

DEEP GEOLOGICAL REPOSITORIES: A SAFE AND SECURE SOLUTION TO DISPOSAL OF NUCLEAR WASTES

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1.0 ABSTRACT

Permanent safe solutions are needed for isolating from the human environment the radioactive waste resulting from the operation of commercial nuclear power plants, as well as long-lived wastes from other nuclear applications in research, industry and medicine. The only option currently regarded by the scientific and engineering community as viable is deep disposal in stable geologic formations. National and international repository concepts are being developed for this option.

A further – and more urgent – challenge is presented by the need to deal with the many tonnes of plutonium and highly enriched uranium, which have arisen from dismantling of nuclear weapons. Most of these materials may be converted into fuel for nuclear reactors. The deep disposal of the resultant spent fuel along with conditioned plutonium is a key economic and security issue for the world.

There is a common solution to the challenges of ensuring long term safety for spent fuel and of preventing weapon grade materials being illegally diverted and misused. Deep geologic repositories are the answer. The paper describes the specific engineering, geological, hydrogeological and geotechnical challenges involved at each phase in the development of a geologic repository. It then briefly considers the particular case of Australia. We point out that there is a requirement for geologic disposal of limited quantities of Australian wastes, that this could be accomplished in a national or international framework and that relevant expertise is available for repository implementation in Australia.

2.0 THE CHALLENGES

2.1 Long-term Safety

Long-lived radioactive wastes are produced primarily in nuclear power generation – but also in other applications such as medical isotope production, medicine, research and industry. These wastes present a potential hazard to living organisms if they are not isolated from the environment. The isolation times required to ensure safety are in some cases extremely long (over 100,000 years) - although never infinite, as for some chemo-toxic wastes. The largest inventory is in the form of spent reactor fuel, of which there are currently about 130'000 tonnes spread around the world in over 400 nuclear facilities. This is growing at a rate of around 10'000 tonnes per year.

Ensuring the safety of all future generations by proper management of these wastes is an ethical responsibility of the current generation, which benefits from nuclear technologies. The benefits are enjoyed not only by consumers of nuclear electricity, but also by suppliers of services through the nuclear fuel cycle and furthermore by all societies making use of nuclear technologies.

2.2 Nuclear security

Security is the term used when discussing a different type of hazard potentially arising from nuclear materials. Highly enriched uranium and plutonium are fissile materials, which can be used to make nuclear explosives. It is imperative to ensure that such materials do not get illegally diverted and misused. Global civil stocks of separated plutonium from reprocessing of spent fuel may exceed 250 tonnes by the year 2010 – and less than 10 kg will suffice for a crude nuclear bomb. Moreover, the welcome move towards disarmament by the major weapons states is, in the short term, increasing the hazard potential. Some 200 tonnes of plutonium

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and 2000 tonnes of highly enriched uranium will become available for other purposes as surplus weapons are dismantled.

Given the drastic economic conditions in Russia, for example, the temptations of individuals to divert valuable nuclear materials are large. Society must face the challenge of ensuring that the weapons grade materials are converted into forms unsuited for use in bombs and are safeguarded permanently from misuse. The uranium can be diluted to lower enrichments and burned in nuclear power reactors. This produces spent fuel, a waste form which is much more proliferation-resistant because it is intensely radioactive initially. The plutonium can also be burned in mixed oxide reactor fuel or it can be immobilised into a non-reactive matrix such as glass or the Synroc material originally developed in Australia. Ultimately, however, the aim is to remove these materials permanently from the human environment.

3.0 THE ONLY FORESEEABLE SUSTAINABLE SOLUTION

As described above, the challenge is to ensure the safety and security of current and future generations by permanently isolating long-lived radioactive materials from the environment. Isolation can be achieved for long times by building, maintaining and guarding strong and secure surface storage facilities. However, the consequence of this approach is to pass on a legacy to future generations who then must continue to commit resources and to maintain institutions, to care for the storage facilities.

The ideal solution would be to permanently remove the material from our earth (e.g. by ejection into space) or change it to a less harmful form. The former option has been considered periodically since the 1970's and always it has been found to be too risky and too costly. Transforming radioactive materials to more benign forms is possible using nuclear transmutation processes in a reactor or a particle accelerator. This has also been studied for 30 years. The current consensus is that transmutation is a complex and costly process, which could reduce the quantities of long-lived wastes – but it cannot get rid of all problematic radionuclides.

Today, the only solution judged by scientist as being capable of removing the hazards of radioactive waste without placing undue burdens on future generations is deep geologic disposal. The concept was first proposed 50 years ago by the US National Academy of Sciences. Since then there have been decades of scientific and technical development in many countries. Currently, only a single, purpose-built facility has been licensed for operation (the WIPP repository in New Mexico, USA), but various countries have repository projects entering the implementation phase.

In the following section, the fundamentals of the geologic disposal concept are briefly described before highlighting the unique engineering and geotechnical problems of direct interest to Geoeng 2000. Finally, in view of the fact that recent proposals have been made for an international repository in Australia, we address the capability of Australia to provide the right environments and the necessary engineering and geotechnical expertise for such a project.

4.0 GEOLOGIC PREPOSITORIES

4.1 Multibarrier system

A geologic repository provides ultimate protection by ensuring that radioactive materials emplaced within the facility can never return to the environment in concentrations, which could be harmful. This is achieved by several safety barriers, which function both in series and parallel. The barriers are usually described as:

- Waste form – the radionuclides are immobilized in a highly insoluble, corrosion resistant form such as glass or synthetic minerals; the leaching of radionuclides from the waste in a deep geologic environment will require tens or hundreds of thousands of years.
- Containers – a durable container around the immobilized waste material can provide substantially complete containment for thousands of years
- Backfill – the gaps between the waste containers and the walls of the boreholes or tunnels into which they are placed is filled with a material, which provides mechanical support and can also retard movement of groundwater and the migration of radionuclides.
- The geological medium – this can provide a suitable mechanical and chemical environment for the waste for extremely long times, up to a million years or more; it also prevents any rapid movement of groundwater through the repository and will retard geochemically any radionuclides which could be leached from the waste.

The net effect of this multibarrier system is to ensure that, for correctly sited, designed and constructed repositories, no releases of radionuclides from the repository can occur for very long times and no significant concentrations of radionuclides will ever reach the biosphere. The challenges in geologic disposal are to ensure that siting and implementing the repository are correctly done – and to demonstrate convincingly to all stakeholders that the safety performance will indeed be as intended.

4.2 Phases in development

The activities involved in implementing repositories progress in a phased manner. At each step multidisciplinary efforts are involved and the engineering, geotechnical, geological and hydrogeological aspects are of great importance throughout. The phases can be defined as:

- Exploration – suitable sites fulfilling a range of technical and socioeconomic criteria must be identified and characterized so that their future evolution and performance can be assessed.
- Design – the system design will depend upon the waste inventory, the choice of engineered barriers, the host rock and the disposal depth. The key issue is to ensure that the repository will be safe both in the operational phase (which lasts for decades) and in the post-closure phase. Economic considerations are obviously also important, although clearly of lower priority. The final facility design will evolve in an iterative process between geologists, engineers, geochemists, hydrogeologists, materials scientists and safety analysts.
- Construction and operation – a repository is a major underground facility, which will require several years to build. Since the operation extends over decades, the usual designs have parallel activities of emplacing wastes in tunnels or caverns and simultaneously constructing new emplacement areas. Since the former activity is a nuclear operation and the latter a conventional construction activity, clear separation of the two working areas is required.
- Closure and post-closure – after completing all waste emplacement, remaining void spaces are backfilled (possibly after a period of underground monitoring), all shafts and other access routes are also backfilled and sealed, and the surface environment restored to its pre-existing natural state. Subsequent monitoring, although not necessary to ensure safety, will likely continue in order to provide public assurance of proper safety performance.

4.3 Nuclear specialities

The above operations appear broadly to parallel conventional underground operations; however, there are two key differences. The first is that all activities for a radioactive waste repository will be carried out under a nuclear technology regime. This means that the requirements on quality assurance, operational safety, and public involvement are far more demanding.

The second, and even more fundamental, difference is that repository designers, constructors and safety analysts are interested in understanding the evolution of the system for unprecedentedly long times into the future (over 100'000 years). Various human activities have extremely long-lasting or permanent consequences for our environment (e.g. exploitation of raw materials, increasing of atmospheric CO₂). However, only with the advent of the challenge of disposing of very long-lived radioactive waste did society become directly aware of such far-future issues. Multidisciplinary teams trying to understand how a repository system might evolve over many thousands of years have played a pioneering role, which will be followed in other environmental areas.

5.0 SPECIFIC ENGINEERING, GEOLOGICAL AND GEOTECHNICAL CHALLENGES

In the following subsections we will look at some of the specific scientific and technical challenges which geologic disposal of radioactive waste presents to practitioners of the disciplines gathered at Geoeng 2000. These challenges arise throughout the repository development phases described above. The items raised are intended to be illustrative rather than exhaustive.

5.1 Exploration phase:

The search for suitable repository sites and the subsequent investigation of their geological, hydrogeological and geochemical characteristics differs in several ways from conventional resource exploration:

- Rather than seeking geological anomalies such as ore bodies, the repository specialists look for uniform geology with no singularities (such as major faults) in the region of interest. They are faced with the unusual task of demonstrating that the inability to detect such features really reflects their absence rather than the limitations of the detection methodologies.

- Hydrogeology is the key discipline, since moving groundwater is the only plausible mechanism for radionuclides to migrate away from the repository. However, the ideal sites for repositories have very little or no groundwater movement so that the specialists are faced with the difficult task of performing hydrogeologic testing in a low energy system with extremely impermeable geologic media.
- The geological medium around a repository must provide an effective isolation barrier far into the future. Accordingly, it is not permissible to degrade the effectiveness of this barrier by intensive invasive measures during the investigation and characterization phase. Emphasis is on maximizing non-destructive, remote testing and minimizing boreholes or shafts, which penetrate the geological host formation.
- Finally, a less technical constraint is also of huge importance during the investigation phase of repository development. Most local communities welcome the prospect of an oil, gas or gold discovery in their backyard. However, the prospect of a radioactive waste repository in that backyard, brings a multitude of social concerns, which make full involvement of the public in repository planning an absolute necessity.

5.2 Design phase:

The repository design phase is perhaps the step requiring most imagination and multidisciplinary involvement. The over-riding consideration is that the physical and chemical evolution of all components of the repository system and their complex interactions must be sufficiently well understood to give confidence that the safety performance will be adequate for very long times. One approach here is to aim not, for technically sophisticated and complex designs, but rather for simple and robust engineered systems. Robust systems here are defined as those based on simple geology, hydrogeology, chemistry, physics and system design. They have large safety factors and some degree of redundancy. Some of the interesting problems facing the repository designer are the following:

- The facility must provide passive, long-term safety. The conventional tools of regular inspections and maintenance are not available to the repository engineer who works under the demanding requirement that all future generations must be protected, without any burdens being placed upon them.
- The waste inventory is heat generating over long times. The influence of raised temperatures on all engineering components must be considered and, conversely, the impact of repository design (tunnel dimensions, spacings, etc.) on resulting temperatures must be quantified.
- Paradoxical requirements can also arise. To minimize water ingress and transport the host rock should have low hydraulic conductivity. On the other hand, gases are produced within the repository (primarily by corrosion of containers) and these cause least problems if the host rock has a high gas permeability.
- Assuring a suitable geochemical environment is a key safety issue. This means a reducing groundwater environment, and low organic content. These requirements place restrictions on the materials which the designer can employ in the repository.
- Finally, a topical issue presenting a challenge to the repository designer is retrievability. In principle, geologic repositories are designed to ensure that the waste never returns to the human environment. However, there is a strong societal trend to demand that waste be retrievable from a repository should future societies wish to do so. The task of maximizing passive safety, whilst enabling possible future retrieval, is not straightforward.

5.3 Construction and operation

In the construction and operation phases the most obvious challenges faced by engineers and geotechnical specialists may be that the repository project is sited in an inhospitable, remote location. There are good reasons for such siting, including minimizing impact on humans, choosing the most suitable geologic conditions irrespective of infrastructure challenges and enhancing the possibilities for safeguarding the nuclear materials at the site. A further difficulty for the engineers is that the excavation methods may have to be optimized, not to lower costs or increase tunneling rates, but rather to minimize the excavation damage caused by the tunneling methods. For this reason, full face drilling, rather than drill and blast technology, has been proposed in various repository programs.

Finally, the construction and operation phases are made more difficult because of the nuclear designation of the facility. Extensive and highly formalized measures must be taken to ensure proper radiation protection of workers and public and to guarantee that safeguards concepts ensure that there can be no diversion or misuse of nuclear materials.

5.4 Closure and post-closure

Finally, the closure and post-closure phases provide interesting challenges of a geotechnical nature. Tunnel and shaft backfilling and sealing using naturally occurring, long-lived materials must be developed and implemented. Long-term monitoring of geotechnical and hydrological parameters will certainly be required by society. The questions of which parameters to monitor and the relevance of observed changes for system safety have not been fully answered in any geologic disposal program to date.

6.0 THE AUSTRALIAN DIMENSION

The preceding sections have addressed in a generic sense the challenge of geologic disposal and in particular the issues where geotechnical expertise is needed. The following remarks focus is on the question of why this is of relevance for Australia, a country, which does not produce nuclear waste from commercial power plants or from nuclear weapons activities.

6.1 Does Australia need a geologic repository?

Although Australia has extensive uranium reserves and an active uranium mining industry, it is not a user of nuclear power. Does this mean that the issue of geologic repositories for radioactive waste is irrelevant in Australia? The answer is negative for two different reasons.

Firstly commercial nuclear reactors are not the only source of long-lived radioactive wastes, which require deep disposal. Small quantities can arise from medicine and industry and research reactors such as that at Lucas heights also produce limited amounts of high-level and intermediate level wastes. These are not suited for disposal in the national near surface repository planned by the Australian government, and must eventually go into a national deep geologic repository or else must be exported for disposal in a facility elsewhere. There are currently no international repositories accepting waste from other countries (although transfer of waste between nations has taken place often in the past). The consensus in the scientific and technical community, however, is that shared disposal facilities will become a necessity in the future if all countries with small waste inventories are to achieve safe, economic disposal.

This brings us to the second possible reason for Australian interest in geologic disposal – Australia could choose to become a host nation which imports nuclear waste for disposal. Pangea has published several papers describing the geologic and environmental conditions which make Australia an ideal candidate for safe and secure disposal (References 1 to 7). From the global surveys undertaken by Pangea, a few regions stand out as especially promising, if one seeks repository sites without regard to the restrictions of national boundaries. The Australian continent is the largest and most geologically stable of these regions.

By hosting an international repository, Australia would not only contribute to global safety and security; it would also gain a range of tangible benefits, which have also been described in the Pangea papers. Of course, the problems of developing a repository in Australia are not scientific, technical or economic; they are political. The position of the current government is that it is not their policy to import radioactive waste. Pangea respects this political position, but is nevertheless committed to completing and documenting its present feasibility studies, which cover all the relevant issues. The results of these studies should provide more information on which to base future political views or technical initiatives.

6.2 Australia's relevant expertise

Should Australia choose sometime in the future to become directly engaged in implementing geologic disposal within a national or international framework, a relevant question is the availability of appropriate scientific and technical expertise. For the non-nuclear aspects of repository implementation, expertise is certainly to be found in Australia. Engineers are needed for designing and constructing the extensive hardware needed, including dedicated ships, transport and storage casks, long sections of new railroad and special port facilities. The repository investigation and construction requires geological and geotechnical know-how, which is widespread in a country heavily dependent on resource exploitation.

Where new initiatives would be needed are in the nuclear field, although the existence of a world-class facility like ANSTO provides an excellent springboard. Further new opportunities would arise in R&D at academic institutions. It is a challenging task to understand the future evolution of a repository system well enough to be confident about its long-term safety. In nations with mature waste disposal programs, front-line R&D has been going on in this area for decades. This knowledge must be transferred to and built upon by the

Australian scientific and technical community, in order to take its societal responsibilities seriously, in the event of Australia choosing to implement a geologic disposal facility.

7.0 CONCLUSION

The messages, which this paper is intended to communicate, can be summarized in the following points:

- The existing and future stocks of radioactive waste materials present nations with a global environmental and societal challenge. Current generations benefiting from diverse nuclear technologies have an ethical responsibility to ensure the continued safety and security of future generations.
- Geologic disposal is the only answer that is foreseeable today. Decades of intensive development have gone into ensuring that the concept is backed by sound science.
- The scientific challenges presented are multidisciplinary; engineers, geologists, hydrogeologists and geotechnical experts are amongst those who have a key role to play.
- Although it has no nuclear power reactors, Australia has reason to be interested in geologic disposal. It has small quantities of long-lived wastes, which must eventually go into an Australian geologic repository – or else be exported. It could itself offer a disposal service to the international community.
- The scientific and technical expertise needed for such a major undertaking would largely be available in Australia but new initiatives would be required to marshal the necessary forces.

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