidents to be excluded by countermeasures within the repository itself or associated with the waste packages.

Technical and administrative measures guarantee that the radiation protection limits will not be exceeded. An incident such as overrun of the hoisting cage will be avoided by design (including special brakes) and operation of the hoisting equipment according to regulations of the mines inspectorate. Compliance with the waste package requirements will be guaranteed by waste package acceptance criteria as a part of a sophisticated quality assurance regime.

Monitoring of Radioactive Discharges and During the Operational Phase

During the operation of a repository, radioactive contaminated air and water are discharged. The resulting exposures to individuals living nearby the repository need to be assessed. In order to assess the exposures and to ensure compliance with the license and the requirements in the radiation protection ordinance monitoring is required. The monitoring of a repository has to be focused on a nuclide-specific procedure which can be performed both within the repository underground and on the surface. In principle, the discharges are so low that no monitoring is needed at the points of radiological impact (i.e., emission monitoring of the adjacent environs). However, for the "Konrad" repository monitoring will be carried out to make sure that in any case, the exposures are below the calculated values (measurements of direct radiation, activity measurements of air, waters, soil and vegetation).

LONG TERM SAFETY

Safety Goals for the Post-Closure Phase

In the Federal Republic of Germany, the long-term radiation protection objective for members of the public is laid down in the safety criteria for the disposal of radioactive wastes in a mine. Its numerical value amounts to 3.10^{-4} Sv/a (30 mrem/a). The reasoning for having chosen this value arises from average variations of natural background radiation of some 3.10^{-4} Sv/a in the Federal Republic of Germany. As far as members of the public are concerned, the limit of 3.10^{-4} Sv/a applies both to the operational phase and the post-closure phase. This criterion guarantees no undue radiation burden on future generations, or in other words: the degree of isolation from the environment by disposal has to be such that no future risks to human health or effects on the environment do not exceed those acceptable today. The risks to future individuals must not be greater than risks to which the current generation is subjected.

The safety goals are chosen to be in line with the recommendation of ICRP-46, which stipulates a fraction of the individual dose limit of 1 mSv/a for normal scenarios, i.e., for situations which are likely to occur.

In addition, ICRP recommends that risks due to scenarios unlikely to occur should be limited to less than 10^{-5} per year to the critical group. Risk has been defined here as probability that a serious detrimental health effect will occur in a potentially exposed individual or his descendants. This risk objective corresponds to the dose limit of 10^{-3} Sv/a.

Demonstrating Compliance With Safety Standards in the Application

Demonstrating compliance with safety goals has to take account of uncertainties within the input data and predictions of likely repository evolution. In principle, two methodologies are available: the deterministic and the probabilistic analysis approach (risk assessment). A rigorous risk assessment requires the quantification of the occurrence of even unlikely events as functions of time (mostly geologic events), the estimation of the range of possible values for each modelling parameter and the shape of the probability distribution. On the other hand, one is aware of the uncertainties regarding permeability figures, K_d-values, the degree of validation of computer-codes and the speculative character of human attitudes in the far future, let alone the difficulties in quantifying the probabilities for disruptive events. Taking into account these uncertainties and the expense of carrying out rigorous risk assessment methodologies, it seems more appropriate to demonstrate compliance with safety goals by a deterministic approach choosing the scenario and data most likely to occur and in a conservative manner varying input parameters (i.e., sensitivity analysis). Hence, only a deterministic approach has so far been used in demonstrating compliance with the safety goal of 3.10^{-4} Sv/a (30 mrem/y) in the application for the "Konrad" repository.

Long Term Safety of the Repository "Konrad"

The long-term safety of "Konrad" is determined by the hydrogeologic parameters such as permeability of the individual strata, porosities and the hydraulic gradient. In the safety analysis it is assumed that after closure of the repository, the voidage within the backfilled mine (located at a depth of 800 to 1300 m) will be re-filled by formation-waters and that the original pore-water pressures will be re-established. Water percolation caused by the hydraulic gradient, the mobilization of radionuclides and their advective transport with water can then start. Taking into account both retardation mechanisms such as sorption, and transport enhancing effects like organic complexing and dispersion, calculations indicate maximum concentrations in the biosphere at 3.10^5 yrs for non-sorbed radionuclides (I 129, Cl 36, Ca 41), and for U-isotopes and actinides at 10^7 years. Maximum individual doses peak also occur at the above times.

The calculation of the individual doses has been based upon ingestion by consumption of: contaminated drinking water, milk and meat of animals drinking only contaminated water, plants irrigated only with contaminated water and consumption of contaminated fish. The dietry habits for the future is assumed to be the same as that today. With an emplaced activity of about 10^{18} Bq, the calculated individual doses are a few millirems at the times given above.

Preliminary Evaluation of the Results

Some of the modelling and calculational assumptions are uncertain or even speculative for the far future, e.g.:

- the constant hydrogeologic and hydraulic conditions,
- the definition of a "critical group" with the same attitudes and dietry habits as exist now.

The greater the time span, the more uncertain or speculative these assumptions become. Thus, calculated individual doses can only be relied upon for a limited time horizon. A "time cut-off" of about 10,000 years seems sensible for the following reasons: We are expecting sweeping climatic change within the next 10,000 years or so, after a period of about 10,000 years, the bulk of the radioactivity has decayed, radiotoxicity calculations indicate, that the residual radioactivity in the repository is less than that of natural uranium ore-bodies (by averaging the radioactive waste over the equivalent volumes for comparison purposes). In addition, comparisons of radiotoxicity of radioactive wastes with toxic substances from coal-burning for energy-generation indicate the same level of toxicity after 10,000 years (related to the same energy output).

Nevertheless, it seems to be generally accepted, not to abandon the safety goals or to cease the calculations after this time span. On the contrary, it is suggested to reinforce the calculated individual doses by additional considerations. A recent IAEA draft on underground disposal of HLW recommends comparing far future concentrations or releases of radionuclides from the repository into environment with concentrations or releases from naturally occurring sources such as the upper part of the earth's crust. On the other hand, calculated individual doses even far in the future are useful indications in the assessment and comparison of disposal options for specific nuclides.

Calculated individual doses and the emplaced long-lived nuclide inventory are strongly interrelated. Some experts in the Federal Republic of Germany argue on the grounds of the large calculational uncertainties for individual doses in the far future, that decisions on the amount of long-lived nuclides to be emplaced should not be based upon this criterion. However, this argument logically requires a different or additional demonstration of safety not relying on individual doses in the far future.

For the planned "Konrad" repository, conservative boundary conditions for modelling the migration of radionuclides are chosen. Pessimistic k_E-values have been selected; disruptive events like a glaciation in the future or a change to a more arid climate will improve the results, i.e., diminish the hydraulic gradient as the driving force for water percolation and nuclide migration. Denudation and uplift do not impair the repository site during the next 10,000 years or so. Magmatic and severe tectonic events have been judged very unlikely and, therefore, excluded. The human intrusion-issue is not regarded to be a matter of major concern. Documentation of the site and repository will be available for successive future generations. Inadvertent human intrusion due to loss of documentation and information about the repository in the far future has to be considered for human beings capable of exploring mines in deep formations. However, human beings mining to depths of excess 1,000 m in the far future can also be assumed to be capable of detecting radiation, which will either cause them to cease drilling or mining, or to take appropriate countermeasures.

CONCLUDING REMARKS

The application documents for the "Konrad" repository demonstrate, in the opinion of the applicant, compliance with the pertinent safety goals. As to long-term safety, the deterministic approach with a dose limit seems to be no less appropriate than an equivalent risk limit and risk assessment. What is needed, either way, is first a better validation of computer codes and models and an approach for drawing conclusions from modelling.

Secondly, being aware of the uncertain character of calculated individual doses for the far future, there is a need to compare the safety of a repository or the releases of radionuclides from a repository with natural phenomena demonstrating the radiation environment will not appreciably be altered for future generations by disposal of radioactive wastes. Regardless of these remaining uncertainties and the tasks before us, we are sure that the disposal of radioactive wastes can be safely managed and ethically justified to the generations to come after us.