SAFETY ISSUES IN THE DISPOSAL OF SOLID RADIOACTIVE WASTE

ASSESSING APPROACHES

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The safe management of radioactive wastes from all stages of the nuclear fuel cycle is an important technical, economic and social issue. It is also important to deal with wastes arising from the use of nuclear materials in medicine, research and industry. In some countries issues around how such waste management is undertaken have been controversial and may affect the future use of these technologies. This article addresses the disposal of solid radioactive waste, with particular emphasis on the safety issues.

The key distinction between disposal and other waste management operations, such as storage or conditioning, is that disposal is intended to provide a permanent and final solution for the waste while protecting people and the environment from harm. There is no intent to retrieve waste after disposal, but for solid waste placed in a disposal facility it is usually possible to do so if required in the future.

There are several options which have been proposed over the last several decades for the disposal of solid radioactive waste. These include: near surface disposal; deep geological disposal; and seabed or sub-seabed disposal.

The London Convention, 1972 presently prohibits disposal of solid radioactive waste at sea. Thus there are only two general disposal options currently available.

A key decision that needs to be made as early as possible in waste management is what types of wastes are suitable for disposal in the different kinds of repositories envisaged by the national waste disposal plans. This should logically lead to the segregation of the waste in different categories based on the envisaged disposal methods.

For most waste types the distinguishing feature is the longevity of the radioactive components. Thus long-lived waste, which may require tens of thousands to hundreds of thousands of years to decay to practically harmless levels, will need to be disposed of in geological repositories, while short-lived waste may be placed in near surface disposal facilities.

Regardless of the longevity of the radioactivity in the waste, repositories are designed to operate on the combined principles of isolation and containment. Containment involves various barriers (waste form and packaging, engineered components, natural media, etc.) which are expected to contain the waste for an initial period. As a result of their progressive degradation, a slow release and transport by groundwater of the remaining fraction of the radioactive inventory originally contained in the waste may occur. This is what is generally considered to represent the normal evolution of the disposal system. To proceed to the implementation of a disposal facility, knowledge about the behavior of the system components, and how future variations might affect their performance is also required. This is done in safety assessments and they need to generate sufficient confidence that safety standards for the proposed system will be met both now and in the future. Safety assessment for radioactive waste disposal is an iterative process that needs to be carried out with different levels of detail at the critical stages of the authorization procedure. *(See figure, page 56.)*

A generally accepted practice for assessments is the pairing of waste categories with disposal options. *(See table, page 57.)* Included are the generic human intrusion scenarios considered relevant for the different types of disposal facilities, which are further discussed in the following sections.

NEAR SURFACE DISPOSAL

Near surface disposal is an option used for disposing of radioactive waste containing short-lived radionuclides in quantities which would decay to radiologically insignificant levels within a few decades or a

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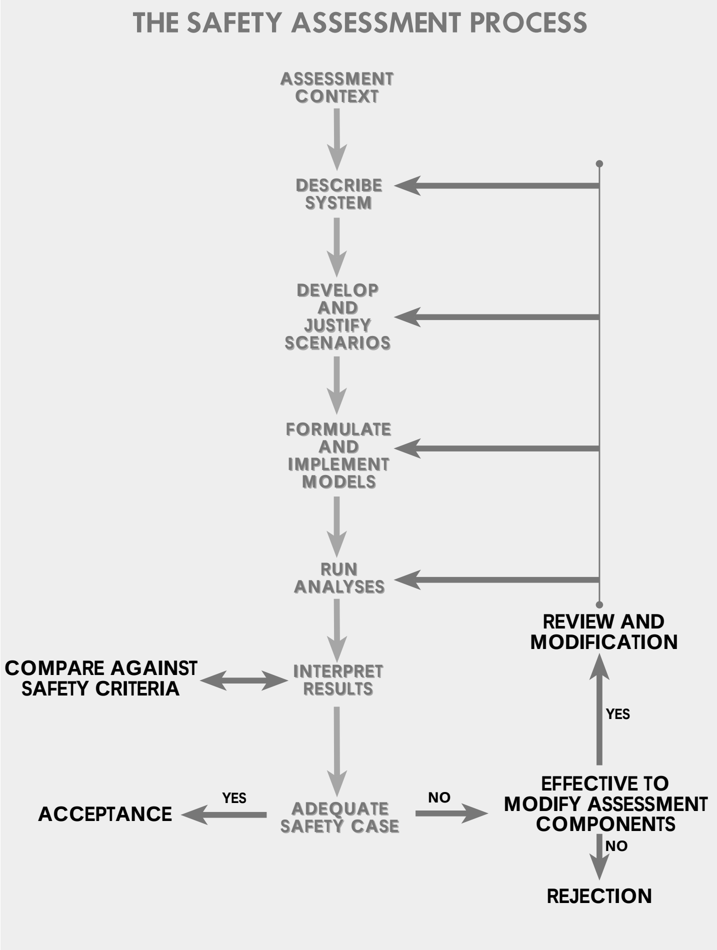
few centuries. Acceptably low concentrations of long-lived radionuclides may also be disposed in near surface repositories. There are two main facility types: (a) shallow facilities consisting of disposal units located either above (mounds, etc.) or below (trenches, pits, etc.) the original ground surface, and (b) facilities where the waste is emplaced at some greater depth in rock cavities or boreholes. In the first case the thickness of the cover over the waste is typically a few meters, while in the second case the layer of rock above the waste can be some tens of meters.

A special feature of near surface disposal is the requirement to assure institutional control over the repository site for a certain time. The rationale behind this requirement is that institutional controls will protect the waste from human intrusion, and other processes that might cause the containment barriers to lose their integrity. Safety assessments for such facilities commonly examine a variety of scenarios including human intrusion based on home construction, farming, drilling a well for water consumption as well as road building and erecting commercial structures. As long as safety assessment results show that the various scenarios would have radiological consequences exceeding the normal dose/risk limits, institutional control is required. On safety grounds, institutional control will only end when the estimated impacts of the scenarios that institutional control is designed to prevent meet the safety standards.

A key decision that needs to be taken in this respect is what is a reasonable duration for the institutional control period. It is also one of the key elements for defining the waste acceptance criteria for the repository. A loose international consensus exists that periods as long as some hundreds of years may be practical. In some cases the regulatory decisions taken to date would seem to imply that institutional controls might be required for much longer times. This creates potential problems in regard to the credibility of an open ended commitment and to the ethical justification of such a long-term burden on future generations.

Since most intrusion scenarios, with the exception of well drilling, do not penetrate more than some meters below the surface, a greater depth of isolation may have the benefit of less demanding requirements in respect to institutional control. Obviously, this will need to be confirmed, on a case by case basis, by the safety assessment.



GEOLOGICAL DISPOSAL

For long-lived wastes containing man-made radionuclides -- defined in the draft IAEA Safety Glossary as radioactive waste that contains significant levels of radionuclides with half-life greater than 30 years -- geological disposal in a facility located in a suitable host rock at a depth of at least some hundreds of meters, is the only

DISPOSAL OPTIONS FOR DIFFERENT TYPES OF WASTE & REFERENCE HUMAN INTRUSION SCENARIOS

Disposal option	Type of waste	Intrusion scenarios	Notes
Geological disposal; in stable, low permeability host rocks, usually at depth greater than at least 200 m.	■ High-level waste. ■ Spent fuel (if declared waste). ■ Other long-lived waste (NORM generally excluded for practical reasons).	■ Drilling through waste package. ■ Drilling through repository boundaries (not through waste). ■ Drilling through plume of contaminated water. ■ Mining through repository	Probability of intrusion is very low. To be minimized by siting and estimated on the basis of site specific considerations.
Near surface; rock cavity repository.	■ Short -ived, low- and intermediate-level waste (LILW). ■ LILW exceeding waste acceptance criteria for shallow depth disposal.	■ Drilling through waste package. ■ Drilling through plume of contaminated water. ■ Mining through repository.	Drilling near repository may be part of normal evolution scenario.
Greater confinement facilities / boreholes.	■ Disused radioactive sources. ■ LILW exceeding waste acceptance criteria for shallow depth disposal.	■ Drilling through or in proximity to waste package. ■ Residential scenario.	Probability of intrusion is relatively low. To be determined on the basis of site specific considerations.
Near surface; shallow depth repository.	■ Short-lived, LILW.	■ Construction scenario. ■ Residential scenario. ■ Combination of above.	After the end of institutional controls, the probability of intrusion is high.
Near surface: for large volume, long lived, low specific activity materials.	■ Uranium and thorium mine and mill waste. ■ Other NORM.	Basically the same scenarios as for other near surface, shallow depth disposal activities.	The same as above. In consideration of longevity of waste, probability of eventual intrusion is unity.

viable solution. Examples of this waste type are spent fuel and high level waste (HLW) from fuel reprocessing. These generally contain about 99% of the total radioactivity generated in the nuclear fuel cycle, are heat producing, and have intense radioactivity. Other types of low- and intermediate-level wastes may also contain levels of long-lived radionuclides too high for near surface disposal. As a matter of fact several Member States have decided to solve the problem of the long-lived, low- and intermediate-level radioactive waste by placing them in the same geological repositories as for spent fuel and HLW. An alternative solution chosen in some cases is to dispose of at least part of this kind of waste at a depth of a few tens of meters below the surface.

Geological repositories generally incorporate a variety of highly reliable engineered barriers, in addition to the deep geological setting. Radionuclides would have to travel long distances to reach the accessible environment, and thus no radiological impacts are estimated to occur for many thousands of years. The length of time that the safety assessment needs to address and the long delay before any radiological impacts are estimated to occur cause uncertainty in the estimated results. This may create problems in presenting the safety case to experts and lay members of the public alike. Many people feel that dose or risk estimates for a remote time in the future are not believable, since the status of the biosphere and the habits of human populations at the time are impossible to predict. This leads them to question the safety case as a whole. To overcome, at least partially, this communication difficulty, a series of approaches are being explored, including the use of standard or stylized biospheres, the use of additional safety indicators based on fluxes and concentrations of naturally occurring radionuclides and the investigation of natural analogues to support the modelling assumptions used in safety assessments. These approaches are not expected to replace the usual arguments presented to show that the disposal system is able to provide reasonable assurance of adequate safety. Rather these additional arguments appear valuable as they allow a safety case to be based on multiple lines of reasoning. This by itself is seen as a positive factor as such a safety case might prove more convincing for different sectors of society.

LONG-LIVED WASTE & NORM

There is a particular class of high volume radioactive wastes which contain only naturally occurring radioactive materials, that are long-lived but are of relatively low specific activity. The largest amount of these wastes arise from the processing of uranium ores to obtain fuel for the production of nuclear energy. There are also large volumes of other wastes with similar characteristics that are generated by other industrial activities such as the mining of phosphate minerals to produce fertilizers or the extraction of hydrocarbons. These wastes are referred to as NORM wastes (NORM stands for "naturally occurring radioactive materials"). NORM wastes are generally considered to be outside the nuclear sector and thus are not controlled by the same regulatory bodies as other radioactive wastes, while uranium mine and mill tailings are regulated as a type of radioactive waste in most countries. This leads to similar kinds of waste being regulated in significantly different ways.

The long life of the radionuclides contained in mine and mill tailings and in other NORM waste would seem to indicate the need for a significant level of isolation. However, there are hundreds of millions of tonnes of these wastes in some countries and it is not practicable to dispose of all of them in geological repositories. Where this cannot be done, the waste is placed in conventional mine tailings embankments using well engineered containment systems. The engineered features of the containment system ensure that the normal releases and doses arising meet conventional dose/risk criteria. However, the containment barriers cannot be expected to maintain their initial performance for the hazardous life of the waste (hundreds of thousands of years). In addition there is the problem of unacceptable doses that would arise as a consequence of intrusion. Institutional controls can, as discussed before, provide for the maintenance of the containment barriers and prevent intrusions as long as they last, but not likely for the length of time that the longevity of the radiological hazard would ultimately require.

WASTE SAFETY STANDARDS

Over the last few years the IAEA has been aware of the need to identify and ultimately harmonize the key principles and criteria which should apply to the disposal of the various types of radioactive wastes. This is not as straightforward as it might first appear. There are widely variable time frames involved, from a few tens of years to as much as hundreds of thousands of years. It is very difficult for most people to grasp the meaning of times beyond a few generations. It is also difficult to produce long-term performance estimates of the engineered and natural components of the disposal system that will turn out to be convincing for large sectors of society. Even more problematic is the difficulty in trying to determine the behavior of individuals and society over these time periods.

Some of the proposed criteria however, require that estimates of both of these be determined (e.g. a risk criterion requires that both the likelihood of some future event and its consequence be estimated). Related to these long time frames is the issue of uncertainty. Even with the best current understanding of the way the engineered, geological and biological components of the system behave, it is not unusual to have an uncertainty as large as several orders of magnitude in the final outcomes of the performance assessment. Furthermore, at a certain point in the assessment process, it is not unusual for the analysts to reach the conclusion that further reductions in the uncertainty are not reasonably achievable. This means that regulators and other decision makers may have to make decisions in the face of uncertainties which are much higher than those with which they may be accustomed.

Another element which has arisen in the past is that the standards and requirements for

STATUS OF IAEA SAFETY REQUIREMENTS & GUIDES FOR RADIOACTIVE WASTE DISPOSAL

The IAEA has issued a number of safety requirements and guides for different types of radioactive waste and disposal options.

■ Near Surface Disposal: The publication, *Near Surface Disposal of Radioactive Waste,* was issued in 1999 as a Safety Requirement. Two Safety Guides have been issued, one in 1994, *Siting of Near Surface Disposal Facilities,* and one in 1999, *Safety Assessment for Near Surface Disposal of Radioactive Waste.*

■ Uranium & Thorium Mine & Mill Tailings; other waste containing naturally occurring radioactive materials (NORM): A Safety Guide, *Management of Radioactive Waste from Mining & Milling of Uranium/Thorium Ores,* is planned for preparation in 2001.

■ Geological Disposal: One publication, *Geological Disposal of Radioactive Waste,* is in preparation for issuance as a Safety Requirement. Also in preparation is another publication, *Safety Case for Geological Disposal,* for issuance as a Safety Guide. One Safety Guide, *Siting of Geological Disposal Facilities,* was issued in 1994.

disposing of the different types of waste have often been considered in isolation of one another. This may give rise to inconsistencies in the way each type is judged. This is undesirable from a purely technical perspective but is even more undesirable from a public perception perspective.

In order to address this issue, the IAEA is working to develop a common framework for judging the acceptability of facilities designed to dispose of the various types of radioactive wastes. Any approach would, as a minimum, require the application of good engineering practice and the reduction of dose in accordance with the optimization principle of radiation protection. However, the practical realities of meeting the principles and criteria ultimately put in place must be taken into account. This is challenging when the diversity of waste volumes, activities and lifetimes is considered. In spite of these challenges, progress is being made and it is hoped that a common framework will be available shortly. This in turn will likely be reflected in unified safety requirements and guides over the next few years.

A key issue in moving forward to the development of more repositories is the level of trust and confidence within the diverse sectors of society in most countries. While the safety assessments mentioned above continue to receive the confidence of specialists working in the field, they are clearly not sufficient to provide confidence within the broader community. The IAEA is aware of these differences between stakeholders and is exploring ways to bridge them by involving individuals with more diverse backgrounds in future work programmes. Besides the previously mentioned work on multiple approaches to produce the safety case for disposal facilities, the Agency has also produced a document on regulatory decision making in the presence of the large uncertainties associated with assessments of performance and safety covering very long periods of time.

In respect to the production of up-to-date safety standards, the IAEA has been developing a broad range of safety requirements and guides under the RADWASS programme. *(See article, page 30.)* There are specific documents in this programme related to the disposal of radioactive wastes. *(See box, this page.)*

It can be seen that early emphasis was given to the development of documents for near surface disposal. This was in accordance with the wishes of Member States. Many more countries require near surface disposal facilities to handle radioactive wastes from hospitals and industry, than from uranium mines and mills or nuclear power plants. However, work is well advanced in developing a guidance document for uranium mining and milling wastes and work is getting underway to develop requirements and a safety guide for geological disposal.

It is thus anticipated that within the next few years, a complete set of up-to-date safety requirements and guides, with some supporting technical documents, will be available to cover all aspects of radioactive waste disposal. ❐