Comments of the Arius Association

Royal Commission Issues Paper Four

Management, Storage and Disposal of Nuclear and Radioactive Waste

Introduction

Over the decades since the 1970s, there have been numerous studies on the issue of multinational cooperation in the nuclear fuel cycle generally and on the concept of multinational storage and disposal in particular. In the following comments and responses to questions posed by the Royal Commission, we make use of our intimate knowledge of this body of work and also of over 15 years of direct experience in promoting the concept of multinational storage and disposal facilities for spent nuclear fuel and radioactive wastes. The Arius Association was established in 2002 as a not-for-profit organisation to coordinate the efforts of a number of nations with mostly small nuclear power programmes that are interested in the possibility of sharing radioactive waste disposal solutions. Documentation about Arius is supplied with these comments. In 2009, Arius helped to establish the Working Group on a European Repository Development Organisation (ERDO-WG). Europe was chosen as the main focus of work in this period, since a cooperation framework (Euratom) already exists in the EU, but Arius interests extend to other global regions, such as Asia and the Arabian Gulf. Arius is currently completing a project sponsored by two charitable foundations (Sloan Foundation; Hewlett Foundation) to explore and promote the possibilities for countries to share spent nuclear fuel and radioactive waste management solutions in these regions.

Before Arius was established, our first individual efforts in this area were related to the Pangea Project, which was developed at the start of this century and was based on the idea of finding extremely stable geological environments around the world for the disposal of radioactive wastes. Environments were identified that are geologically relatively simple, where the factors controlling long-term safety remain stable and are most amenable to forecasting over hundreds of thousands or millions of years. A key focus was on the desert regions of Australia. Pangea failed, as many other disposal initiatives have done, due to a lack of sufficient public and political support. More about the history of the project can be read in the documents we are providing to the Royal Commission.

The structure of our response to Issues Paper Four – Management, Storage and Disposal of Nuclear and Radioactive Waste is as follows:

- A short introduction summarising current views of the global community on the benefits and challenges of multinational storage and disposal concepts
- Detailed responses to the specific questions posed by the Commission
- A collection of papers published over the years on this important and sometimes controversial topic

For many of the issues raised, we are also in possession of further in-depth analyses and assessments (e.g. on financial aspects, geological reviews, legal and regulatory reviews); some of these are of a commercial nature.

Current Views on Multinational Disposal Concepts

Discussions throughout the waste management community and a number of projects and reports produced by international agencies (e.g. the IAEA) have made clear that there is a widespread appreciation of the potential advantages of shared disposal facilities for radioactive wastes[1]. At the same time, the global waste management community is well aware of the major political obstacles to international solutions. Political and societal problems have also affected almost all national programmes over the last 30-40 years. There is considerable frustration at the slowness of progress towards implementing national repositories for spent fuel and long-lived radioactive wastes, with the many delays being determined largely by the lack of either political or societal support – or both.

Several scenarios have been advanced for shared disposal solutions, the most credible of which are:

- a group of countries works together to develop a shared disposal facility in one of them, with the possibility that other waste management facilities (stores, fabrication plants etc.) are also shared between the countries;
- a country with a major nuclear power programme develops its own national disposal facility and subsequently offers space to other users on a commercial basis;
- a country with a stable political base, well-established scientific, technical and security credentials and excellent geological siting possibilities develops a disposal facility and offers it on a commercial basis to other countries.

The current ERDO-WG work in Europe is an example of the first approach, the Pangea Project was an example of the latter and there are no examples of the second approach – indeed, no existing and developed national programme on geological disposal currently wishes to countenance this option for fear of damaging the basis of consent that they have built up carefully over many years.

An opportunity to fulfil our ethical responsibilities to future generations by preparing proper disposal facilities in a co-operative effort between a willing, well suited host nation and a number of customer countries, under arrangements recognised as being fair to all, would certainly be welcomed by the technical community. Also, in the wider circle of stakeholders, including the general public and the political leadership concerned with global security issues, there is a broad appreciation of the technical benefits - and of the societal challenges – resulting from international waste disposal solutions.

Although many individuals do consider the time to be ripe for international initiatives, there are other schools of thought. From some national programmes, there is understandable apprehension that increasing attention on international options may lead to questioning of the need for (or, at a minimum, the timing of) national repositories. In particular, national disposal programmes near to implementation of facilities are concerned about any distractions from this path and would prefer to complete their tasks without additional complicating issues being raised. Should we wait with international proposals until some national repositories are operating? There is some truth in the opinion that international disposal may become more acceptable once this is the case. The counter-arguments are that numerous programmes may have (or have already had) problems establishing a national geological repository, for financial, socio-political or technical reasons. Perhaps a globally optimised choice could be easier to implement. In any event, for environmental, safety and security reasons, acceptable solutions to the disposal of unwanted nuclear materials must be welcomed by all, and every serious effort to achieve these solutions deserves support.

There has been considerable work over the last decade to explore the feasibility and implications of international solutions. Two central examples are the SAPIERR projects[2] funded by the European

[1] The radioactive wastes that are of direct relevance here are all those that remain hazardous for many thousands of years. The focus is on spent nuclear fuel and on the high level radioactive wastes (HLW) resulting from reprocessing of such fuels; but further long-lived wastes also require the same degree of isolation from the human environment.

[2] There were two projects. SAPIERR I: *Support Action on a Pilot Initiative for European Regional Repositories* 2003-2005 and SAPIERR II: *Strategic Action Plan for Implementation of European Regional Repositories* 2006-2008

Commission and managed by ourselves at Arius, and the various publications of the International Atomic Energy Agency (IAEA) on this topic.

SAPIERR looked at all the main technical, societal and economic issues affecting shared disposal in the European Union and developed models for waste inventories from different groupings of countries. The overall feasibility was clearly demonstrated and the main findings were that there are no unique technical issues to multinational disposal solutions, there are considerable economic advantages to all participating countries from sharing fixed costs and economies of scale, and the societal issues are not unique or different in nature to those faced by any national programme. The positive findings of SAPIERR led to the establishment of the ERDO-WG.

The IAEA has published a range of reports whose titles speak for themselves (see below), the totality of which illustrates the interest that has been shown by the international community. One of the main drivers to making disposal solutions available to all on a timely basis is to increase global nuclear safety and security. One of the principal authors of several of these reports has been Charles McCombie, who is President of Arius and was formerly the Head of Pangea International.

TECDOC-1021: *Technical, Institutional and Economic Factors Important for Developing a Multinational Radioactive Waste Repository* published in 1998. The report concluded that the multinational concept was not in conflict with the generally accepted ethical position relating to waste management. It further concluded that the economics of scale would be a major benefit and that nuclear materials transport would not significantly impact public health.

TECDOC-1413: *Developing Multinational Radioactive Waste Repositories: Infrastructural Framework and Scenarios of Cooperation,* published in 2004. This endorsed the findings of the first report and came to the conclusion that multinational repositories could enhance global safety and security, in addition to offering significant global advantages.

TECDOC-1482: *Technical, Economic and Institutional Aspects of Regional Spent Fuel Storage Facilities,* published in 2005. Although the storage and disposal concepts are different, there is nevertheless a linkage between them: long-term storage of radioactive waste is the precursor to disposal. This study also confirmed the potential viability of the regional storage concept.

In the IAEA study on *Multilateral Approaches to the Nuclear Fuel Cycle*, published in 2005, multilateral approaches to enrichment, reprocessing and disposal were all examined. The study concluded that the IAEA should continue its efforts to work on the underlying factors in support of multilateral approaches to spent fuel disposal and, in addition, to assume political leadership to encourage such undertakings. Arius was the expert organisation invited to talk on disposal issues.

TECDOC 1658: *Viability of Sharing Facilities for the Disposition of Spent Fuel and Nuclear Waste – An Assessment of Recent Proposals,* published in 2011, included the more recent proposals and discussed under which conditions these could be viable approaches.

IAEA Nuclear Energy Series Report NW-T-1.24: *Options for Management of Spent Nuclear Fuel and Radioactive Waste for Countries Developing New Nuclear Power Programmes,* published in 2013, looked at all of the national and multinational options that a new nuclear country could consider for managing its spent nuclear fuel. Charles McCombie was the sole author.

The report *"Framework and Challenges for Initiating Multinational Cooperation"* will be produced shortly. It explicitly addresses the risks and benefits of a multinational repository project.

Response to the Commission's Questions

A. NUCLEAR AND RADIOACTIVE WASTE *(p.4)*

No questions

B. FACILITIES AND TECHNIQUES FOR THE MANAGEMENT, STORAGE AND DISPOSAL OF WASTE *(p.5-8)*

4.1) a) *Are the physical conditions in South Australia, including its geology, suitable for the establishment and operation of facilities to store or dispose of intermediate or high level waste either temporarily or permanently? What are the relevant conditions?*

If one were unrestricted by national boundaries, how would one go about choosing a repository site which would not only be extremely safe but also be simple enough that the safety case could be demonstrated with great transparency - for the public as well as for the experts? A set of 'signatures' for such a site was developed in the Pangea Project, based on consideration of the features, events and processes taken into account in state of the art safety analyses of repositories. These characteristics, which can be identified as essential or as favourable, can be summarised thus:

- Stable geology (providing long isolation times)
- Flat topography (reducing the driving forces for advective groundwater flow)
- Near-horizontal sedimentary strata (simpler to explore and extrapolate)
- Stable, arid climate with little erosion (eases problem of extrapolation into the future)
- Low permeability (reduces groundwater movements in host rocks)
- Old and saline groundwater (indicates slow natural circulation; non-potable)
- Stratified salinity (counteracts thermal buoyancy effects)
- Reducing geochemical conditions (reduces solubilities of radionuclides)
- Absence of complex karst systems (simplifies hydrogeological modelling)
- Low population density (reduces intrusion risks)
- No significant resource conflicts (reduces intrusion risks)

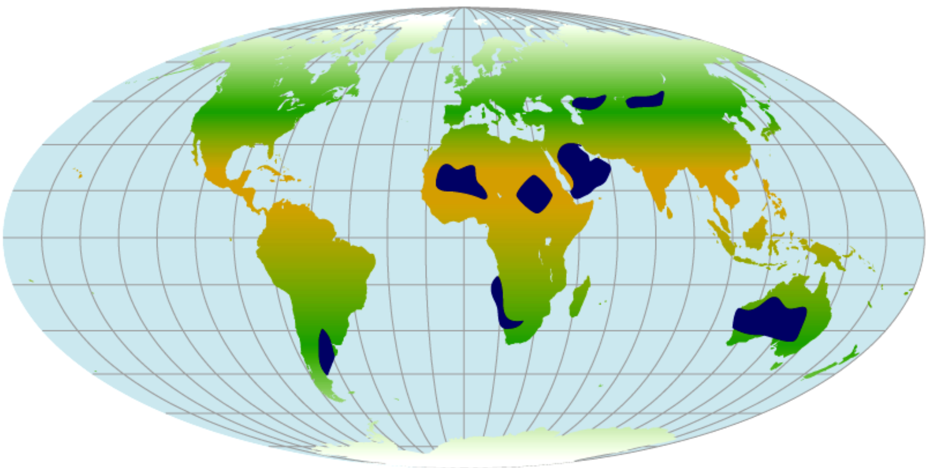
In addition, there are obviously further technical criteria concerned with engineering feasibility, infrastructure requirements etc. Also of critical importance are the non-technical criteria needed to achieve acceptance.

A key fact that will influence the conclusions drawn by the Royal Commission is that all of the above requirements can be met in South Australia (and also in other Australian regions, such as Western Australia and the Northern Territories).

This can be simply illustrated. The Pangea project began by identifying large, flat, historically-arid areas of the world with stable and simple geological formations, which led to a group of areas that were part of the Pangea continental mass, which started to break apart some 80 million years ago. Figure 1 shows that these areas, which have been subjected neither to large tectonic forces nor to the influences of repeated glaciation, are primarily in the southern hemisphere. The largest contiguous stretch is in the desert basins of Western and South Australia. Of course, much finer resolution is needed on the way to identifying specific suitable sites. In the response to question c) below, a methodology for narrowing in to such sites is described, along with listings of the necessary information to be gained at each stage.

Although the emphasis above is on technical aspects of site selection, other socio-economic factors are also included (although not in a comprehensive manner) in order to reflect the high importance of simultaneously considering all relevant issues.

Pangaea Supercontinent – 200 million years ago



Potential Signature Areas – Present Day

Composite of:
- Quaternary Aridity
- Low Population
- Low-sloping Topography
- Low Seismicity - Stable Tectonics

b) *What is the evidence that suggests those conditions are suitable or not?*

The evidence that conditions of the type listed above will result in safe disposal facilities is based on scientific analyses of the features and processes that determine repository safety.

Understanding the following seven key technical (long-term safety related) siting factors is central to the repository siting process:

1. **Advective Groundwater Transport**

   This is normally the most important mechanism whereby radioactivity in deeply buried wastes in a repository can be mobilized from the solid waste materials and it dominates considerations of the isolation and containment capability of proposed sites. When advective transport is minimal, and diffusive processes dominate, the eventual transport of radionuclides away from a repository will be extremely slow and transit times will be so long that most radionuclides will decay within the repository or the host geological formation.

2. **Direct Exposure of Waste at the Ground Surface**

   Whether through erosion or uplift, a successful site must have no mechanisms capable of directly exposing wastes at the ground surface over periods of up to a million or more years.

3. **Other Transport Mechanisms: Human Intrusion, Biotic, Tectonic**

   All other credible mechanisms for moving emplaced wastes to the biosphere must also be shown to be insignificant threats. These include inadvertent human intrusion (e.g. due to mineral exploration), tectonic processes (seismic activity, volcanism), and even highly-unlikely processes such as biotic transport mechanisms (e.g. plant or animal intrusion, microbially-enhanced transport).

4. **The Biosphere**

   Regardless of the quality of the geological barrier, it is desirable to site a repository in a location where any eventual releases of radioactivity would have minimal impact on human or ecological receptors. Given the extremely long times before any release is conceivable, it will be problematic for most potential repository locations to describe the future biosphere conditions with much certainty.

5. **The Extremely Long Times that must be considered**

   Repository safety analyses are routinely carried out for a million years into the future. These time scales challenge the conventional basis for the design of technological systems. Designs for such systems are usually based on a combination of past experience and theoretical projections, which can be supported by testing and observations of performance on relevant time scales. Because it is not possible to test and observe the engineered components of a repository over representative time scales, a repository's safety would ideally be guaranteed by natural processes that have already demonstrated their performance over millions of years.

6. **Confidence In / Reliability of Projected Behaviour**

   In general, repositories are held to stringent safety standards defined both internationally and by national radiation safety regulatory authorities. These standards require a high level of containment of the emplaced wastes, as even a small fraction returning to the biosphere can result in violating the standards. It must be demonstrated that repositories will continue to meet these standards for an extremely long time and national regulations often define different practical yardsticks and measures for different times in the future. This will require developing an unprecedented level of confidence in our ability to understand the long-term future performance of the repository system.

7. **Time and Effort Needed to Assemble an Adequate Site Database**

   With the growing awareness of the complexity in structure and processes that typically exists in geological systems, the time and effort involved in characterising potential repository sites has far exceeded early estimates. Today, the value of choosing and designing repository systems that lend themselves to simpler analyses is increasingly recognized. This is a major advantage of regions such as South Australia, with extensive areas of relatively simple geology.

Each of the seven factors described above is sensitive to the characteristics of the repository site. It is possible to go through each factor in turn, and identify favourable site characteristics for addressing that factor. Table I presents a set of favourable characteristics associated with each factor that was developed for the Pangea Project, with the specific conditions of south and west Australia in mind. As evidenced by other national repository development programmes, these goals can be achieved by other combinations of geological characteristics – not all countries are working in layered sedimentary rocks for example.

Goal	Site Characteristic
Factor: Advective Groundwater Transport	
Minimizing moving groundwater Low hydraulic gradients Low permeability Low water quantities Lack of other hydraulic driving forces	 Flat site topography Clay/shale sedimentary units Low rainfall, low infiltration Increasing salinity with depth (has positive stability)
Minimizing releases from waste packages Low corrosion rates Low solubilities	 Reducing groundwater Reducing groundwater
Enhancing retardation in geosphere Long horizontal flow-paths, large vertical diffusion distances High sorption	 Long time/distance to exfiltration areas Clay/shale sedimentary units, not fracture-dominated
Factor: Direct Exposure of Waste at the Ground Surface	
Minimal orogenic uplift Minimal erosion	Tectonically stable region Flat site topography, tectonically stable, arid climate, no glaciation
Factor: Other Transport Mechanisms: Human Intrusion, Biotic, Tectonic	
Mining Boreholes, including wells Biotic intrusion Tectonic disruption	Minimal mineral potential Low permeability, saline groundwater Sufficient depth Tectonically stable region
Factor: Biosphere	
Low population density Minimal ecosystems Minimal agricultural capability	Arid, remote, saline groundwater Arid, saline groundwater Arid, saline groundwater
Factor: Extremely Long Times Frames Considered	
EBS lifetime 10^3 – 10^4 of years Geological processes 10^5 - 10^6 years	Stable host rocks, low permeability, stable hydrogeochemistry Tectonically stable region, stable climate
Factor: Confidence In / Reliability of Projected Behavior	
Independent indicators Lack of structural complexity	Old groundwater Uniform, horizontal, simple geological structures
Factor: Time and Effort Needed to Assemble Site Database	
Homogeneity, extrapolability, simple processes	Uniform, horizontal, simple geological structures

c) *What requires further investigation now and in the future?*

Table II presents a sequential process for identifying candidate regions, sub-regions and, eventually, sites, starting from the large areas described above. It was used in the Pangea Project. Because of the signature target of near-horizontal, layered sedimentary strata used in the project, the uniformity of the areas lends itself to an efficient siting process and the results from exploratory programmes can be extrapolated for considerable distances. Additionally, all of the signatures in Table II can be readily measured and many of them are already available from public climatic and geological records. Many of the signatures are correlated, such that the presence of the more readily observed signatures will provide increased confidence that the signatures that require intrusive testing, such as old and saline groundwaters, will be present.

STAGE	KEY SIGNATURES	SELECTION PROCEDURE
1. Global Areas	• Stable geology, with minimal tectonic or volcanic activity. • Very flat topography with minimal relief. • Stable arid climate, not susceptible to glaciation. Continent or country should be stable politically, and be technically advanced,	• Study of world geology, continental evolution. • Regional maps. • Regional maps. • Stable democratic society, knowledge of nuclear issues
2. Regions (100 - 1,000km)	• Extensive near-horizontal, layered geologic strata. • Very flat topography with minimal relief. • Saline, non-potable groundwater.	• Exclude extensive aquifers. • Exclude vicinity of “rainy”, mountainous regions • (see all of Table II)
3. Sub-regions (20 – 100km)	• Should be geologically simple so that exploratory boreholes represent large areas, • If multiple sub-regions are considered, they should have diverse geological environments, • Avoid obvious local political problems, • Be optimized for cost and time.	• Avoid local manifestations of the exclusion criteria of Table II, • Optimize land ownership, overall infrastructure requirements.
4. Specific potential sites (10km)	• Should have identified suitable host rock, • Should have readily understood and demonstrably good geosphere • No insurmountable societal conflicts.	• Same as above: - plus: • Geological and hydrogeological information from boreholes (i.e. groundwater ages, salinity profiles, etc). • Check ownership, negotiate compensation schemes etc.
5. Site characterization at preferred site	• Site should appear intrinsically safe, • Should be economically constructable,(suitable rock, infrastructure etc.) • Should be politically approved.	• Affirm on basis of Performance Assessment, cost and political acceptability.

4.2) a) *Are there nuclear or radioactive wastes produced in Australia which could be stored at a facility in South Australia?*

For Australian wastes, three types of facility are needed. Australian low-level wastes (LLW), which originates from medical, industrial and scientific applications that are of benefit to the whole country, must be disposed of. A repository facility for disposal of LLW already exists in WA at Mount Walton and a site for a National Low Level Waste Repository is currently being sought by the Australian Government. It makes environmental and economic sense to build and operate such a centralised disposal facility. The problems associated with successfully implementing the project are, as for all radioactive waste facilities, more societal than technical. One fundamental reason is that wastes are produced over the whole country but a common national disposal facility providing a service to all must be hosted by a specific community. Overcoming this perceived inequity is the challenge currently facing the Australian Government. However, disposing of LLW in a near surface repository is a relatively straightforward and technically simple task and the requirements for a suitable site are not very demanding. The exceptionally comprehensive technical effort that was undertaken in Australia to screen potential sites for LLW disposal could well be interpreted as driven by politicians, hoping to find technical solutions to societal problems.

The political handling of the Australian intermediate level waste (ILW) issue is a more obvious mix of science and politics. The small quantities of ILW produced in Australia, primarily from operating a research reactor and production of medical isotopes, can be safely stored on the surface for a long time, but the only safe and ethical ultimate solution is disposal in a deep geological repository. The surface store is simply a robust and secure building – a sophisticated warehouse. It can be safely built and operated at almost any location, provided proper care and maintenance activities are assured. The Federal Government's declared intention to set top scientists to work to identify the best location for such a store is a clear example of the misuse of science in establishing government policy.

On the other hand, the requirements for siting a deep geological repository for ILW are stringent and world-class science is indeed required here. Guaranteeing long-term safety depends upon gaining a good understanding of the deep geological environment upon which the isolation of the wastes depends, as discussed in answer to the previous question. Australia does not presently generate nuclear power and thus does not have significant quantities of long-lived waste, but this does not remove the need for a deep repository. Australia will ultimately need such a facility if it chooses to manage its own ILW without international co-operation. This has been recognised by the Australian Government in raising the concept of a National Geological Repository, but the establishment of such a facility has been postponed - to be done at some undefined later date using funding from some unidentified source.

The work required to identify and evaluate a suitable site for a deep geological repository for long-lived ILW is essentially identical to that which would be required to site a similar facility for nuclear power generation wastes such as spent nuclear fuel or HLW. Indeed, were Australia eventually to have such nuclear fuel cycle wastes of its own, it would make sense to dispose of all long-lived and high activity wastes at the same site, in different sections of the same repository. Co-located disposal facilities of this type are being developed or planned in several countries, e.g., Finland, France and the UK.

b) *In what circumstances would the holders of those wastes seek to store or dispose of that waste at facilities in South Australia?*

If any, or all, of the disposal facilities mentioned became available in South Australia, there would be few or no problems in persuading Australian holders of the relevant wastes to make use of the facility. In particular, if the LLW and the geological repository for ILW or HLW were co-located there could be significant opportunities for economies of scale and for ease of management.

4.3) a) *Would the holders of nuclear or radioactive waste outside Australia seek to store or dispose of that waste in South Australia? Who holds that waste?*

There are numerous nations that have openly expressed an interest in being customers of an international repository in a suitable host country. These fall into different categories:

- Countries with extensive nuclear power programmes, but no current credible route for disposal of the accumulated spent fuel and other long-lived and highly active wastes, and hence with acute problems of interim storage. Examples are South Korea, Japan, Taiwan.
- Countries with small nuclear power programmes and thus with the problem of possibly having to implement an expensive national repository without having the benefit of funding derived from large electricity sales. Examples are the Netherlands and Slovenia.
- Countries starting or contemplating starting a nuclear power programme and wishing from the outset that they can avoid the necessity for an expensive small repository by exporting their spent fuel to a shared facility. Examples are the UAE, Poland, Vietnam, Thailand and Indonesia.
- Countries that do not have nuclear power but do have smaller quantities of long-lived radioactive wastes that can only be safety disposed of by geological disposal. This category includes almost all countries using nuclear technologies for medicine, industry or research. Their interest in multinational solution is illustrated by the participation in Arius and/or the ERDO-WG of countries like Austria, Ireland, Netherlands, Denmark, etc.

b) *What evidence is there that they are seeking options to store or dispose of wastes elsewhere including in locations like South Australia?*

There is ample evidence of interest. This is illustrated by the formal statements of many Member States of the IAEA when they report under the Joint Convention. In particular, for newcomer nuclear power nations, the national strategy for managing spent nuclear fuel and radioactive wastes often includes the option of export; one clear example is the UAE. Other States with small programmes also pursue a “dual track” option in which national disposal plans are pursued in parallel with an option for export. Examples are the Netherlands and Slovenia. In addition, it is widely recognised that one of the attractive features of the current Russian offers to implement new nuclear plants in other countries is the potential for Russia to take back the fuel that it would supply. The most immediate and largest scale business opportunities for Australia, should it offer to import spent nuclear fuel, would likely be from South Korea, Taiwan or, perhaps, Japan, since all of these countries have large and increasing spent fuel inventories – and great difficulties in siting new storage or disposal facilities for these.

c) *If so, what kinds of waste and what volumes might be expected?*

The potential wastes for disposal are generated in over 400 nuclear power plants (NPPs) and other nuclear facilities throughout the world. These materials contain long-lived radionuclides and fall into four main types:

- spent nuclear fuel (UOX or MOX);
- high-level radioactive waste (vitrified or perhaps in future immobilised in ceramics such as SYNROC);
- intermediate-level radioactive waste (normally conditioned in cement);
- unwanted nuclear materials derived from weapons dismantling.

For all waste types to be emplaced in a repository, detailed waste acceptance criteria must be developed and a specific safety case made. This must cover both operational and post-closure phases and must demonstrate convincingly that the disposal will be safe for present and future generations. Handling procedures at the waste generator's facility will be monitored to ensure that they meet the requirements of the particular waste form, the storage facilities and the transport system. Prior to transport of a spent fuel or packaged waste consignment to the repository, a formal quality assurance procedure must be followed to ensure that the consignment is properly identified, a full inventory documentation check undertaken and the consignment is loaded into appropriate transport packaging suitable for transport according to regulatory requirements.

Globally, it is currently estimated that there is about 270,000 tonnes of spent fuel awaiting disposal, with the vast majority destined for direct disposal, should a route be opened. The amount in storage, not to be reprocessed, grows by about 9000 tonnes each year. National repository programmes for geological disposal of spent fuel are only advanced enough in Finland and Sweden to be termed viable, and they will handle a total of less than about 20,000 tonnes of this global stockpile. Thus, if a facility were available in Australia for spent fuel disposal, then the upper inventory that it might wish to consider could be of the order of a few hundred thousand tonnes, depending on how long the repository was to operate and offer a service.

Some countries also possess vitrified high-level waste from reprocessing of spent fuel. The total amount of material that might be routed to an Australian facility from non-reprocessing nations (i.e. not including France, UK, Russia) is, however, likely to amount to only a few thousands of m^3.

It is more difficult to estimate the amounts of long-lived ILW and other materials that are awaiting geological disposal. The UK and France, which each have reprocessing programmes, have generated considerably more ILW than other nuclear power nations. Together they account for most of the estimated 1.2 million m^3 that could arise in the EU by 2030. The SAPPIER project, which looked only at smaller EU nuclear power countries, estimated that the 14 countries assessed would, between them, produce only about 31,000 m^3 of ILW by 2040. Given that reprocessing nations are likely to take care of their own wastes, it seems reasonable to estimate that even a large group of smaller programme users of an Australian facility would be unlikely to ship more than a couple of hundred thousand m^3 of ILW.

d) *What would the holders be willing to pay and under what arrangements?*

Shared repositories are certainly attractive from an economic point of view. Deep geological repositories have life-cycle costs in the order of billions of US dollars. This is true even for countries with low projected waste volumes; for example, the Swiss estimate of life-cycle costs for disposing of HLW or spent fuel from a 120 GW(e) nuclear programme is several billion US dollars. Larger programmes estimate geological disposal costs that are significantly higher: the current UK plans estimate repository cost to be over 10 billion GBP. Moreover, a large part of the costs of any deep repository are fixed independently of the inventory, since they are needed for exploration, for gaining access to the underground by shaft sinking, for installation of infrastructure, and for the complex permitting and licensing procedures. The marginal costs of excavating more disposal volume underground are relatively small. Accordingly, large savings are possible if countries combine their efforts or if a large disposal programme were to accept wastes from foreign sources. The advantages for customers that could contract for foreign disposal of nuclear power wastes include:

- Offers a lower cost solution than national disposal
- Solves the problem of finding sufficient national storage capacities for spent fuel – and thus clears the way for extending reactor lifetimes
- Demonstrates that a final end-point for spent fuel is available and thus removes a common obstacle to new nuclear build programmes

- Allows the sites of decommissioned reactors that host storage facilities for "orphan wastes" to be completely released for other uses.
- Provides certainty to a balance sheet, thus lowering the cost of capital.
- Provision of an insurance against the failure of a national repository.

For a country accepting foreign wastes for disposal, there could clearly be enormous direct economic benefits. For countries paying for wastes to be disposed abroad there could also be financial advantages, because economies of scale allow lower unit costs (and excellent geological conditions can obviate the need for the use of expensive materials in the engineered barrier systems). For society in general, it is certainly better to channel resources to other causes rather than expending them on duplication of expensive technical and geological work in numerous countries.

Commonly quoted potential prices for accepting spent nuclear fuel for disposal are in the order of 1M USD/ton. The Pangea reference concept was for disposing of an inventory corresponding to around 75'000 tonnes of spent fuel over 40 years of operation, although there are no fundamental reasons for either limit. In addition to the direct income from offering disposal services, however, there are immense potential "add-on" benefits through providing other associated services. The total waste management and disposal system foreseen in the Pangea Project included packaging and national transport of spent fuel or wastes (if required by the customer country), international transport in a fleet of dedicated ships, rail transport to the repository site, buffer storage and final disposal. It was estimated that some 8000 jobs could be created in Australia during the construction of a sea terminal, rail link and repository. Further employment opportunities exist in the manufacture of transport packages and ships. The operation of the facilities would likely provide long-term employment for more than 1500 people. Many of the positions created would be in areas of high technology, engineering and science. In addition, there would be employment in necessary service industry branches. Finally, the economic boost of the project to the host nation would provide further opportunities for employment. In a study done for Pangea by Access Economics, the economic impulse to the State and nation has been estimated to be of the order of 1% of the Gross National Product of Australia.

4.4) a) *What sorts of mechanisms would need to be established to fund the costs associated with the future storage or disposal of either Australian or international nuclear or radioactive wastes?*

The principle that "the polluter pays" is universally accepted in radioactive waste management. This means that the owners of any such waste produced must provide all the funding for its management through to the stage of final disposal. For Australian wastes, those wishing to use the repository must pay the costs of this; for wastes from governmental research labs such as ANSTO, the Federal Government must provide funding. Should nuclear power ever be introduced into Australia, the power plant owners should be compelled to establish segregated funds at the outset so that, for every kWh of electricity sold, a contribution goes to the fund.

If a disposal service is provided, the clients must provide the funding. The price they pay will be determined by numerous factors, including the costs of implementing facilities, the taxes required, the profit margins to which the service provider is entitled, benefit packages to affected communities or States and possible competition from other service providers. Given the high up-front costs of implementing a repository, a sensible approach could be to have future users agree to pre-finance the development costs. There is a precedent for this, as discussed below.

b) *Are there relevant models in operation which should be considered?*

At a national level, there are many examples of well-structured schemes for ensuring that future users of disposal facilities stock the dedicated funds which have been established for development.

Schemes of this sort are embodied in the legislation of numerous nuclear power nations. There are also developed concepts for the case of a common facility financed by a variety of users, each with different quantities and types of wastes. Arranging external funding for implementing nuclear facilities intended to provide a service to foreign nations also has some precedents. For example, the French reprocessing facilities at La Hague were constructed based on pre-financing by future base-load customers. In the Pangea Project, a detailed concept was developed based on pre-financing, with discounts to attract early customers.

> ***c)*** *What mechanisms need to be put in place to increase the likelihood that the South Australian community, and relevant parts of it, derive a benefit from that activity?*

Again, there are many national examples of local communities deriving benefits from hosting a nuclear facility that provides services to a wider client base. In the SAPIERR studies, reviews were done of the variety of benefits that can be offered. These range from direct payments, through infrastructure improvements to high-tech work places. Repository developers have been shown to be very willing to agree to benefits packages, most effectively with direct input from the host community. One SAPIERR report deals in detail with the issues of national and local benefits to repository hosts. The following text is excerpted from this report.

The following **national benefits** may be appropriate:

- Tax revenue from waste disposal activities (ring-fenced for relevant use) and a profit sharing agreement
- Support for relevant infrastructure projects related to repository development and operation
- Support for integrated development projects and full involvement in all relevant decision making concerning facility design and operation
- Guaranteed local hiring and use of national experts wherever possible
- Location of company headquarters in host country

The following **community benefits** may be appropriate:

- Lump sums, clearly specified in advance for 'community service'
- Like lump sums, annual payments should be linked to project milestones (site selection; licensing; operation); limit capability for community dependence.
- Communities must be allowed support to access alternative views and independent experts.
- Tax revenue from waste disposal activities (ring-fenced for relevant use) and a profit sharing agreement, with local/national balance carefully negotiated.
- Trust Funds could be established to support the community in the long-term and demonstrate commitment to future generations.
- Local employment should be a priority.
- Support for relevant infrastructure projects related to repository development and operation, with care taken over local and regional sensitivities.
- An open and transparent property value protection scheme should be developed.

- Support for integrated development projects and full involvement in all relevant decision making concerning facility design and operation.

- Location of offices in the host community.

- Clearly defined roles for local bodies in the decision-making process.

- Support for local capacity building.

- All of the above benefits may be best collected within an overall contractual agreement with a formal local partnership, involving elected and non-elected parties. Partnerships should be backed by ring-fenced funding.

C. RISKS AND OPPORTUNITIES *(p.9-11)*

4.5) a) *What are the specific models and case studies that demonstrate the best practice for the establishment, operation and regulation of facilities for the storage or disposal of nuclear or radioactive waste?*

The successful implementation of nuclear projects depends on establishing an appropriate institutional framework with responsibilities being clearly allocated to all stakeholders, including the government, the regulator the facility implementer and the public. The international organisations such as the IAEA and the EC provide comprehensive advice on a proper institutional framework. The most important requirements are technical competence at both the implementer and the regulator, and also clear independence of the regulator. Most developed nuclear power countries have, with time, taken the necessary steps to fulfil these requirements. A good example of a new nuclear power nation moving quickly and effectively to reach this position is the UAE, which is currently constructing 4 new large nuclear plants.

All established nuclear power programmes have tried and tested techniques and facilities for the handling and storage of radioactive wastes. Countries with power programmes going back many decades, such as France, Germany, Switzerland, Sweden, Finland, the UK and the USA all have extensive waste management systems that provide a range of examples of technologies and approaches.

The societal requirements for achieving success in geological disposal have proven more difficult to achieve, but some good examples are as follows:

Sweden: after extensive dialogue with potential spent fuel repository host communities, there was actually competition between two potential sites for the facility. The implementer, SKB, subsequently rewarded both communities for their willingness to help – with the larger lump sum going to the community which did NOT get the repository since the successful host will have long term benefits.

Finland: here also a volunteer community came forward to accept the spent fuel repository. Excellent relationships exist between the developer, Posiva, and the community, which insisted that the company relocate its headquarters to there. The repository project seems likely to receive a construction license later this year, after passing extensive review by the regulatory authority. This will be the world's first geological repository for spent fuel and provides comprehensive examples of all aspects of repository development.

Canada: after a false start, NWMO of Canada established a modern dialogue with numerous communities, resulting in around 14 of them expressing interest in potentially hosting a deep geological repository for spent fuel. Canada also has a volunteer community for a soon-to-be-implemented geological repository for LILW.

Switzerland: a centralised storage facility for spent nuclear fuel was agreed to by a host community after an interesting concept was developed for the sharing of benefits amongst all communities within a certain distance of the facility, with a higher weighting on the host itself and the immediate neighbours. This approach avoided the often controversial issues raised when there is a sharp cut-off in benefits.

b) *What are the less successful examples?*

Countries that have taken longer to establish a correct institutional framework include Japan, where some of the errors leading to the Fukushima accident have been attributed to an inadequate separation of roles and responsibilities.

Less successful examples in the societal area related to geological disposal are easier to find!

Germany: the early nomination of a specific site (Gorleben) without a transparent selection process has led to decades of resistance,

USA: politics has heavily influence the hugely expensive and as yet unsuccessful repository projects. Unrealistic setting of target dates by politicians led to unnecessary pressures on technical work, failure to meet deadlines and loss of confidence in the implementer (USDOE). Political dealings then led to a poorly justified selection of Yucca Mountain in Nevada and further political deals then led to the multi-billion project there being declared as not workable by the present administration.

c) *Where have they been implemented in practice?*

No custom built repositories for spent fuel or HLW have yet been implemented. As noted above, the closest nations to this milestone are Finland, Sweden and France, all three of which hope to have operating repositories by 2025-30.

d) *What new methods have been proposed?*

Over several decades, a variety of concepts for final disposal of HLW have been reviewed at intervals. The proposals include ejection into space and transmutation of all radionuclides to less harmful shorter lived isotopes as well as disposal into subduction zones, in Arctic ice sheets or in deep boreholes. None of these has been shown to be more promising than geological disposal in mined caverns in stable geological formations, with the result that geological disposal is now regarded as the best solution globally. Recently, there has been a revival of interest in deep (several kilometres) borehole disposal, a technique that may be suitable for relatively small but highly radioactive waste packages. For example, this is now being assessed in detail in the USA for disposal of separated Cs wastes.

e) *What lessons can be drawn from them?*

It is generally agreed that the scientific and technical understanding of and the methodologies for geological disposal are well established. There is little significant of a generic nature that remains to be resolved in order to implement disposal to an acceptable standard. Issues now tend to be dominantly location-specific. The crucial lesson is that implementing a nuclear facility today requires one to meet challenges that are also institutional and societal – with the latter being perhaps the most challenging. However, much can be learned from the successes – and the failures – that others have experienced. An essential element of any approach is the open and complete flow of information.

4.6) a) *What are the security implications created by the storage or disposal of intermediate or high level waste at a purpose-built facility? Could those risks be addressed?*

Security issues related to storage and disposal facilities can be addressed at two levels – globally and locally. The global aspects are simpler, since most nuclear security consequences of a multinational facility are positive.

- **Limited numbers of facilities to be secured:** gathering waste from disparate storage locations into a limited number of disposal facilities is clearly capable of enhancing security. Current storage conditions are quite variable among nations in terms of the physical protection they offer and the strength of the security they can provide. They are overseen by disconnected organisations with different standards and financial capabilities. A single facility, involving many nations, should in principle be easier to control and, for the public, more transparent to monitor.
- **Enhanced engineered and institutions security measures:** The 'few multinational repositories' model would ensure that the highest possible standards were adopted in all aspects of safety and security – for wastes that might otherwise be subject to differing control regimes. It might be expected that common, centralised storage facilities and repositories would be built to the highest security specifications. Indeed, this is likely to be a stipulation of the countries and communities that host them.
- **Enhanced levels of international oversight:** a few international disposal facilities for spent fuel would present a simpler safeguards surveillance task and would be likely to attract more interest and attention in ensuring that safeguards were maintained into the far future.
- **Improved financing arrangements:** the general economic advantages of shared disposal that result from economies of scale are widely recognised. Sharing should make finding the funds for long-term disposal projects easier. It should also result in closer financial control and oversight.

At the local level, hosting any nuclear installation clearly requires specific security measures to be put in place. There is a long history of such measures being successfully applied for a diverse range of facilities. In practice, storage or disposal facilities provide lesser challenges than other front-end nuclear applications, such as enrichment or nuclear reactor operation.

b) *If so, by what means?*

The security risks can be addressed by a number of passive and active measures. Storage facilities today for spent fuel are inherently very secure if they are based on dry cask storage technologies, since the massive casks themselves provide a strong barrier to any attempts at misuse. Nevertheless, most such facilities are still relatively accessible on the ground surface compared to storage or final disposal in a repository deep underground, which should be considerably more secure. Clearly the physical barriers can be complemented by active controls, guard forces, remote surveillance etc.

4.7) a) *What are the processes that would need to be undertaken to build confidence in the community generally, or specific communities, in the design, establishment and operation of such facilities?*

This is a crucial question. Trust and confidence can be built only if the operator is competent and open in all its dealing with stakeholders. Additional measures that can be taken include the establishment of advisory groups including independent, highly qualified technical experts and trusted national figures. In the Pangea project there was a scientific review group[3] that included representatives of national Australian organisations as well as chosen external experts. These persons provided advice and guidance without being remunerated, not because they assumed that Australia should definitely host an international repository, but rather because they believed that an open debate in a fully informed public should be allowed to take place.

[3] The Members were Dr Peter Cook, Prof Brian Anderson, Prof Charles Curtis, Dr Roy Green, Dr Kurt Lambeck, Prof Albert Matter, Sir Gus Nossal, and Dr Phil Playford

4.8) ***a)*** *Bearing in mind the measures that would need to be taken in design and siting, what risks for health and safety would be created by establishing facilities to manage, store and dispose of nuclear or radioactive waste?*

The main risks are the conventional risks associated with the implementation of any large engineering or mining project. Australia has extensive experience with construction, operation and transport risks associated with such projects and the scale of such risks for a storage or disposal facility are certainly less than for large mineral extraction operations.

The risks that tend to dominate public thinking, however, are the radiation risks to the public or to workers at the nuclear facilities. Experience has shown that transport radiation risks and public or worker radiation doses due to a storage facility are very small and are highly regulated. For deep geological repositories, there is as yet no practical experience of operational risks but the regulatory limits that will have to be met – and which have been illustrated as practical in several national projects – are very strict. Following completion and closure, doses from a repository at all future time must typically be shown to be less than 0.1 mSv/y, which is far less than for present nuclear facilities, which typically limit worker doses to 20-50 mSv and public doses to 1 mSv/y. Typical natural background radiation doses from rocks, soils, cosmic rays etc, average around 2.5 mSv/y globally and can, in some places, be over 100 mSv/y.

b) *What needs to be done to ensure that risks do not exceed safe levels?*

Strict regulations, strictly enforced are essential. In addition the implementer must establish and maintain an effective safety culture that is adhered to by all staff. Geological disposal safety assessment has developed sophisticated approaches to evaluating hazards, risks and potential radiation doses to future generations that have been subject to rigorous regulatory and peer review by scientists. Both generic and site-specific assessments have all indicated doses and consequent risks to be orders of magnitude lower than natural background exposures over hundreds of thousands of years into the future and over a wide range of natural evolution and disruptive scenarios. There is consequently an extensive international foundation for assessing risks and ensuring that safety standards are met.

c) *Can anything be done to better understand those risks?*

Site-specific and project-specific studies are needed to quantify the conventional risks arising from any planned nuclear facility. Radiation risks are well understood based on decades of international studies. Nevertheless, debate still takes place on issues such as the effects of very low level radiation and a national implementer or regulator of a nuclear facility must be aware of the status of such debates.

4.9) ***a)*** *Bearing in mind the measures that would need to be taken in design and siting, what environmental risks would the establishment of such facilities present?*

The environmental risks are similar to those in any large industrial project involving mining activities. They are commonly evaluated objectively in a strategic environmental assessment. They can be minimised by appropriate siting and operational management of the facility. The management of spoil, water, dust and similar factors needs to be considered. However, excavation of a deep repository is small in scale compared to mineral extraction and proceeds at a slower pace of excavation and construction. For a storage or disposal facility in Australia, there are wide choices of sites where any environmental impacts can be minimised.

b) *Are there strategies for managing those risks? If not, what strategies would need to be developed?*

There is wide global experience with the management of risks from storage and disposal facilities. There are few or no examples of such facilities leading to environmental damage. The recent counter example to this is at the WIPP facility in the USA where a chemical explosion in a repository, combined with inadequate ventilation measures led to minute releases of radioactive materials. The probability of such an accident could have been reduced by more stringent controls on the inventory of chemical substances being introduced into the repository; the small releases would have been even lower with better management of the filter ventilation systems. However, the public debate resulting from the minor accident and the huge expenditures foreseen for remediation reflect more the public sensitivity to radiation than the actual heath impacts of the releases.

c) *How would any current approach to management need to be changed or adapted?*

No fundamental changes are needed. Maintaining vigilance and constantly refreshing the safety culture referred to above are the key challenges. An international facility would be expected to have additional levels of oversight and additional requirements for transparency towards the national and local publics, as well as to the client countries using the facility.

4.10) ***a)*** *What are the risks associated with transportation of nuclear or radioactive wastes for storage or disposal in South Australia?*

b) *Could existing arrangements for the transportation of such wastes be applied for this purpose?*

c) *What additional measures might be necessary?*

One feature of a global solution to waste disposal is that longer-range transport of wastes becomes necessary than with smaller, widely distributed national repositories. Safe transport of radioactive materials is therefore a fundamental consideration in an international repository project. At a technical level, satisfying the requirements of the IAEA Transport Regulations for all modes of transport can ensure safety of the public and workers. At the non-technical level, where radioactive waste transport is often portrayed by the press and perceived by the public as a problematic safety issue, measures to enhance communication and improve understanding will be important. There are three transport stages, as described below:

Land transport to the designated international ports of the customer countries

Spent fuel, HLW and the more radioactive ILW will be transported in purpose-designed, robust, heavy steel transport casks. These packages are the primary safety system for all transport operations and are designed and tested to survive all credible accidents. All transport packages will be subjected to quality assured inspection and maintenance regimes.

Nuclear power utility sites already have a proven, safe, secure and monitored transport system in place to cover existing operations. The transport systems within the waste generators’ countries will comply with national and international transport regulations. Rail transport will be the principal mode of transport from the collection point to the designated international port. This is a standard proven operation.

Sea transport

Spent fuel and waste materials could be transported by purpose-built ships, manned by trained crews, complying with International Maritime Organisation (IMO) requirements for the safe transport of nuclear materials. They would operate under the International Maritime Dangerous Goods (IMDG) and Irradiated Nuclear Fuel (INF) codes, which cover all aspects of the ships and the packaging of the wastes. Since 1969, hundreds of ship voyages carrying spent nuclear fuel and HLW have been undertaken between Japan and Europe and between European countries - without any incidents resulting in the release of radioactive material.

The ships have specific features reflecting operational and safety requirements and the latest developments in ship design technology, including:

- duplicated, high reliability propulsion system, generators, power distribution and control systems;
- double hull construction with subdivisions;
- separate cargo holds with radiation shielding, energy absorbing barriers, fire protection and radiation monitoring;
- sophisticated satellite navigation and voyage monitoring systems;
- on board location system, which can operate to a depth of over 6000 metres.

A dedicated sea terminal in Australia country could provide port facilities for the docking of vessels and the transfer of waste shipments onto dedicated rail rolling stock for onward transport inland to a repository site. The terminal complex would contain infrastructure and facilities to support the shipping and rail transport activities and the associated operational and regulatory procedures. The support and maintenance functions for the ships, rail locomotives, rolling stock and transport packages may be divided between the terminal and the repository site.

Rail transport to the repository

Since there may be no existing connections between the sea terminal and the repository, it may be necessary to construct a completely new rail link for the transfer of waste shipments. The rail link would also act as the main supply route to the repository during the operational phase.

The rail link route selection would be optimised to take account of:

- minimisation of environmental impact;
- rail operations, train size and controlling gradients;
- possibilities of using existing track;
- geological and geotechnical characteristics;
- socio-economic factors (e.g. potential to improve access to remote areas).

Main workshops for the heavy maintenance of locomotives and rolling stock could be provided at the sea terminal, the repository complex or another suitable en route location.

Depending on the chosen location, road, rail or port facilities may already exist. For a large repository project, however, it could be preferable and affordable to implement dedicated facilities. This also increases the “added-value” of the project to Australia.

4.11) a) *What financial or economic model or method ought be used to estimate the economic benefits from the establishment or operation of facilities for the storage or disposal of nuclear and radioactive waste?*

There are many national storage and disposal programmes from which unit costs for all items in a cost estimate can be derived. These items include:

- transport, storage and disposal casks
- specialised ships
- rail lines
- site exploration (siting) and characterisation costs
- regulatory process
- repository excavation costs
- storage and repository operations, manpower and materials
- benefits packages to host communities

- national and local taxes
- etc.

The charges to customers that would cover all such costs are easily within the range that client countries would be willing to pay for the services provided. This is a result of the enormous economies of scale that are apparent at most stages in the process.

> ***b)*** *What information or data (including that drawn from actual experience in Australia or overseas) should be used in that model or method?*

Overseas experience increasingly demonstrates that hosting storage or disposal facilities can be an economic benefit. It is for this reason that competition to host national facilities has arisen between communities in various countries including Sweden, Finland and Canada.

For Australia, the most detailed analyses of costs and benefits were done in the Pangea project, for which a detailed report was produced by Access Economics.

4.12) a) *Would the establishment and operation of such facilities give rise to impacts on other sectors of the economy?*

> ***b)*** *How should they be estimated and what information should be used?*

> ***c)*** *Have such impacts been demonstrated in other economies similar to Australia?*

Again, national programmes provide illustrations of beneficial impacts that go beyond those associated directly with the radioactive waste management activities. For example, some countries (e.g. Sweden, Japan, Italy, Spain) have proposed co-locating generalised energy research institutes with the nuclear facilities. The improved infrastructure around the storage and disposal facilities could also be attractive for other technical and industrial enterprises. With Australia's high-technology capability, it would also be sensible to localise as much as possible of the advanced engineering associated with waste management projects. Fabrication of the expensive waste containers and overpack, construction of railstock or even shipbuilding could all be possibilities. A special opportunity for Australia could also be presented at some future date because of the Australian unique experience with development of advanced waste solidification technologies (Synroc).

There are, however, few examples as yet of such imaginative extensions of spent fuel and waste storage or disposal facilities. This is primarily because the world is just now starting down the path towards safe and secure geological storage. Australia could play a key role in the future, limited only by the drive and imagination of those entrusted with the development of the world's first international provider of services for the back-end of the nuclear industry.