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Geological Disposal of Radioactive Wastes – Concept, Status and Trends

Almacenamiento Geológico de Residuos Radiactivos – Concepto, Situación y Tendencias

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Abstract

Europe is close to implementing its first geological repositories for spent nuclear fuel. The European Commission has endorsed geological disposal as the favoured strategy for dealing with Europe's long-lived radioactive wastes, pointing out that it is technically feasible now, and that can demonstrate the required guarantees of long-term isolation. This article reviews the origins and the scientific and technical basis of the concept of geological disposal, looking in particular at how isolation and containment are provided and the timescales over which containment is needed. It goes on to look at the status of geological disposal internationally and at some trends and issues which both implementers and regulators are addressing.

Keywords: geological disposal, radioactive waste, waste containment

Resumen

Europa está a punto de poner en práctica sus primeros almacenamientos geológicos para el combustible nuclear gastado. La Comisión Europea ha respaldado el almacenamiento geológico como la mejor estrategia para hacer frente a los residuos radiactivos de larga vida. El almacenamiento geológico es técnicamente factible actualmente, y se pueden demostrar las garantías requeridas de aislamiento a largo plazo. El artículo revisa los orígenes y los fundamentos científicos y técnicos del concepto de almacenamiento geológico describiendo en particular los métodos utilizados para proporcionar el aislamiento y la contención en las escalas de tiempo en las que la contención es necesaria. Asimismo revisa la situación del almacenamiento geológico a nivel internacional y algunas de las tendencias y cuestiones que ejecutores y reguladores están planteando.

Palabras clave: almacenamiento geológico, residuos radiactivos, contención de residuos

1. Introduction

The objective of this short paper is to provide an overview of deep geological disposal – what it is, why we need it and which important issues are being addressed today by waste management agencies, regulators and decision makers. It is timely to look at these topics because almost 50 years has passed since the concept was first seriously considered and Europe is now almost of a single mind as to the need for such facilities if we are to

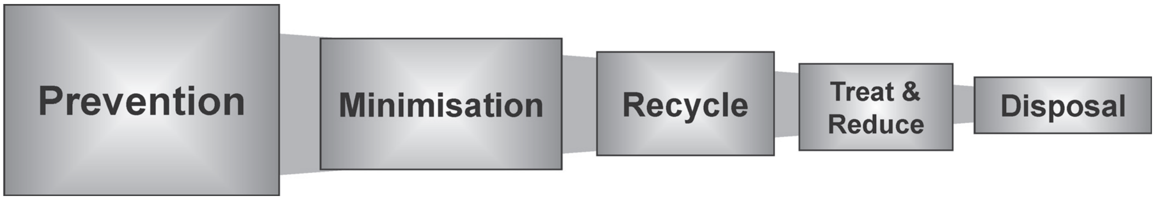

Fig. 1.- The concept of progressive reduction in waste volumes, arising from any industrial process, if modern management concepts are utilised.

Fig. 1.- Concepto de reducción progresiva del volumen de residuos, aplicable a cualquier proceso industrial, si se utilizan los conceptos modernos de gestión.

continue with nuclear power – indeed, the first national repository is under construction, in Finland.

Each of the larger European countries produces several hundred million tonnes of waste every year. Although care is obviously required in managing all of this material, only a fraction, typically around 1%, is considered to be significantly hazardous and an even smaller fraction, perhaps around 0.1%, is regarded as extremely toxic. About 60% of hazardous waste produced in Europe comes from manufacturing industry, with the chemical industry being the main single producer. Some of these hazardous wastes cannot be treated to make them safe and can only be managed by disposing of them safely, which generally means by burial in the ground. At present, only a tiny fraction of wastes worldwide is disposed of by deep burial: much hazardous waste is still buried in shallow landfills.

The more advanced countries have embarked on major programmes to reduce the amount of waste they have to dispose of. Clearly, development of clean processes can completely prevent the production of some wastes. Schemes that minimize waste production at source are followed by recycling programmes to deal with as much of the inevitable waste products as possible. Wastes that have no use can be treated, by incineration for example, to destroy hazardous substances or reduce their volume. However, there is always some residue that requires disposal (Fig. 1).

The European Union generates about 35% of its electricity from nuclear energy, although this has historically only produced about 0.05% by volume of its power production wastes (European Commission, 2004a). The nuclear industry shares the same approach to prevention and minimisation of wastes as that described above. Some countries also recycle (reprocessing spent fuel), but all nuclear industry processes (and several from other industries and activities) produce a certain amount of radioactive waste that has to be managed. Unlike hazardous wastes from other sources, the most toxic radioactive wastes are destined for deep geological disposal – burial in carefully engineered facilities located in stable rock formations at depths of several hundreds of metres. After some decades of operation, such repositories can be closed and sealed, at the convenience of future decision-makers. Few countries use geological disposal for non-radioactive hazardous wastes. However, the increasingly stringent environmental controls that have developed in many countries over the last 30 years, combined with the inexorable increase in waste arisings from industrial countries and the wiser use of the land surface are likely to see more interest placed in the wider use of geological disposal in the future.

Despite their small volume, the whole concept of carefully designed geological disposal using the ‘multibarrier’ system[1] of containment has been developed specifically for these wastes, with the earliest work dating back to the late 1950s in the USA. Geological disposal at a depth of some hundreds of metres in a carefully engineered repository was first formally advanced as an appropriate, safe solution to radioactive management almost fifty years ago, in the United States (NAS, 1957). However, progress has been slow and the timescales of geological repository development programmes are unusually long, compared with any other industrial or engineering enterprises – typically several decades, even some hundreds of years. The WIPP repository for military transuranic wastes (New Mexico, USA) was the first purpose built geological repository to be successfully licensed and began operating five years ago. Slow implementation for commercial wastes is largely a matter of failure to obtain political and public acceptance of technical proposals, the way in which they have been advanced and the way in which people have been involved in the process. Nevertheless, the last few years have seen an acceleration in activity in several countries and it is now likely that Finland, Sweden and possibly the USA will have operational spent fuel repositories within the next ten years.

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[1] where the waste containers, the engineered components of the repository and the surrounding geological environment work in concert to contain radionuclides

One aspect of radioactive waste disposal that sets it aside from the management of other types of waste is the inclusion of long periods of interim storage prior to disposal. This is partly an inevitable consequence of the slow progress in building repositories, but it is also increasingly proposed as a response to public demands to proceed cautiously with disposal, in a 'staged' approach (NRC, 2003) that allows plenty of time for decisions to be made and permits retrieval of wastes if required.

2. The aim of deep geological disposal

Deep geological disposal is typically a management option retained for high level wastes (vitrified HLW from reprocessing spent nuclear fuel, or the spent nuclear fuel itself if it is not to be reprocessed) and the longer-lived intermediate level wastes (ILW), either of which categories has a significant content of radionuclides with half-lives of tens of thousands of years or longer (Table 1).

Historically, there have been two approaches to disposing of hazardous wastes: 'concentrate and contain' and 'dilute and disperse'. The latter is often taken to imply uncontrolled releases of toxic substances into the environment and is now generally frowned upon, even though it may be the most reasonable and best practicable option for small quantities of some substances. Concentrating radioactive wastes into one location means that they can be contained more easily and many radionuclides can be confidently left to decay in situ to harmless levels without any concern that normal natural processes will mobilise them into the environment. Geological disposal is a clear example of this approach: concentrate, contain and isolate hazardous material in a location that is well out of harm's way. It can be done, with reasonable expenditure of resources, in such a way as to have zero effect on the biosphere for many thousands of years. Achieving zero impact, even for a few hundred years, is already a major advance on any other management option and on what society achieves for any other persistent hazardous materials. It also seems to match society's expectation of who they want to protect and for how long.

However, concentrate and contain does mean that wastes in a geological repository could be vulnerable to intrusion by people in the future. Also, some radionuclides have such long half lives (Table 1) that they will remain in the repository until natural geological processes expose them or mobilise them. At this point, 'concentrate and contain' reverts to 'dilute and disperse', as these residual radionuclides are dispersed into the surrounding rocks and waters in low concentrations to join the naturally occurring radionuclides already present.

Radionuclide	**Approximate half-life (years)**
Fission and Activation Products	
Carbon-14 (^{14}C)	5700
Chlorine-36 (^{36}Cl)	300,000
Nickel-59 (^{59}Ni)	75,000
Selenium-79 (^{79}Se)	65,000
Niobium-94 (^{94}Nb)	20,000
Technetium-99 (^{99}Tc)	210,000
Tin-126 (^{126}Sn)	100,000
Iodine-129 (^{129}I)	16,000,000
Caesium-135 (^{135}Cs)	2,300,000
Transuranic actinide and natural U-Th decay chain radionuclides	
Radium-226 (^{226}Ra)	1600
Thorium-230 (^{230}Th)	77,000
Thorium-232 (^{232}Th)	14,000,000,000
Protactinium 231 (^{231}Pa)	33,000
Uranium-234 (^{234}U)	240,000
Uranium-235 (^{235}U)	700,000,000
Uranium-238 (^{238}U)	4,500,000,000
Neptunium-237 (^{237}Np)	2,100,000
Plutonium-239 (^{239}Pu)	24,000
Americium-241 (^{241}Am)	430

Table 1.- Some important radionuclides in long-lived wastes

Tabla 1.- Algunos radionucleidos importantes en residuos de larga vida.

The overall objective of deep disposal is thus to isolate the wastes from the biosphere until such time as natural processes of decay and dilution prevent any radionuclide from returning in concentrations sufficient to pose an unacceptable hazard. Clearly, many processes, such as mobilisation, transport, retardation, retention, dilution and re-concentration need to be accounted for in evaluating whether this aim can be met, for a range of possible scenarios of future evolution of the disposal system. In the multibarrier approach, the individual engineered barriers around the solid waste act together to provide a variety of 'safety functions' which control the inevitable releases of radioactivity from the repository and their movement through the rock.

3. Containment periods

A fundamental issue in geological disposal is the period over which we expect to contain the wastes, as they clearly cannot be isolated for ever from the inexorable processes of geological and environmental change. A properly implemented repository can contain long-lived wastes such as spent fuel and HLW until they have decayed to levels of hazard commensurate with natural uranium ore deposits: a few thousand to a few hundred thousand years. Clearly, protection needs to be matched to the changing hazard that the waste represents as radioactive decay progresses.

The greatest hazard with HLW and spent fuel wastes destined for geological disposal is associated with the early time period – the first few hundred years. Here, when there is the potential for major impacts if people were to be exposed to the wastes, the design process aims to provide a containment system that gives maximum protection, and the need for compliance with radiological protection regulations should be at its most stringent. After this high hazard period, containment requirements need not be any more demanding and, in fact, become less rigorous with increasing time. At some point in time, containment can be argued to become unnecessary (and, at some later time, unachievable). When does the importance of the containment system decline to the former point?

Figure 2 shows the progressive reduction in radioactivity of spent fuel compared to that of an equivalent amount of natural uranium ore used to manufacture the fuel. A plot of radiotoxicity decline with time would show similar form and a similar cross-over time. The key message is that there is a 'back-to-nature cross-over' point when the hazard of a spent fuel repository becomes similar to that of natural systems, albeit not necessarily systems found in similar environments or regions of the planned repositories. Spent fuel radiotoxicity 'cross-over' occurs after one to a few hundred thousand years, whilst that for HLW occurs much earlier – after only a few thousand years. These could provide benchmarks in time for the provision of protection, beyond which the containment objectives change.

Beyond this natural 'cross-over' time there is a strong case, based on the parallel with nature, on society's real expectations and on sensible use of resources, for saying that we have done enough. There is no logical or ethical reason for trying to provide more protection than the population already has from Earth's natural radiation environment, in which it lives and evolves. It is a scientifically tenuous position to argue that additional protection (e.g. down to a few microsieverts of exposure) can be provided so far into the future and unreasonable to expect it, or to regulate for it.

But what about the period before this cross-over point? Here, the repository system must function to provide protection that can be judged by estimating the radiological impacts of any releases and comparing them with regulatory requirements, based on radiological doses and commensurate risks. Dose and risk limits are often laid down in national environmental regulations, which themselves are based on internationally recognised radiological standards. For example, regulations may stipulate target levels of radiation dose (or consequent risk of serious health effects) to hypothetical individual members of the public. A repository developer would be expected to show that any potential doses or risks fell below such target levels, for all reasonable circumstances, and for at least several thousands of years into the future – much longer in some countries. Here, it must be acknowledged that the concept outlined above, of their being some back-to-nature state, is still being discussed, and many regulations require compliance with the same dose or risk target for all times. At present, the USA, after having been a notable exception for many years, with an effective cut-off time of 10,000 years for the main safety case arguments, is now considering a long-term standard that is directly related to natural background radioactivity. The US Environmental Protection Agency is proposing a 3.5 mSv/a standard for the period between 10,000 and 1 million years that is equivalent to average natural background radiation exposures in some parts of the USA. Much of the background to the development and use of safety principles for radioactive waste management is described by Chapman and McCombie (2003).

4. Providing containment

Containment in the intermediate period between the total containment of around a thousand years and the 'return to nature' state of a few hundred thousand years is thus what primarily concerns the designer when establishing a particular repository safety concept. Contrary to popular misconceptions, the greatest challenge is not containing elements such as plutonium, since these are extremely immobile in most geological environments. The principal issue is to show that the multibarrier system will limit releases of mobile radionuclides, such as those of iodine and chlorine. Once water has contacted the waste, it is not possible to exclude the release of some of these radionuclides into the geosphere and, eventually to the biosphere. Safety over the long-term is predicated on these releases to the biosphere being of no consequence because they are very slow and at very low concentrations, controlled by dispersion, retardation and dilution in the rocks and groundwaters of the natural barrier.

A wide range of host geological formations has been considered worldwide for deep repositories, including

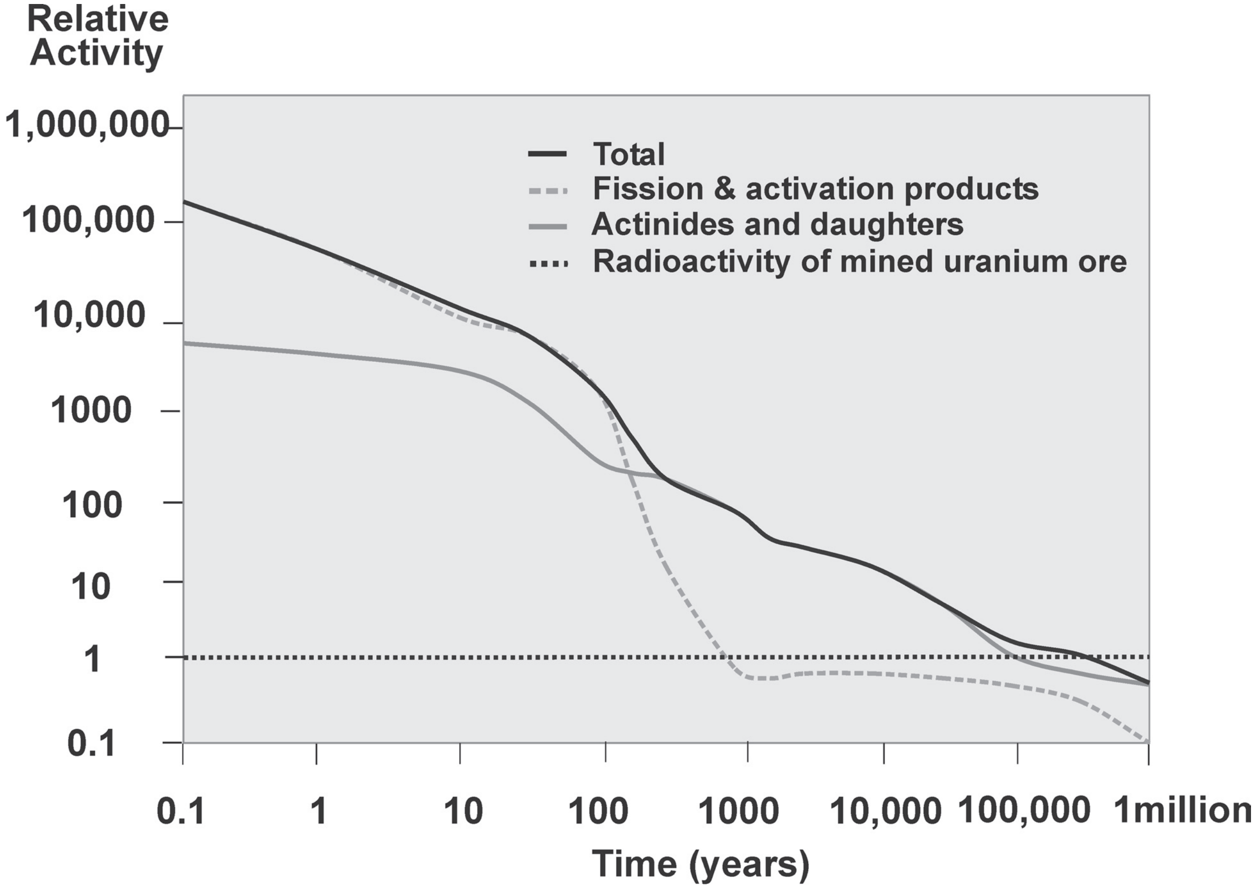

Fig. 2.- Relative radioactivity of typical spent fuel as a function of time after discharge from the reactor, showing the early, dominant contribution of the fission and activation products. After a few hundred years, the actinide elements become dominant. After a few hundred thousand years, the total activity of the fuel is similar to that of the uranium ore from which the fuel was produced (redrawn, after Hedin, 1997).

Fig. 2.- Actividad relativa del combustible gastado en función del tiempo desde la licencia del reactor. Inicialmente, se observa la contribución dominante de los productos de fisión y activación. Después de unos cientos de años, los actínidos se hacen dominantes. Después de unos cientos de miles de años, la actividad total del combustible gastado es similar a la del depósito de uranio a partir del que se produjo el combustible (redibujado de Hedin, 1997)

hard crystalline rocks (such as granite, gneiss and volcanic tuff), argillaceous rocks (clays, mudrocks, shales) and evaporate formations (dome and bedded salts). In most disposal concepts being considered internationally, the host geological formations (although selected for their low permeability) are still sufficiently permeable that some groundwater movement can occur. The releases are then controlled by the rate and volume of flow of the groundwater. In some geological environments, (clays and claystones) flow may be so limited that extremely slow solute diffusion is the dominant process by which radionuclides can migrate. A special case is presented by repository concepts involving emplacement in salt deposits. In a normal evolution scenario, no groundwater will contact the waste packages and the predicted releases will be zero at all times considered. In addition, so called 'high isolation' environments can be found in flat, arid, tectonically stable regions of the world where there are effectively no driving forces for deep groundwater movement. The prime focus of safety assessments for salts, clays and 'high isolation' environments may then be on disruptive processes or events which can disturb the natural barrier.

The key features of a favourable disposal environment (in terms of its geological, hydrogeological and geochemical attributes) can be summarised as (not in order of importance):

- tectonic stability over long periods of time, or where the deep environment is not significantly affected by local tectonic processes and events;
- very low groundwater fluxes at depth and preferably where there is minimal coupling between flows in the upper parts of the rock mass and those at greater depth;
- very old, stable and reducing groundwater at depth;

- resilience (at depth) to the effects of climate change – in particular, the groundwater system needs to be suitably buffered against such changes;
- thermal stability of the rock–water system;
- rock mass with geotechnical properties that allow for repository construction;
- lack of fast transport pathways from the repository to the surface;
- a preference for diffusion-dominated radionuclide movement (i.e. essentially static groundwater conditions), rather than advection in slowly moving groundwater;
- ability to disperse any gas generated within the repository (e.g. by anaerobic corrosion of metals).

A carefully chosen geological environment has the potential to act as a cocoon for the repository engineered barrier system (EBS), protecting it from gross fluctuations in stress, water flow and hydrochemistry. Large fluctuations in these properties are generally experienced in dynamic regions of Earth's crust, such as near-surface rock and groundwater systems that are more easily and rapidly affected by changes in climate and in land use. The deeper environment is sheltered from these effects, with increasing depth buffering against and smoothing out in time the magnitude of surface perturbations. This isolation from surface effects is an extremely important function of the natural barrier system in the majority of safety concepts, as it enables that part of the disposal system that can actually be designed and optimised (i.e. the EBS) to function predictably for long periods of time. The end result in terms of containment within the multibarrier system is that many radionuclides decay in situ. Only the most mobile and longest lived radionuclides migrate out into the rock around the repository. A tiny fraction of these returns to the biosphere, in very low concentrations, owing to physical and chemical processes of retention, dilution and dispersion.

5. Illustrating safety

Putting all the technical aspects of repository design and performance together is often done via an integrated safety assessment, involving modelling the processes that affect the way a repository evolves over long time periods into the future. Over the last thirty years, numerous safety assessment have been carried out to evaluate how containment will be provided (often called the 'safety concept' for a design) and whether specific designs and, more recently, detailed, site specific repository systems can achieve regulatory safety targets. Calculated radiological impacts of repositories under normal future evolution scenarios (including those involving environmental changes) are generally orders of magnitude below impacts from natural background radiation and, by any normal standards of human judgement of risk acceptability, are effectively zero.

However, providing confidence in these modelling studies has not always been easy and some people remain sceptical of the results, which is why they are often described as estimates or as being illustrative of performance (rather than predictions of actual behaviour, which they cannot be owing to uncertainties about the far future). One of the best means of providing confidence that a system will behave as it is designed is by analogy. The use of natural and archaeological analogues of materials and processes that occur in repositories (Miller *et al.*, 2001) has proved a tremendously powerful means of illustrating that we understand repository evolution and can scope radiological impacts confidently. Examples of natural analogues are to be found, for example, in uranium ore deposits, where processes of migration and retention of natural radionuclides that have been active over millions of years can be examined.

6. Status and trends in geological disposal

Geological disposal is now the accepted solution for long-lived and highly active radioactive wastes in every country that has a final management solution. Only countries that are undecided at a political level on the overall waste management programme have yet to make the decision. In Europe, at the end of its most recent five-year programme (whose extensive results are summarised in European Commission, 2004a) the European Commission declared (European Commission, 2004b) that: *"Disposal in deep (>300 metre) geological repositories, the favoured strategy in Europe for long-lived high-level radioactive waste, is now possible"*. In the same document, the Commission also states that: *"Deep geological disposal is technically feasible now and can demonstrate the guarantees of long-term isolation and protection the public demands"*.

Following decades of research and development it has become the preferred option for the eventual disposal of solid, high level and long-lived intermediate level wastes in almost every country with a nuclear power programme. Whilst the timescales and routes to eventual disposal vary from country to country – with different approaches to interim storage, for example – emplacement in a geological repository is the anticipated end-point. This preference is generally expressed in national policy documents or laws. The IAEA Joint Convention on Spent Fuel and Radioactive Wastes (IAEA, 1997) also obliges all signatory states to submit regular, detailed overviews of their national waste management programmes. The European

Commission is also set on establishing binding legislation that would require each Member State of the European Union to declare a proper schedule for disposal of its nuclear power wastes.

After decades of research, a key technical trend today is a move of emphasis from supporting scientific research towards practical considerations – after all, several countries are on the verge of constructing repositories. Whilst a number of scientific issues would benefit from further study, and whilst scientific knowledge and understanding will continue to grow, evolve and contribute to confidence in geological disposal, the real technical issues today are with practical implementability. For example, the major programmes will have to move from largely conceptual engineering designs for the EBS to much more practical designs that consider how to emplace and manage large items and active materials in the underground environment. Work in underground laboratories such as Grimsel and Mont Terri in Switzerland, Äspö in Sweden and Mol in Belgium are all now addressing these practicalities by mounting full-scale engineering demonstrations of EBS emplacement.

The requirements on a deep geological repository are, however, not just the technical issues discussed earlier in this paper, which is perhaps the main reason why progress has been slow over the last decades, as not all these requirements were recognised from the outset and many national programmes have been slow to respond to some of them. Requirements over and above straightforward technical feasibility and demonstration of safety to regulatory standards include:

- **Ethics:** Can geological repositories be implemented without being “unfair” to present day stakeholders or to future generations, who should also not be subjected to unnecessary burdens?
- **Security:** Do repositories provide sufficient protection against deliberate misuse of the hazardous materials they contain?
- **Environmental Acceptability:** How can a repository be constructed and operated without undue disturbance of the environment? How will the local community be affected
- **Public acceptability:** What are the public views on waste repositories? How can the public best be included in the decision making processes? Can a sufficient degree of societal consensus be achieved?
- **Economic viability:** How much do repositories cost? Does geological disposal make the nuclear fuel cycle uneconomic?

Much work has been carried out in each of these areas over recent years. Perhaps the main problem has been meeting the requirement of public acceptability. Attaining a sufficient level of public acceptability and of societal consensus has been one of the major factors that have prevented implementation of geological repositories. In all countries with geological repository programmes there has been some degree of public lack of acceptance or even direct opposition. The shortcomings of past industry policies of public involvement have been recognized today and several international initiatives are underway to try to improve the situation (e.g. COWAM, 2003; RISCOM, 2003). One approach to providing increased opportunities for interactions between nuclear experts and the interested public is to adopt a phased or staged procedure for implementing major projects. Staging involves repeated consultation of a wide range of stakeholders, including the public. No major decision should be taken without ensuring that there is sufficient acceptance of the choice made. The characterising feature of every national programme over the last 30 years has been how well it identifies and manages critical decision points that must be navigated. There are numerous decision points in a ‘staged’ process (NRC, 2003) and an important consideration for every programme is how the decisions are made and who is involved. Some decisions might be seen as entirely internal technical matters (e.g. container material), some decisions seem to be entirely external and outside the control of programme managers (e.g. political approvals, licensing), but every decision could involve a range of stakeholders and could be approached in different ways.

The European Commission, having stated a firm EU preference for geological disposal of its long-lived radioactive wastes, is promoting legislation that would require all European Union member states and future member states to establish specific deadlines for siting repositories and for implementing these facilities. Many smaller European Union countries, or larger countries with small amounts of waste, or with no national solutions in place, need to face the problem that deep geological repositories are expensive facilities. These nations also need safe and secure long-term waste management options. For this reason, there is increasing interest in the concept of shared deep geological repositories in Europe, with a number of countries agreeing to cooperate in implementing a regional facility (see the results of the first European study of regional repository feasibility: SAPIERR, 2005).

In coming years, there will be significant policy decisions taken in several European countries with respect to deep geological disposal. In 2006, France must reformulate its policy concerning the weighting on the three different long-term management options currently being studied (long-term surface or underground storage, transmutation, and geological disposal). After a long period of consultation and reflection following earlier programme failures, the United Kingdom is expected to decide on an option for management of its large legacy of radioactive wastes. This is seen as especially important today, when the UK's future energy policy needs to be decided, with the role of nuclear power being central to this decision. Implementation of deep geological repositories is not, however an urgent task. The target deadlines set for opening and operating deep geological repositories in many countries are decades into the future – but it is essential to have a programme that will eventually achieve this objective. The desire to see proper solutions for historic wastes from nuclear power and to have solutions for wastes from Europe's essential new, future nuclear programmes, together with the need to have secure systems for isolating radioactive materials from potential terrorist activity means that simply watching and waiting is no longer an acceptable response from political decision makers.

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References

Chapman, N.A., McCombie, C. (2003): *Principles and Standards for the Disposal of Long-Lived Radioactive Wastes*. Elsevier, Amsterdam. 277 p.

COWAM (2003): *European Commission Network: Nuclear waste management from a local perspective – reflections for a better governance*. Project final report, November 2003. http://www.cowam.com/documents/cowam-fr2003.pdf

European Commission (2004a): *Geological Disposal of Radioactive Wastes Produced by Nuclear Power: from concept to implementation*. Report No: EUR 21224. Available at: http://europa.eu.int/comm/research/energy/pdf/waste_disposal_en.pdf

European Commission (2004b): *Euradwaste'04. Radioactive waste management community policy and research initiatives*. Conference Summaries. 6th Commission Conference on the Management and Disposal of Radioactive Wastes.

Hedin, A. (1997): *Spent nuclear fuel – how dangerous is it?*. Swedish Nuclear Fuel and Waste Management Company, SKB (Stockholm). Technical Report TR-97-14.

IAEA (1997): *The Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management*. GOV/INF/821-GC(41)/INF/12. International Atomic Energy Agency, IAEA, Vienna.

Miller, W.M., Alexander, W.R., Chapman, N.A., McKinley, I.G., Smellie, J.A.T. (2001): *Geological Disposal of Radioactive Wastes and Natural Analogues*. Pergamon Press, Oxford. 316 p.

NAS (1957): *The Disposal of Radioactive Waste on Land*. National Academy of Sciences. Publication 519, NAS Washington DC, September 1957.

NRC (2003): *One Step at a Time: The Staged Development of Geologic Repositories for High-Level Radioactive Waste*. National Academies Press, Washington, DC, 20001

RISCOM (2003): *Transparency and public participation in radioactive waste management*. Riscom II final report. Swedish Nuclear power Inspectorate, SKI, Stockholm. Report 2004:08.

SAPIERR (2005): *Support Action: Pilot Initiative on European Regional Repositories*. European Commission Project: www.sapierr.net