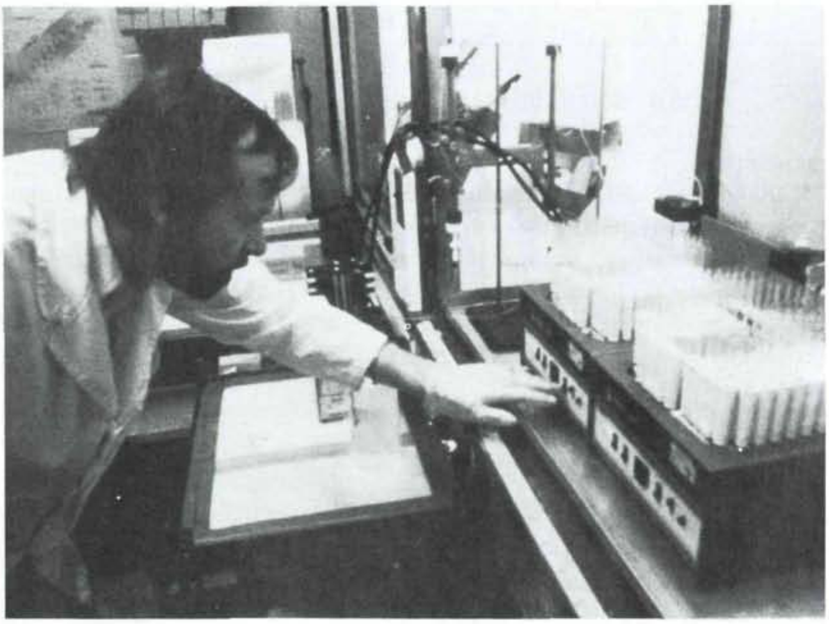
Assessing the radiological safety of waste repositories



A review of procedures, methods, and problems

by Gordon Linsley

Techniques for safety analysis of waste repositories have developed in recent years to match increasing worldwide efforts to find optimum methods for disposing of radioactive waste. Results of safety analyses must be considered in designing a suitable disposal system to ensure compliance with radiological criteria set by national authorities.

This article gives a brief overview of some main features of safety analysis procedures, indicates problem areas, and illustrates methods by reference to results of some safety analyses.*

Radiological standards

Most radiological protection standards in use have their basis in the recommendations of the International Commission on Radiological Protection (ICRP). These include a system of dose limitation containing the three basic principles, justification of a practice, optimization of protection, and limitation of individual radiation exposures.

The dose-limitation system was designed for radiation exposures from sources or practices which actually occur, for example, in occupational exposure or in the controlled routine release of effluents to the environment.

However, in the case of radioactive waste disposal, there is no certainty that human exposure will occur, since in many cases repositories are being designed to achieve isolation for very long time periods. For the purpose of safety analysis, various scenarios are considered in which the release of radionuclides into the environment could occur and which would involve human exposure to radiation – for example, by migration following leakage from the repository or by accidental intrusion into the repository.

Because of precautions taken in repository design, the likelihood of events occurring that lead to human exposure usually will be small. The timescales that must be considered are extremely long and, consequently, various questions arise concerning, for example, appropriate protection standards for future populations and the problems of increased uncertainties of prediction.

To take account of these special aspects, radiological criteria specific to solid waste disposal currently are being developed. One emerging feature is the movement towards risk limitation (as well as dose limitation). In this case, risk is calculated as the probability that a radiation dose will be received multiplied by the probability that the dose received will give rise to deleterious health effects. This allows those postulated events that would have a high radiological impact (but

Mr Linsley is a staff member in the Agency's Division of Nuclear Fuel Cycle.

* Guidance on methods for safety assessment is given in Agency *Safety Series* documents for disposal in geological formations, in shallow ground, and in the marine environment.

Photo on top: Invaluable insights are gained from field investigations and laboratory tests in assessing the safety of waste disposal facilities. (Credit: AIF)

a low probability of occurring) to be put into proper perspective; for example, repository damage by meteorites.

Although this type of criterion reflects more accurately the nature of the radiological hazard from solid waste disposal underground, it is recognized that there may be difficulties in practical application. This is especially so in relation to specification of the probability of occurrence of events that give rise to an exposure.

Methodology for safety assessments

Most principles related to safety assessment in a shallow ground facility are common to high-level waste (HLW) repositories in deep geological formations.

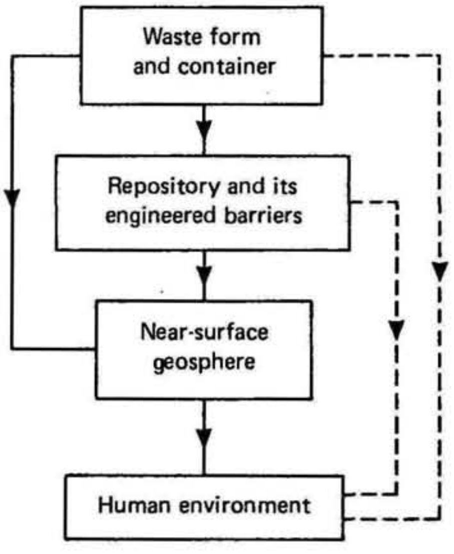
For a shallow ground facility, the disposal system can be described as a combination of the following components:

- Waste type, waste form and, where applicable, stabilizer, container, overpack, and/or migration retardant
- Repository and its engineered barriers, including backfill of excavations and ground cover
- Near-surface geosphere (sediments, rocks) at the repository site
- Human environment (soil, surface waters, shallow aquifers, atmosphere, biota).

The safety analysis of such a system has the following three basic components:

- Identification of phenomena that could lead to a release of radionuclides, or influence the rates at which releases occur, or influence the rate of transport of radionuclides through the environment
- Estimation of the probabilities of occurrence of these phenomena and quantification of their effects on the disposal system
- Calculation of the radiological consequences of releases (that is, doses to individuals and populations and, if required, estimation of subsequent health effects).

The first two items usually are considered under the heading of "scenario analysis" and the third item usually is referred to as "consequence analysis".



From a shallow ground repository, radionuclides possibly could be released and transported to the human environment in several ways. The broken lines represent an abnormal situation.

Scenario analysis

The phenomena that are potentially relevant to scenario analysis for repositories in shallow ground are human activities (for example, construction, farming, drilling for mineral resources); natural processes and events (erosion, flooding, groundwater movement); and waste and repository processes (gas generation, mechanical disturbance of soil or rocks at the repository site).

Results of scenario analyses consist of the definition of scenarios (that is, the release and transport parameters required for consequence analyses) and the estimates of the probabilities of occurrence of these scenarios as a function of time. When scenario analyses are carried out for specific disposal systems and sites, it will usually be possible to eliminate some potentially relevant phenomena from detailed consideration, either because they have very low probabilities of occurrence or because their effects can be shown to be insignificant.

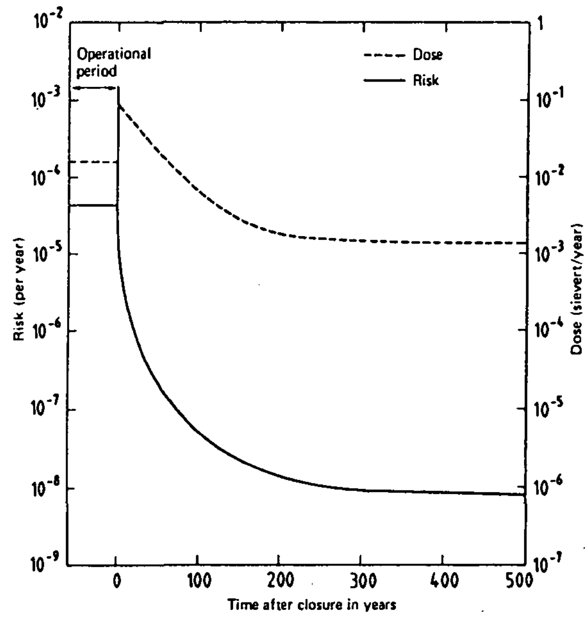
Consequence analysis

After the repository release scenarios have been defined, the consequences to humans have to be estimated. Calculation of consequences requires the development of a computational system that enables the transport of radionuclides through the environment to humans to be modelled and radiation doses to be assessed.

As a first step, a prediction of radionuclide release rates from the repository is made, followed by estimates of the radionuclide concentrations in the various compartments of the environment. The second step consists of a prediction of transport rates of released radionuclides between various compartments and humans. The third step involves a prediction of radionuclide interaction with humans, resulting in calculation of doses to individuals and to the population for each scenario identified during scenario analysis.

Consequence analysis involves following the progress of the released radionuclides to humans via different pathways – for example, through drinking water and the consumption of aquatic foods, bathing and swimming, and more indirectly through plants and

Example of generic analysis



In this example, results are shown from a generic assessment of maximum annual individual doses and risks from disposal of general low-level wastes in a shallow disposal trench with minimum engineering. The scenarios considered were contact by water followed by radionuclide migration; fires in the burial trench during the operational phase; and disturbance by human action after the site had been closed and use restrictions had been lifted. (For purposes of these calculations, it was assumed that restrictions on site use were lifted as soon as operations stopped.) Maximum individual doses were estimated assuming that each release postulated in the scenarios actually occurs, while the individual risk calculations take into account the probability of event occurrence. Over the time periods indicated, the potential risks to individuals mainly are due to exposure during possible excavation for building, and, at later times, primarily from farming and water pathways. One particular use of generic calculations of this type is to give a preliminary indication of the periods when restrictions on site access are likely to be needed, after closure of site operations, to comply with radiological criteria. (Source: Pinner, et al., UK, 1984)

domestic animals (plants can accrue radionuclides via irrigation or through topsoil).

Results of the overall safety analysis may be expressed in different ways depending upon the radiological criteria to be satisfied, for example, in terms of probabilities, individual doses, individual risks, and collective doses and risks. (See the box above for results of a generic analysis.)

Generic and site-specific studies

It is useful to distinguish between generic and site-specific studies. The generic study usually is conducted at an early planning stage, when an actual site may not yet have been identified and when little relevant information for assessment purposes is available. The assumptions made are necessarily generalized and the parameter values for use in modelling may only be obtainable from the scientific literature; their choice requires the use of expert judgement. Assumptions and data used in such studies tend to be conservatively biased, so as to avoid the possibility of underestimating in the absence of more appropriate information.

Generic studies are valuable since they serve to focus attention on aspects that are likely to be radiologically most important and, hence, they enable research priorities to be properly allocated. In particular, they indicate the scenarios, the pathways to humans, and the radionuclides in the waste that are likely to be of the greatest significance. As more information becomes available about the waste repository design and its intended location, the realism and reliability of assessments can be improved.

A site-specific study is necessary before a waste disposal facility can be licensed. In this study, use is made of all information that can be obtained about the repository, its site, and the surrounding environment.

In recent years, the progressive development of safety assessments – from preliminary generic studies to more realistic assessments using data related to well-defined repositories and environments – has been seen in several countries. (See the box on page 24, which is taken from the Nagra Project Gewähr and charts such a progression for underground high-level waste disposal.)

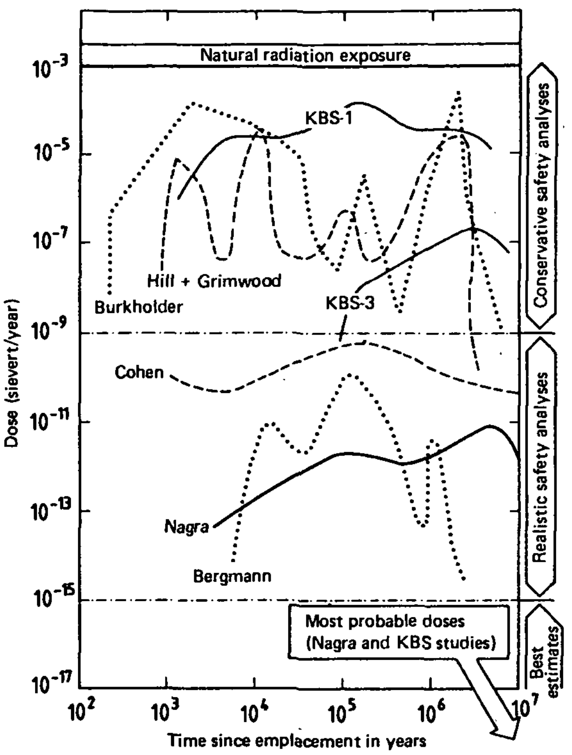
Reliability of model predictions

Since the safety assessment of radioactive waste repositories is heavily dependent on the use of mathematical models, it is necessary to consider how much confidence can be put in their predictions.

All environmental models necessarily have uncertainty associated with their predictions since they are simplified representations of complex environmental systems. The problem of model uncertainty is particularly difficult to resolve in relation to repository safety assessments. This is because directly relevant experimental results and environmental measurements for use in validation are hard to obtain, especially in relation to the long time periods over which the models are applied. There are, nevertheless, a variety of approaches that can be applied by the safety assessor to increase confidence in results of model application.

- Ideally, a model should be validated by means of comparisons of its predictions with appropriate observations. Full validation of all models used in waste repository safety analysis is not possible, but partial validation of sub-models can be achieved by the use of laboratory and field experimental data.
- In some cases, less controlled types of validation can be performed by making comparisons with natural

Progression of safety assessments



Shown here are results (calculated yearly doses) from various safety studies on final disposal of high-level waste (HLW) and spent-fuel elements. Although the studies relate to different types of waste forms, containments, repositories, and geological environments, there is a general trend towards lower predicted individual doses as more realism is introduced into the assessments. Sweden has prepared what are probably the most comprehensive safety analyses to date (KBS-1 for vitrified HLW in 1978, and KBS-3 for non-processed spent fuel in 1983). Both studies relate to disposal in granite, and the geological, hydrogeological, and geochemical data are derived from results of specific field investigations. The KBS studies were prepared for and accepted by the Swedish Government as a management demonstration and they served as a basis for a decision on issuance of operational licenses for Swedish nuclear power plants. The Swiss Nagra studies have a similar objective. Some early guiding works have con-contributed much to the understanding of repository behaviour and to the development of analysis methodology. The model calculations of Burkholder (USA, 1976) were generic studies for HLW in porous soils. Those of Hill and Grimwood (UK, 1978) were generic studies for vitrified HLW in crystalline rock. The worth of these studies lies particularly in the sensitivity analyses done to assess the relative significance of individual barrier parameters and in allowing criteria to be formulated for selection of repository locations. Bergmann's studies (USA, 1978) related to the final disposal of HLW in generically described salt and schist formations. Disposal options in salt or anhydrite normally result in no predicted radiation doses via migration paths. Because of the absence of water in these dry rocks, "normal" release mechanisms are completely absent. Significant radiation doses generally result only from postulated accident scenarios — such as water penetration through faulting or anthropogenic exposure of the repository. (Source: Nagra Project Gewähr, Switzerland 1985)

systems that contain naturally occurring radionuclides; for example, Oklo (Gabon) and Morro de Ferro (Brazil). These have the advantage of providing real evidence of transport processes over the very long timescales that must be considered in relation to underground waste disposal. Difficulties with this type of validation are that experimental conditions are not generally well understood and may not be directly relevant to the environment surrounding the repository.

- One method of circumventing the problem of model uncertainty is by the use of "worst case" models. This approach gives no indication of the reliability of prediction, but provides confidence that there is little chance of under-prediction. It may be used to demonstrate that doses are well below limits as, for example, in the generic studies referred to earlier.
- Model comparison exercises have a valuable role in safety assessment. They enable the numerical accuracy of modelling codes to be checked, but in addition they may be used to compare different modelling approaches to predicting transfer in defined circumstances. This often results in valuable insights being obtained. Various international model comparison exercises relevant to underground waste disposal are taking place at the present time; for example, the Swedish sponsored INTRACOIN (geospheric far-field radionuclide transport models), HYDRACOIN (groundwater transport models), and BIOMOVS (biospheric radionuclide transport models).
- Statistical techniques may be used to evaluate what effect uncertainty about the values of individual model input parameters has upon the uncertainty of the overall model predictions. It has to be borne in mind, however, that this type of uncertainty analysis does not provide a check on the validity of the model itself.

Demonstrating the reliability of predictions of radionuclide transfer from underground repositories is not easy and is often an indirect process. Confidence in model predictions has to be built up by the combined use of a variety of techniques, such as validation, model comparison, and parameter uncertainty analysis.

Continuing research

In summary, the results of safety studies indicate that the radiological impact of waste repositories will be small and that compliance with radiological protection standards can be achieved. It is nevertheless recognized that there are considerable uncertainties associated with these assessments, mainly because of the long timescales involved. Many of the current research efforts in this field are aimed at reducing uncertainties.

It is interesting to note that much of the progress on this topic is happening as a result of activities at an international level through intercomparison and validation exercises, and through discussions at international fora.