Radioactive waste disposal: Radiological principles and standards

An overview of national and international efforts to establish criteria for the safe disposal of spent fuel and high-level waste

by Dr. J. O. Snihs

The first large-scale geological repositories for the final disposal of spent fuel from nuclear plants are not expected to be in operation until well into the next century. Such repositories will demand high levels of safety to protect the environment and the public from potential radiological risks.

While national policies differ in classifying spent fuel as a waste product or as a resource for recycling fuel, the safety of spent fuel storage and radioactive waste disposal has been extensively studied at the national and international levels. The work includes criteria developed by Nordic countries in 1989 and subsequently revised and published in 1993. This article briefly reviews these criteria in the context of international and national studies on the disposal of high-level waste including spent fuel.

Major national and international reports

In 1984, the Nuclear Energy Agency of the Organization for Economic Co-operation and Development (OECD/NEA) published the report, *Long-Term Radiation Protection Objectives for Radioactive Waste Disposal.* It stands as one of the first international reports on the special problems connected with disposal of long-lived radioactive waste. Among questions discussed in this report are the limitations of individual dose or risk, the application of optimization of protection, and the use of collective dose for future assessments.

In 1985, the International Commission on Radiological Protection (ICRP) published *Radiation Protection Principles for Disposal of Solid Radioactive Waste* (ICRP publication 46). It discusses the concept of risk constraint for a source, probabilistic events, and uncertainties about the future. The principle of optimization should be applied but it is only one input in the process of deciding a strategy and option for waste management and disposal. Particularly emphasized are ethical considerations in weighing the significance of future detriments.

The IAEA, already in 1983, published an advisory report on criteria for underground disposal of radioactive wastes (Safety Series No. 60). In 1989, it was followed by the publication *Safety Principles and Technical Criteria for Underground Disposal of High-level Wastes* (IAEA Safety Series No. 99). It took into account recommendations and discussions in NEA and ICRP publications.

The IAEA Radioactive Waste Management Safety Standards (RADWASS) programme started in 1991 and is aimed at establishing a coherent and comprehensive set of principles and standards for the safe management of waste and formulating the guidelines necessary for their application. RADWASS publications will provide Member States with a comprehensive series of internationally agreed documents that reflect an international consensus. Within the RADWASS programme the following documents of relevance to waste management have been published:

- *The Principles of Radioactive Waste Management*, IAEA Safety Series No. 111-F (1995);
- *Establishing a National System for Radioactive Waste Management*, IAEA Safety Series No. 111-S-1 (1995);
- *Siting of Geological Disposal Facilities,* IAEA Safety Series No. 111-G-4.1 (1994); and
- *Classification of Radioactive Waste*, IAEA Safety Series No. 111-G-1.1 (1994).

The set of publications in the RADWASS programme is now being reviewed to ensure a harmonized approach throughout the Safety Series.

The IAEA is also supporting the work on drafting an international convention on radioactive waste safety. Progress made so far is encouraging and if the pace is maintained a draft convention could be finalized towards the end of 1996.

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In the ICRP's new recommendations on radiological protection (ICRP Publication 60, 1990), radioactive waste problems are not particularly addressed. However, in the general system of radiological protection, the optimization of protection, as well as dose limits, now include the concept of potential exposure. It is expressed as the likelihood of incurring exposures where these are not certain to be received. They should be kept as low as reasonably achievable (ALARA).

Another important publication on the development of criteria for disposal of high-level waste is the proceedings of an NEA workshop in Paris. The report — *Disposal of High-Level Wastes, Radiation Protection and Safety Criteria,* published in 1991 by the NEA in Paris — features an informative overview of existing national and international approaches to problems and the current status of guidelines and criteria. In the report, collective dose or risk limits are used more for comparison of repository design alternatives. Among other points are the following: Individual dose limits or risk limits as safety indicators are generally in the range of 0.1 to 1 mSv per year or 10^{-6} to 10^{-5} per year, respectively. Optimization of protection is generally agreed as a principle but its application has to be adapted to what is achievable in practice. A similar level of safety should be provided for all future generations as that provided for current generations. A special problem discussed in the report is how to demonstrate compliance with safety criteria. There is no straightforward answer to that question, which has to do with an understanding of the whole waste disposal system. High-quality and good engineering practice are needed throughout the process, using validated models and site-specific data, and appropriately selecting scenarios and scrutinizing uncertainties.

National reports. At the national level, there has been considerable work as well. For instance, in a joint 1990 Swiss-Swedish report, *Regulatory Guidance for Radioactive Waste Disposal — An Advisory Document* (SKI Technical Report 90, Stockholm), a number of principles and problems are discussed. It addresses problems concerning uncertainties over long time periods and urges the validation of all models used for performance assessments of assumed repository systems.

Other national documents include the *French Basic Safety Rules* in 1991; a 1992 report by the National Radiological Protection Board (NRPB) in the United Kingdom, *Radiological Protection Objectives for Land-based Disposal of Solid Radioactive Wastes,* and the US Environmental Protection Agency (EPA) regulations, *Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Waste,* published in the US *Federal Register* 20 December 1993.)

In the French Rules, ALARA is applied as a principle in the criteria for a repository. The individual dose equivalents are limited to 0.25 mSv per year for extended exposure associated with events which are certain or highly probable. For a period of at least 10 000 years, the stability of the geological barrier must be demonstrated. Beyond this time period, the quantitative assessments may be supplemented by more qualitative assessments. The risk concept is introduced for potential exposure situations.

In the NRPB's publication, it is recommended that future populations shall have an equivalent protection as that for populations today. Moreover, the radiological risk to a critical group, attributable to a single waste disposal facility, shall not exceed the risk constraint of 1 in 100 000 per year, and the ALARA principle should be applied. However, if the individual risk to an average member of the critical group does not exceed a design target of 1 in 1 million per year, then the ALARA principle would be required only for the detailed design of the facility and not in comparison of various sites or options. Site-specific calculations relating to the biosphere and human behaviour should not continue beyond about 10 000 years into the future. For times greater than that, reference models of biosphere and human behaviour can be used in combination with constraints on radionuclide release rates from the geosphere.

The 1993 EPA regulations stipulate that disposal systems for spent nuclear fuel, high-level and transuranic waste will have to be designed so that, 10 000 years after disposal, the undisturbed performance of the system will not deliver an annual committed effective dose of radionuclides greater than 15 mrem to any individual in the accessible environment.

The EPA regulations took effect 19 January 1994. Under them, the protection period has been lengthened from 1000 years to 10,000 years. The EPA noted that wastes placed in the disposal systems will remain radioactive for thousands of years. Results of EPA studies show that potential radionuclide releases resulting in exposures to individuals would not occur until more than 1000 years after disposal because of the containment capabilities of the engineered barrier system.

The EPA regulations do not apply, however, to the Yucca Mountain Site Characterization Project. The EPA will develop a separate standard for the potential disposal of spent fuel and high-level waste at Yucca Mountain, under the guidance of the National Academy of Sciences, as directed by a 1992 congressional mandate.

The Nordic criteria. In parallel with these national and international developments, the Nordic countries developed criteria issued in 1989 and subsequently revised in 1993 after extensive review by international and national experts, among others. (*Disposal of High Level Waste — Consideration of Some Basic Criteria,* the Radiation Protection and Nuclear Safety Authorities in Denmark, Finland, Iceland, Norway and Sweden.)

They are in many parts very similar to those found in international and other national documents. This is not surprising, since Nordic specialists have taken active part in international work in this field. The Nordic criteria include:

- ***General considerations and objectives.***

General objective: The objectives of disposal of high-level waste shall be to protect human health and the environment and to limit burdens placed on future generations.

Objective 1 - Long-term safety: The risk to human health and the effects on the environment from waste disposal, at any time in the future, shall be low and not greater than would be currently acceptable. The judgment of the acceptability of a disposal option shall be based on radiological impacts irrespective of any national boundaries.

Objective 2 - Burden on future generations: The burden on future generations shall be limited by implementing at an appropriate time a safe disposal option which does not rely on long-term institutional controls or remedial actions as a necessary safety factor.

- ***Radiation protection principles.***

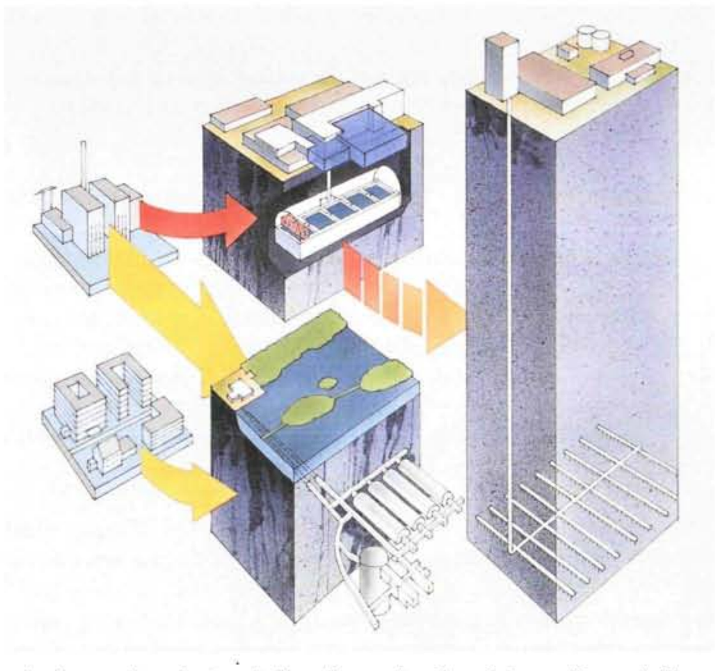
Applied principle 1 - Optimization: The system of waste disposal shall be optimized. In doing so radiation doses and risks must be compared and balanced against many other factors that could influence the optimized solution.

Applied principle 2 - Individual protection: Up to reasonably predictable time periods, the radiation doses to individuals from the expected evolution of the disposal system shall be less than 0.1 mSv per year. In addition, the probabilities and consequences of unlikely disruptive events shall be studied, discussed and presented in qualitative terms and whenever practicable, assessed in quantitative terms in relation to the risk of death corresponding to a dose of 0.1 mSv per year.

Because of different diets, living habits and environmental conditions, there is always a "tail" in individual dose or risk distribution. Sometimes this tail may exceed the respective constraints though the average value in the critical group remains low. This is not specific to waste disposal. Acceptance of the tail is not contrary to present practices and is consistent with the individual protection principle.

In general, dose assessments beyond about 10,000 years are very uncertain. Dose assessment in the relative sense can be made for longer time

Swedish System for Disposal of Spent Fuel and Radioactive Waste



In Sweden, radioactive wastes from nuclear plants and other sites, such as hospitals, are disposed of in specially built repositories. Low- and intermediate-level wastes from hospitals and nuclear plants are sent to a repository built 50 meters below ground. Spent fuel from nuclear plants is currently stored in a storage facility. Plans call for it to be sent to a repository that will be built 500 meters underground early in the next century.

periods assuming hypothetical critical groups. In that case the resulting doses or risks should be interpreted as safety indicators (relative measures of safety), not as predictions of really occurring doses.

Applied principle 3 - Long-term environmental protection: The radionuclides released from the repository shall not lead to any significant changes in the radiation environment. This implies that the inflows of the disposed radionuclide into the biosphere, averaged over long time periods, shall be low in comparison with the respective inflows of natural alpha emitters. The activity inflow should be averaged over long-term periods, i.e. 10^4 years or more, as it is not possible to determine accurately when releases or their peak values occur.

The activity inflow constraint should be such that: the resulting peak individual doses should not be in excess of the dose limit and even in the most extreme cases well below the level of deterministic health effects; the resulting activity concentrations in primary recipients at the disposal site fall within the range of the typical concentrations of long-lived natural alpha emitters in similar environments; the activity inflow from all wastes to be disposed of globally is low compared with the respective inflow of long-lived natural alpha emitters.

Calculations indicate that an appropriate constraint probably would fall within the following ranges: 10 to 100 kBq/per year for the long-lived alpha emitters; and 100 to 1000 kBq/per year for the other long-lived nuclides per amount of waste, which is produced when one ton of natural uranium is processed into nuclear fuel and then used in a reactor.

- ***Assurance principles.***

Assurance principle 1 - Safety assessments: Compliance of the overall disposal system with the radiation protection criteria shall be demonstrated by means of safety assessments which are based on qualitative judgment and quantitative results from models that are validated as far as practicable.

Assurance principle 2 - Quality assurance: A quality assurance programme for the components of disposal system and for all activities from site confirmation through construction and operation to the closure of the disposal facility shall be established to achieve compliance with the design bases and pertinent regulations.

Assurance principle 3 - Multibarrier principle: The long-term safety of waste disposal shall be based on passive multiple barriers so that deficiencies in one of the barriers do not substantially impair the overall performance of the disposal system and realistic geologic changes are likely to affect the system of barriers only partly.

Furthermore, the Nordic criteria contain technical and geological recommendations on site geology, repository design, backfilling and closure and waste packaging.

Ongoing work and challenges

Continuing work on criteria is being done at the international level through an IAEA Working Group on Principles and Criteria for Radioactive Waste Disposal. The group's experts are addressing issues concerning dose versus risk, post-closure monitoring, safety indicators in different timeframes, the applicability of optimization, retrievability, and safeguards in the context of waste disposal.

One question of interest is the time frame for which it is meaningful to consider the assessments of environmental consequences of a repository for high-level waste or spent fuel. Some experts argue that the safety of the near generations should be the paramount concern. Others believe that all future generations must be equally protected. In my view, every generation has the right either to control safety by itself or to be ensured by earlier generations that the repository is safe. Various tools and models may be used in the efforts to illustrate the radiological safety of a repository over long time periods. The first report of the IAEA Working Group on Principles and Criteria for Radioactive Waste Disposal was published in 1994 with the title, *Safety Indicators in Different Time Frames for the Safety Assessment of Underground Radioactive Waste Repositories*, (IAEA TECDOC-767).

In Sweden, the programme on disposal of spent fuel is proceeding. There is extensive research carried out by the Swedish Nuclear Fuel and Waste Management Co. (SKB) that includes suitability studies on potential sites and planned geological, hydrological, and other research in a laboratory 500 meters underground. Remaining problems include those related to the criteria and methods for selecting suitable sites, and in planning all the radiation safety analyses that must be made. Another concern is how to make information available to local decision-makers and citizens that they can use for their decisions on the acceptability of proposed repository plans. On the regulatory side, applied requirements and regulations based on, among others, the Nordic criteria are being prepared for issuance. Directives will also be issued on how to make appropriate environmental impact assessments.

The resolution of issues in Sweden will receive continuing attention, as the country moves ahead with plans to start building its final repository for high-level waste and spent fuel by about 2010 and take it into operation a decade later.❑