Role and Status of Geological Disposal

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Introduction

For many years, nuclear supporters have been talking of a possible nuclear power renaissance. Today there are definite signs that this is finally beginning to happen. New plants are being built or planned in China, Japan, Korea, Finland, France and even the USA. Phase-out policies are being rethought in countries like Sweden, Belgium and Germany. Countries like Vietnam, Indonesia, the Baltic States and even Australia are choosing or debating initiating a nuclear programme.

Support for these nuclear power developments will be strongly influenced by the progress of waste management programmes, especially final disposal. Conversely, the growing realisation of the potential global benefits of nuclear power may well lead to increased support, effort and funding for initiatives to ensure that all nations have access to safe and secure waste management facilities. This implies that large nuclear programmes must make progress with implementation of treatment, storage and disposal facilities for all of their radioactive wastes. For small nuclear programmes (and for countries with nuclear applications other than power generation) such facilities are also necessary. However, for economic and other reasons, these small programmes may not be able to implement all of the required national facilities. Multinational cooperation is needed. This can be realised by large countries providing back-end services such as reprocessing and disposal, or by small countries forming regional or international partnerships to implement shared facilities for storage and/or disposal.

This paper gives a brief summary of the status of how national waste management programmes are progressing (or not progressing) and of how the credibility of multinational concepts is being enhanced by a number of current initiatives. These include Russian proposals for international facilities, the recent GNEP initiative of the USA, studies on regional repositories in the SAPIERR project and IAEA and EC support for both types of initiative.

Prime conclusions to be drawn are that there is no long-term alternative to geological disposal and that continuing efforts are needed to ensure that the feasibility of implementing safe deep repositories is accepted by scientists, the public and the politicians. However, no deep geological repositories for high radioactive level wastes (HLW) or spent nuclear fuel (SNF) will be operating on the short timescales of the next few years, when key decisions are needed on how to expand nuclear power programmes whilst reducing nuclear threats. The important challenges in this period are therefore storing all sensitive materials safely and securely, and simultaneously working to ensure that safe disposal facilities will be available to all such programmes when they are needed.

A brief look back at geological disposal

A well founded idea

Geological disposal was not (despite the assertions of some of its opponents) chosen as a "cheap and dirty" option to get the radioactive waste “out of sight and out of mind”. The concept of geological disposal is a logical consequence of the easily observable decay of radioactivity with time, which leads to a continuous reduction in toxicity of these wastes. Finite hazardous lifetimes (and low volumes of wastes) led to:

- development of concepts where environmental protection could be aimed at by isolating wastes from man's surroundings for long enough to allow such decay to occur and

- a search for environments which showed sufficient stability for the time periods involved - namely thousands or even hundreds of thousands of years.

There are not many environments for which we have evidence of their evolution and their stability over hundreds of thousands of years. Old, deep geological formations are the most obvious candidate environments that can be accessed with today's technology. Other options have, in fact, been considered. A comprehensive document on all these options was published already in 1974 [1]. Concepts that have been examined (more than once) include disposal in space, under ice caps, in subduction zones, etc., but all have been judged infeasible or unsafe. Transmutation is still being studied in various countries. In the view of most experts, it may eventually change the nature or quantity of radioactive wastes to be disposed, but transmutation will not remove the need for geological disposal.

Consequently, concepts for geological disposal under the continental earth's crust have been developed over many years and the concept of disposal in deep geological formations was recognised by the US National Academy of Sciences as early as 1957 [2] to be the most promising form of confinement for long-lived wastes from the nuclear fuel cycle.

Despite the above historical facts, accusations that nuclear power was started without any consideration having been given to the management of its wastes have often been made by anti-nuclear groups. These opponents have likened the construction of the first nuclear power plants to “building a house with no toilet”. The experts in the nuclear community see this differently. They point out also that for many years, or even decades, there was no technical need for disposal. The quantities of high level waste or spent fuel were too small to justify implementing repositories and, in any case, a cooling time of around 40 years was the sensible technical choice.

Mixed beginnings

In retrospect, however, there was indeed too little effort invested into organising long-term management and disposal; most attention was devoted to implementing practical measures for handling and storing radioactive wastes safely. This is now recognized as a mistake. Even the famous nuclear pioneer Alvin Weinberg has been quoted as saying *"During my years at ORNL, I paid too little attention to the waste problem. Designing and building reactors, not nuclear waste, was what turned me on . . . [A]s I think about what I would do differently had I to do it over again, it would be to elevate waste disposal to the very top of ORNL’s agenda”*

With time, however, things changed; dynamic waste disposal initiatives were started - and, paradoxically, the nuclear opponents were in large measure to thank for this. Because they asserted that lack of demonstrated safe technologies for disposal should preclude the use of nuclear power, governments were pressured to demand specific projects that could provide this demonstration.

The first example was in Sweden, where the Stipulation Act of 1977 made credible disposal concepts a pre-condition for the start up of new power stations. This led directly to the establishment of the pioneering KBS project which developed technical disposal concepts that are valid still today. A similar situation resulted in Switzerland when the new Atomic Energy Act of 1975 and associated regulatory requirements demanded demonstration projects before the year 1985 if new nuclear plants were to be introduced to the country, or even if the existing stations could continue operation. These are clear examples of cases where nuclear sceptics or opponents have given a positive impulse to the planning of geological disposal.

There are also striking counter-examples, i.e. cases where nuclear opponents have slowed or stopped any progress in disposal. In the UK, the Government abandoned a HLW disposal in the 1980s in order to avoid public conflicts over drilling sites; in Spain a specific repository siting programme was scrapped for the same reason; in the Netherlands, the Government blocked a highly interesting programme on disposal in salt domes and ruled that storage for at least 100 years was the option to be chosen. The reasons for opposition to progressing repository programmes are diverse. Some people genuinely believe that the safety of deep geological disposals has not been demonstrated sufficiently and that allowing years or decades for further work will produce some as yet undefined better solution – a "magic bullet". Others object for tactical reasons – an accepted waste disposal solution would remove one of their last anti-nuclear arguments, now that operational safety and economics are both clearly favourable.

A real danger resulting from those tactical manoeuvres of opponents is that an "unholy alliance" could result in all efforts on preparing for geological disposal grinding to a halt. By this, I mean that indefinite storage could become the common solution that satisfies both the nuclear opponents (who wish to block a real final solution) and extremists in the nuclear industry (who know very well that the storage option is much less costly than implementing geological repositories). The losers, in this case, are our children and grandchildren, the future generations who then inherit an unsolved problem passed on to them by us because we did too little to clear up our own mess.

An important new driver

Where are we today on all of the issues influencing efforts made towards implementing deep geological disposal? Unfortunately for the world in general, but productively for waste management, a new and frightening aspect has kept to the forefront. This is the growing concern about the misuse of nuclear materials by nations that are intent on gaining nuclear weapons capabilities, or even more worrying, the possibility of nuclear terrorist acts. In the recent past – in particular since the terrorist attacks on the USA in 2001 – the security issues associated with management of nuclear materials, including wastes, have assumed high profile.

The concerns about the spread of sensitive technologies such as enrichment and reprocessing have correctly taken front place. These concerns have led directly to the Russian and American fuel cycle initiatives described later. However, the back-end of the nuclear fuel cycle cannot be neglected when we are trying to minimise security concerns. Spent nuclear fuel and HLW must be kept away from persons, organisations or governments that might misuse it. A very effective way to make these materials inaccessible is to emplace them in a limited number of highly controlled national or multinational underground facilities. The latter of these options is discussed in more detail later in this paper. First, however, a brief overview is given of how national programmes are progressing with implementation of safe, secure and environmentally friendly final repositories for spent nuclear fuel and HLW.

Status of Geological Disposal Programmes

For at least 25 years after the original 1950's publications on the concept of geological disposal, the validity of this approach was not questioned. It was formally adopted as a final goal, through policy or legal decisions, in many countries, including the USA, Canada, Sweden, Finland, Belgium, Switzerland, France, Spain, South Korea, and Japan. As mentioned above, several of these countries initiated active scientific and technical programmes aiming at implementing disposal, usually some 20 years or so into the future. International organisations such as the OECD/NEA, the IAEA, and the EC established working groups and networks of the organisations involved. Special journals started up. Innumerable conferences were organised around the world; for example the major annual International Waste Management Conference in Tucson, Arizona, USA was held in 2006 for the 32^{nd} time.

Slow progress…

However, virtually every geological waste disposal programme in the world ran into difficulties in keeping to originally proposed schedules. For example, in the US programme, in 1982 [3], a target date for repository operation of 1998 was set. In stages afterwards, the target for a US repository at Yucca Mountain was moved back to 2010 because of unresolved technical, licensing and legal issues. Today 2010 is also recognised as unachievable and there is no official target date specified by USDOE. Other programmes have also been compelled to move target dates back. Through to the present, the only active programme that met its early deadlines has been Finland.

Slippages in deadlines, however, are common in large projects; disposal programmes are not unusual in this respect. Less common are decisions of the type taken in some countries – namely to indefinitely postpone implementation of geological repositories. This has happened several times, in each case due to public opposition leading to governmental decisions to halt siting processes. Examples are the Netherlands, Spain, the United Kingdom, Argentina and the Czech Republic.

In a few countries, there has been a still more radical political reaction to problems encountered by geological disposal programmes. This began in France, where intense opposition to siting efforts in crystalline rock areas, together with growing opposition to disposal per se, led in 1990 to a new law in which the geological disposal option was treated as one of three lines to be followed. The other two, transmutation and long-term storage, were to be studied with equal intensity at least up to a decision date set for 2006. A key result of the major project that resulted from this French programme is the decision taken in by the French Parliament this year that a geologic repository for HLW should be implemented by the year 2025.

Backing off from the choice of geological disposal as the preferred national strategy has taken place in two further countries, namely the UK and Canada. The UK government decided to re-open all alternatives and to have a very wide public debate before choosing a preferred future course. This decision followed on the loss of the proposed Sellafield site as a result of a public hearing that severely criticised the scientific, engineering and societal aspects of work by UK Nirex. In Canada, the Government also decided to re-open discussion on all conceivable long-term spent fuel management options following the review by the Seaborn Committee [4] of the major study submitted by AECL. In the Canadian case, the science and technology was not faulted; the proposed repository concept was judged technically capable of providing safety. However, it was also judged that the public confidence in the safety was insufficient to allow an implementer to proceed to specific repository siting.

For carrying out these re-evaluations, the governments of the UK and Canada set up special bodies, respectively the Committee of Radioactive Waste Management (CoRWM) and the Nuclear Waste Management Organisation (NUMO). After extensive consultation exercises, both have recently produced recommendations that geological programmes should move ahead, although in an extended staged process. (see www.corwm.org.uk and www.nwmo.ca)

But some progress…

The above rather sobering look at the slow progress of geological repositories in some countries contrasts with the advances made in some other parts of the world. In the USA, the WIPP deep repository for transuranic wastes has been operating successfully for some years and has recently been recertified to continue doing so. Furthermore, since the US congress has decided that a licensing application should be prepared for the Yucca Mountain Project in Nevada, a deep repository for used nuclear fuel may well be constructed and operated in the United States in the foreseeable future, despite the significant hurdles still faced. In the Northern European countries, Finland and Sweden, the deep repository programmes are very advanced and steering towards definitive dates for implementation. More influential, perhaps, than the technical developments that have been initiated in these countries, are the societal processes that have been invoked to try and ensure that the repository has a sufficient level of acceptance. In most other countries of the world, the combined technical and societal approaches employed in the Scandinavian countries are looked upon as role models for how things might be arranged also in other programmes.

In the European Union, a 2002 draft directive instructed all European Union member States that specific deadlines for siting repositories and for implementing these facilities must be set. Although the over-ambitious deadlines proposed in the initial draft were dropped, the thrust of the initiative will likely remain. This thrust confirms, at least for the European Union, that deep geological disposal is indeed the preferred waste management strategy for used nuclear fuel and high-level wastes.

Achievements to date

A broad look at the actual situation around the world today reveals the following. The present position is that technologies for implementing deep geological disposal have been developed and extensively tested in a number of countries, although fully implemented in only very few cases. These technologies are based on different conceptual designs for a deep repository, including the choice of the engineered barriers that enclose the used nuclear fuel and also the geological medium in which the repository will be sited. In all of these different programmes, the safety of the deep geological system - as assessed by the range of methodologies developed for this purpose - is invariably shown to be very high. The development of the safety assessment methodology itself has involved many man-years of intellectual effort and also extensive collaboration between researchers in different countries around the globe. Assessing the safety is based upon analysing how the entire repository system will behave far into the future. This estimation in turn is based upon a sound scientific understanding of how the materials will evolve in the deep geological environment, and of how any radionuclides released might be transported through the deep underground, back towards the environment of humans. The safety assessment is not a purely theoretical desk exercise. The models are based upon experimentation in the laboratory and in the field. The understanding that is built up is checked by observing, how natural systems with similar properties behave over the very long time-scales considered. Although there are still dissenters to be found, in the scientific community there is general acceptance of the feasibility of safe disposal. Unfortunately, this general consensus does not yet extend to the majority of members of the public.

As a complement to these overarching comments on the status of geological disposal, many publications include good overviews of programmes world-wide. A recent example is the review by Witherspoon and Bodvarrson [5]. In addition, the IAEA maintains a web site that documents current general trends and also developments in individual countries. Finally, most national waste disposal organisations have their own web sites.

The current status of national geological disposal programmes is thus well documented and it illustrates that progress is being made in many countries – but that this is a slow process. For some countries national repositories may be difficult or unfeasible because of the lack of favourable geological formations, shortage of technical resources, or unacceptably high costs. For these multinational repositories are a potential solution and, in recent years, there has been a rapid increase in interest in this possibility as described in the following section.

Multinational initiatives

In the early years of nuclear development, the concept of nuclear fuel cycle centres, including international repositories, was topical. The IAEA charter itself allowed the Agency to be involved in centralized plutonium storage and management. Various studies were performed on regional nuclear fuel cycle centres and on international spent fuel management. These are documented in [6].

The past five years have seen a continual growth in the interest of many national waste management programmes – especially those of small countries – in the concept of multinational or regional disposal facilities. The prime drivers were originally the economic and political problems that might be lessened by being shared between countries facing the same challenges. The potential safety and safeguards benefits were also recognised at this early stage. Increasingly – in particular after the terrorist attacks in the USA in 2001 and in connection with nuclear proliferation concerns – attention focused on the security advantages that could result. . The most recent manifestation of this is the Global Nuclear Energy Partnership (GNEP) promoted currently by the US Government. The IAEA, honoured in 2005 with the Nobel Prize for its efforts to reduce nuclear risks, has been careful to point out that these risks can also be important at the "back-end of the back-end" of the nuclear fuel cycle, i.e. not only in enrichment and reprocessing but also in storage and disposal, in particular of spent fuel.

In its publications in this area and in recent statements of representatives of the IAEA, two potential routes to achieving international disposal have been described. One of these, the “add on approach”, is the inclusion of disposal within a broader scheme of internationalised fuel-cycle services provision. The other, which does not require global strategic developments and agreements, is the “partnering scenario”, in which a number of countries agree to look for a common disposal solution involving one or two shared repositories. These should be sited in locations to be decided by the multinational participants in the same democratic, consensual approach that has been used by potential siting communities in the more successful national programmes.

In both potential disposal approaches to multinational disposal, significant progress is being made. Below, we describe the add-on approach, using the topical examples of Russia and then examine the partnering scenario, using experience gained in the SAPIERR project of the EC.

The add on option

A single country, or a network of countries with appropriate facilities working together, by providing extended fuel-cycle services to countries adhering to the NPT and wishing to use nuclear power, could limit the spread of those sensitive technologies that are allowed under the Treaty, namely enrichment, reprocessing and storage/disposal of fuel. Crucial pre-requisites would be security of supply of services to all co-operating users (as emphasised by the Multilateral Approaches Group established by the IAEA [7]) and close international monitoring by the IAEA. The whole concept has been raised again recently by IAEA Director General, Mohammed ElBaradei [17, 18]. It is very topical because of the concerns with nations such as Iran expanding their nuclear capabilities to include fuel enrichment.

Although emphasis is on the front end of the fuel cycle, where most security concerns arise, back-end services would also be offered as part of this suite of provisions, either by countries establishing new, dedicated multinational storage and disposal facilities to fit into the scheme or by countries with existing facilities that could be extended for international use.

Within this international fuel cycle scheme, the fuel leasing component is certainly the closest to being an accepted practice. This is almost the practice followed by the former USSR with its satellite States. More recent global concerns about security have led to it being the universally preferred solution, if nuclear power plants are to be operated in countries such as Iran and North Korea. Recent proposals from the US Government have indicated its support for such a scheme. Should it come to pass, the gate will be opened for other large nuclear fuel suppliers to improve the attractiveness of their fuel services, while at the same time enhancing global security. Potential network partners in internationalising the fuel-cycle would all have to be NPT signatories and could clearly include the major suppliers of uranium or of fuel cycle services or of power reactors, i.e. the list includes countries such as Argentina, Australia, Canada, France, Japan, Russia, the UK and the USA.

The most likely country to offer to act as host in this add-on scenario is recognised to be the Russian Federation. Support has been expressed at Government level. The law currently allows import of spent fuel for storage or for reprocessing with return of residues. However, there is solid support for expanding this service to include final acceptance of fuel or even high level radioactive wastes (and, it is acknowledged, also strong opposition). Moreover, once a first move is made, it is not impossible that competition could even arise. Supporters of hosting an international repository have spoken up in Kazakhstan and China in the past and recently again in Australia. Acting as a host is economically attractive for Russia since it would provide either income from provision of services or fuel for the future, or both. However, as has been recently pointed out [10], the law would have to be changed and a number of other conditions would have to be fulfilled if a range of important international stakeholders are to be comfortable with what is offered and the conditions attached.

The recent GNEP proposal from the USA is primarily aimed at making the nuclear fuel cycle more secure. It asserts that this could be achieved by restricting sensitive the processes of enrichment and reprocessing to a restricted number of trustworthy countries (or existing weapon States) that should then provide services to other countries wishing to use nuclear power for peaceful purposes. For this to be attractive to these customer countries there must be sufficient incentives and the supply of services must be guaranteed. One incentive would be to have no HLW or spent fuel to be managed long-term and intimately disposed. This requires the fuel suppliers to take back the spent fuel – probably under a leasing arrangement – or for a third party, trustworthy country to offer storage and disposal services.

Proposals to host an "international nuclear waste dump" have, not unexpectedly, led to public and political opposition. However, offering a global service that enhances world security, and is for the host country both safe and profitable, maybe more acceptable [11]. From a waste management perspective, GNEP does not add much to the existing Russian proposals. In fact, the additional elements in GNEP – in particular the very ambitious or even unrealistic intentions to develop wholly new fuel cycles may be counterproductive. They may lead to the more pragmatic proposals, such as fuel leasing, being postponed for the long times needed for such fuel cycle developments.

A fundamental point is that purely unilateral initiatives (whether they are in Russia, the USA or elsewhere) will very probably not succeed – a proper multinational approach is absolutely essential. The time is now ripe for initiating such an approach by bringing the key players together in a free and open discussion to develop plans for how a specific project can be established.

The partnering approach: SAPIERR

The second option for implementing multinational repositories - partnering by smaller countries - has been particularly supported by the European Union through its promotion of the potential benefits of regional solution, i.e. facilities shared by contiguous or close Member States. For the "partnering" scenario, in which a group of usually smaller countries cooperate to move towards shared disposal facilities, exploratory studies have been performed most recently by the Arius Association, which also co-manages the European Commission SAPIERR project on regional repositories [12].

The Support Action: Pilot Initiative for European Regional Repositories (SAPIERR) project finished at the end of 2005 after 2 years of work involving organisations from 14 different countries. This should be succeeded by a follow-on SAPIERR-2 project (Strategic Action Plan for Implementation of European Regional Repositories – Stage 2). This would establish a dedicated multinational organisation that would develop the shared repository option in a staged process similar to that favoured by national programmes. The SAPIERR-2 project looks in more detail at the following topics: multinational legal and business structures; legal liabilities; economics (costs, benefits); safety and security; public and political attitudes.

We definitely need geological repositories – but when?

As argued above, geological disposal is a necessary final step in the fuel cycle if nuclear power is to be sustainable in the sense that unnecessary burdens are not passed on to future generations. Continuing with nuclear power is therefore justified only if there is a sufficient consensus that safe geological repositories can be implemented. It is often argued that the public confidence needed to achieve this consensus can be achieved only by having operating repositories. This is a dangerous argument for several reasons:

- Even the most advanced programmes will not have operating HLW/SNF repositories for 10-15 years. Decisions on expanding nuclear power are, however, needed much more urgently. In many countries the lifetime of first generation reactors is ending and replacements are needed. In developing countries with rapidly expanding energy needs, use of fossil fuels should be restricted.
- Given the timescales for which repositories must guarantee the safe containment of radioactive wastes, a facility that has been operating, even for years, still does not "prove" that long-term containment will function as expected.
- Technical developments in the nuclear fuel cycle may make the direct disposal of spent nuclear fuel a less attractive option than recovering the fissile material for further use. Retaining the possibility to access the fuel is a prudent approach – provided of course that adequate security measures are taken.
- Small countries will for a long time have too little waste and too little funds available to make implementing a national repository feasible. They should not be forced into this route prematurely. Multinational repositories can and will solve this problem, but not in a short timeframe.

What then is the long-term solution that can justify continuing with and expanding nuclear power production? Disposal solutions must be demonstrated to be feasible. This is not accomplished by simply building a facility. The following requirements are both necessary and sufficient:

- A technical concept involving engineered and natural safety barriers must be developed and its expected performance analysed using appropriate scientific modelling, backed up by comprehensive data collection. The safety level that the facility offers must be recognised by scientists – and by the public.
- The engineering skills needed to implement such facilities must also be recognised as being available today. This can be best done by ensuring that construction of the facilities requires only geotechnical and engineering skills that have been applied already in comparable projects.
- The funding needed to implement repositories must be conservatively estimated and the required funds should be accumulated in dedicated funds that can not be diverted to other uses.
- Finally, given the considerable societal and technical challenges involved in selecting a suitable site, this step should ideally also be accomplished. This means, in the best case, that a specific site has been identified and, in all cases, that the feasibility of doing so is accepted.

When all of these conditions have been satisfied, then the repository implementer can, with a good conscience, sit back and leave the decisions on when to move to implementation to be taken in a broad societal context. Today, the conditions are not satisfied fore most countries. For the few with chosen repository sites (such as Finland) they are; for some more with acceptable siting areas identified (including for example Switzerland) they almost are; for many, the funding condition is not met; and for some there is not yet consensus on the achievable safety.

Storage is not a major problem

If storage of spent fuel is to continue for some long time – as is inevitable – then certain requirements have to be fulfilled. There must be adequate storage capacity available and the facilities must be safe and secure. The storage options available are in the pools that all reactors have for initial cooling of unloaded fuel, or in away-from-reactor dedicated storage facilities. The basic techniques employed are wet storage with the fuel under water that cools and shields it, or dry storage in casks or vaults.

In many of the countries with nuclear power, storage of spent nuclear fuel is not, or is no longer, a major problem. This positive situation often results, ironically, from the unsuccessful attempts of national waste management programmes to move ahead with disposal projects. Delays on the repository front have compelled some countries to increase their storage capacities, either by re-racking pools at reactors or by constructing new storage facilities. In any case, many programmes have planned for long periods of interim storage (up to 40 or 50 years) to allow the fuel to cool sufficiently before moving to geological disposal, or else simply to postpone the expensive task of implementing disposal, and thus allow time for funds to accumulate. Examples of the former include Sweden, Switzerland, Finland, and Japan; the latter approach is illustrated by the Netherlands and Slovenia.

There are, however, some prominent exceptions; in those countries that urgently need expanded storage capacities the reasons are usually political or societal rather than technical. The USA has manoeuvred itself into a corner by trying to implement an aggressive disposal strategy at Yucca Mountain, while centralised storage schemes have been blocked by law (at Yucca Mountain) or by opponents (in Utah: the private spent fuel storage initiative). In Japan, there have been problems in gaining public acceptance at potential centralised storage sites. This problem is even greater in Taiwan and South Korea.

The IAEA keeps track of the storage capacities world wide. Table 1 below shows that there are many facilities operating and many in construction or planned. The new facilities being implemented are mostly of the dry storage type since this can be done in a more cost effective modular way, since the storage my be very log – and thus suited for low maintenance and also because reservations have been expressed about the security aspects of wet stores.

Table I: Capacities of Nuclear Fuel Storage Facilities				
	WET	DRY		
Country & Unit	In Operation	In Operation	Construction	Planned
Argentina (t HM)	986	1000	0	0
Armenia (t HM)	0	74	0	0
Belgium (t HM)	1760	2100	0	0
Bulgaria (t HM)	600	0	0	0
Canada (t HM)	0	75	0	0
Czech Republic (t HM)	0	600	1340	0
China (t HM)	500	0	0	0
Finland (t HM)	1694	0	0	0
France (t HM)	18000	0	0	0
Germany (t HM)	560	10123	8220	0
Germany (Cask-Bund.)	0	0	440	0
Hungary (t HM)	0	580	0	0
India (t HM)	275	590	0	0
Japan (Cask-Bund.)	7755	408	0	0
Japan (t HM)	3140	0	0	0
Korea, Republic of (t HM)	0	1212	0	2000
Lithuania (t HM)	0	360	0	0
Romania (Cask-Bund.)	0	300000	0	0
Russian Federation (t HM)	14960	0	0	38000
Slovakia (t HM)	1690	0	0	780
Spain (Cask-Bund.)	0	1680	0	0
Sweden (t HM)	8000	0	0	0
Switzerland (t HM)	0	2500	600	0
Ukraine (t HM)	2518	0	0	0
Ukraine (Cask-Bund.)	0	9120	0	21350
United Kingdom (t HM)	10300	700	0	0
USA (t HM)	2127	5838.4	2729	82393
Total	**74865**	**336960.4**	**13329**	**144523**
The capacities shown as '0' here might mean the capacity is really small or unknown!				
Table adapted from IAEA website http://www-nfcis.iaea.org/				

The table shows that a global storage capacity of around **570 000tHM** will be available in the near future. How does this compare with the existing stock levels and the annual production of spent fuel?

The total amount of spent fuel that had been cumulatively generated worldwide by the beginning of 2003 was close to 255 000 t HM. Worldwide the spent fuel generation rate, now at about 10 500 t HM/year, is expected to increase to about 11 500 t HM/year by 2010. Projections indicate that the cumulative amount generated by the year 2010 may thus be close to 340 000 t HM. By the year 2020, the time when most of the presently operated nuclear power reactors will be close to the end of their licensed operation life time, the total quantity of spent fuel generated will be approximately 445 000 t HM.

At the beginning of 2003, the IAEA recorded that, of the spent fuel generated to date, about 171 000 t HM of spent fuel were stored in storage facilities of various types (see Table II from Reference 13). As less than one third of the fuel inventory is reprocessed, about 8 000 t HM/year on average will need to be placed into interim storage facilities. The IAEA assumes that current plans are maintained, resulting in the following regional trends:

• West Europe will have slight decreasing quantities of spent fuel to be stored, due to

reprocessing of spent fuel;
• East Europe will double the amount of spent fuel to be stored in the coming ten years;
• America will store all discharged fuel, thus the amount of spent fuel is constantly increasing;
• Asia & Africa like East Europe, will double the amount of spent fuel to be stored in the coming ten years.

The conclusions to be drawn from the above statistics are that of the 570 000tHM storage capacity that will be available, only around 200 000tHM are already in store – which implies that storage could continue for a few decades at the present rate of generation. Lack of available storage is therefore not a strong driver leading to repository implementation. This does not allow for local shortages of capacity of course, butt also does not allow for the relative ease of increasing storage capacities.

Table II: Status of spent fuel stored in world regions t HM

Region	**Amount**
West Europe	36 100
East Europe	27 700
America	83 300
Asia & Africa	23 900
World	171 000
(Status 1 January 2003)	

Conclusions

The conclusions that can be drawn from this review of the past history and present status of geological disposal can be summarised as follows:

- Nuclear power did not live up to early expectations: it was technically more complex than assumed, economically less attractive than expected and socially became progressively less supported after its promising start. Opposition stopped or slowed growth: the nuclear industry did not make sufficient efforts to inform and consult with the public, leaving the field open for intensive and effective lobbying by anti-nuclear forces. The list of counter-arguments (often recycled) focussed on reactor safety, economics, security and waste management
- Despite some severe setbacks, nuclear power over some decades proved itself increasingly to be reliable, safe and economic; many of the objections were thus countered. In addition the positive environmental aspects of nuclear power are becoming increasingly recognized by a public that is becoming ever more aware of the catastrophic consequences that can result from unabated consumption of fossil fuels.
- Despite the widening acceptance or support for nuclear, serious reservations continue to be expressed on two issues – nuclear security and long-term waste management. These issues are linked and are both being addressed today by intensifying efforts to ensure that all hazardous radioactive materials (and in particular fissile materials) are being moved into well safeguarded storage facilities.
- Deep geological repositories are an essential component of the long-term management of radioactive wastes. These do not need technically to be implemented on a short timescale; they can not be implemented on timescales affecting urgent decisions on expansion of nuclear power; enough must, however, be done to establish technical and political confidence in the feasibility of safe disposal. Many nations are trying to progress plans and projects for implementing deep the

geological repositories that will be needed to provide long-term safety and security in any credible waste management system.

- For some countries, it will be infeasible or impossible to implement the costly deep repositories that will be needed to safely store their relatively small quantities of hazardous long lived wastes and/or spent fuel. Therefore national efforts must be complemented by multinational cooperative initiatives that will make appropriate storage and disposal facilities available to all countries that make use of nuclear technologies. Implementation projects that arise from such cooperation could bring huge and mutual benefits to both host countries and user countries of shared multinational repositories.
- The most effective ways forward to ensure security and long-term safety are that immediate efforts are made to ensure secure storage of all hazardous radioactive materials, that advanced disposal programmes continue towards realisation of repositories, and that active steps are taken towards the realisation of shared multinational facilities for both storage and disposal of HLW and SNF.

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