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Author: **Vladan Štefula**

Lead contractor for this deliverable: **DECOM Slovakia**

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USED ACRONYMS

SAPIERR	Support Action: Pilot Initiative for European Regional Repositories
RTD	Research & Technical Development
EU	European Union
IAEA	International Atomic Energy Agency
LLW	low-level radioactive waste
HLW	high-level radioactive waste
EC	European Commission
NEA	Nuclear Energy Agency
tHM	tons of heavy metal
SNF	spent nuclear fuel
LL-ILW	long-lived intermediate level radioactive waste
SKB	Svensk Kärnbränslehantering AB (Swedish Nuclear Fuel and Waste Management Co)
NAGRA	Nationale Genossenschaft für die Lagerung radioaktiver Abfälle (Swiss National Cooperative for the Disposal of Radioactive Waste)
MPC	multi-purpose container
NPP	nuclear power plant

1. OBJECTIVES & SCOPE

The majority of European countries, even those without nuclear power industry, produce long-lived radioactive waste that cannot be accepted in near-surface or subsurface disposal facilities. It is widely acknowledged that disposal in deep geological formations is a technically feasible and safe method for managing these types of radioactive waste. However, construction of a deep geological repository is a very demanding and costly task.

Some countries, especially those with small and medium nuclear programmes, may not have the resources or full range of expertise to build their own deep geological repositories. Other countries may – simply as a good, economical management practice – deem it wise to consider the possibility of sharing both the costs and the benefits of deep geological disposal with other countries. SAPIERR (Support Action: Pilot Initiative for European Regional Repositories) is the project under the 6th Framework Programme of the European Commission which brings together representatives of the European countries interested in the shared solution of deep geological disposal of radioactive waste. SAPIERR is a pilot initiative helping the European Commission to begin to establish the boundaries of the issue, collating and integrating information in sufficient depth to allow potential regional options to be identified in order to scope the new research and technical development that may be needed to implement these. 21 organisations from 14 countries have taken part in the SAPIERR project. It must be noted that the organisations involved in the project represent only themselves and not the official views of the respective countries. However for simplicity, the group of countries in question is referred to in this document as "SAPIERR countries". The list of SAPIERR countries comprises:

- Austria
- Belgium
- Bulgaria
- Croatia
- Czech Republic
- Hungary
- Italy
- Latvia
- Lithuania
- The Netherlands
- Romania
- Slovakia
- Slovenia
- Switzerland.

The scope of the SAPIERR pilot project covers only the clarification of the pre-requirements for possible implementation projects for one or more shared European regional repositories (such hypothetical facilities are hereinafter referred to as "SAPIERR repository"). In practice, the work scope has been restricted to:

- reviewing the international and national legal or regulatory issues that would affect implementation of regional storage facilities or repositories
- constructing a reference inventory of the radioactive wastes arising in all of the 14 countries from which organisations have joined the SAPIERR working group
- evaluating potential designs, implementation timescales and likely costs for shared regional repositories, based on existing documented data on European national programme
- looking at potential scenarios for organising the implementation of European regional repositories
- identifying those aspects that require further study or research before proceeding further.

These tasks have been addressed in the published technical reports:

- Legal Aspects [1]
- Inventory [2]
- Possible Options and Scenarios of Regional Disposal and Future RTD Recommendations [3].

The objective of this report is to summarize results achieved during the project implementation.

2. LEGAL ASPECTS

A number of the SAPIERR countries have policies to phase out nuclear power (e.g. Belgium, Netherlands and Italy) but others have no such plans and may even prolong plant lifetime or expand the programme. In either case, log term management of spent fuel is a responsibility that must be fulfilled. Moreover, radioactive waste management is required also for dealing with wastes from research reactors and other nuclear technologies, and these are very widely spread throughout the Europe.

All of the countries involved in SAPIERR have established a legal and regulatory framework for radioactive waste management. In some cases this has been done only recently – with actual or potential membership in the EU being a strong driving factor. The framework is commonly based on the recommendations of the IAEA Safety Standards documents. These standards have been taken over in large part into the EU legislation and also are embodied in the IAEA Joint Convention. This convention, which has been signed by all of the 14 countries represented in SAPIERR, has also been a strong driver for establishing the necessary framework for safe waste management.

Most countries also have an organised regulatory framework for radioactive waste disposal. Some of the regulatory bodies are, however, newly established and have not yet produced all required standards and guidelines. Many – but not all – of the regulatory bodies have experience in the licensing of waste management facilities for treatment and storage of wastes and also for disposal of LLW. Of course, none of the regulators has licensed a deep geological repository, since no European country in or out of SAPIERR has yet implemented such a facility.

The greatest unity of regulatory approaches has been achieved in the area of radioactive transport. Here the mature and well-tested international transport regulations of the IAEA provide a solid basis. The success in this area could provide a valuable lesson in the less developed area of geological disposal regulations.

Coordination of disposal activities and regulations is a very obvious necessity since virtually all of the countries in the EU and in SAPIERR have agreed that geological disposal is a long term management option that should be pursued. The UK alone has not taken this decision. In fact, most countries have decided that geological disposal is the preferred option, even if other possibilities are formally kept open. The implementation of deep geological repositories in the EU is, however, still a considerable distance into the future. In the next 20 years there will be at most 1-2 operating geological repositories. Many countries – both large and small – are prepared to wait several decades to a hundred years before starting disposal of HLW or spent nuclear fuel.

Waiting a long time is feasible if adequate interim storage capacity is available, and this is – or soon will be – the case in all relevant countries. Waiting a long time is, moreover, often regarded as an attractive option for three main reasons:

- The activity and heat production levels of the radioactive waste decay significantly making handling and disposal simpler.
- The level of societal confidence in geological disposal is still insufficient in many countries; this may change as time passes by.
- The costs of disposal are so high that postponing these to a future date or accumulating them during a long period of time is economically attractive.

The biggest factor influencing progress with disposal of high-level radioactive waste and spent nuclear fuel is probably the low level of public acceptance and political support. However, the economic issues associated with funding of disposal facilities are also a major factor determining disposal policy, in particular in the small nuclear programmes. To meet these economic challenges, most countries with nuclear power plants have established funding mechanisms. In many cases, however, the arrangement is relatively new, so that only modest (or sometimes zero) funds have been accumulated. In several countries with a longer history of nuclear power or with larger nuclear power plant parks, substantial funding has already been accumulated.

The issues of public acceptance and of economics are also those which most strongly influence national policies with respect to regional or international repositories. Large nuclear programmes (e.g. in France, UK, Germany, Spain, Sweden) can relatively easily accumulate sufficient funds for a national repository by passing costs onto electricity consumers. Accordingly these countries tend to focus on achieving adequate public acceptance for their national programmes. This has led to some countries expressing reservations about efforts to promote shared (regional or international) repository solutions, in order to allay concerns of their publics that foreign waste might be imported.

For small countries, the costs are definitely a policy determining factor. Several (e.g. Netherlands, Slovenia) openly acknowledge that their small nuclear programmes make economic national repositories almost infeasible. Consequently, the countries with small nuclear programmes are those with most interest in regional waste disposal solutions, as evidenced by the participation in SAPIERR. Although some of these countries have decided definitely that they cannot afford a national deep repository and must wait until shared solutions become available, the more common policy is to begin to prepare geological disposal programmes whilst maintaining the option of sharing in a regional repository, should this become available. In fact, although most of the small countries have accumulated insufficient funds to implement a national repository, there are certainly sufficient resources available, if pooled, to support a serious joint waste disposal programme aimed at clarifying the options for a shared regional facility.

The various attitudes towards shared disposal concepts are often reflected in the policies and in the legal / regulatory framework of the countries. Many countries currently ban import of wastes for disposal (e.g. Austria, Croatia, Czech Republic, France, Hungary, Latvia, Lithuania). Very few legally ban export; Finland is an exception. A few explicitly acknowledge the possibility of import or export and some have no formal position. Accordingly implementation of a regional repository would almost certainly necessitate changes in a number of national legal systems. A few countries (e.g. Switzerland) have already formulated rather detailed conditions under which import or export of wastes might be permissible.

At an international level, organisations such as the EC and the IAEA have officially given support to the concept of regional repositories. The NEA has remained silent. Reservations or opposition have been expressed only by some major programmes seeking a national solution. It seems clear that more international support for shared disposal facilities could help build acceptance for the concept. The EC and IAEA could help by making more specific the necessary legal and contractual frameworks. Issues of liability, control, inspection, finances, etc. can be regulated in bilateral or multinational contracts. It would be, however, very sensible if such contracts or treaties were to be concluded with support and guidance from an international body such as the EC of the EU.

3. WASTE ARISINGS IN THE EU

Nuclear power plays a role in many of the countries of the EU (14 from 25 countries have nuclear power plants). The countries participating in SAPIERR have limited numbers of power reactors – the total number is 37, to be compared with 161 in the whole EU together with Romania, Bulgaria and Switzerland, of which France alone has 59.

In Figure 1, the installed capacity of nuclear power reactors is presented in the form of a bar chart.

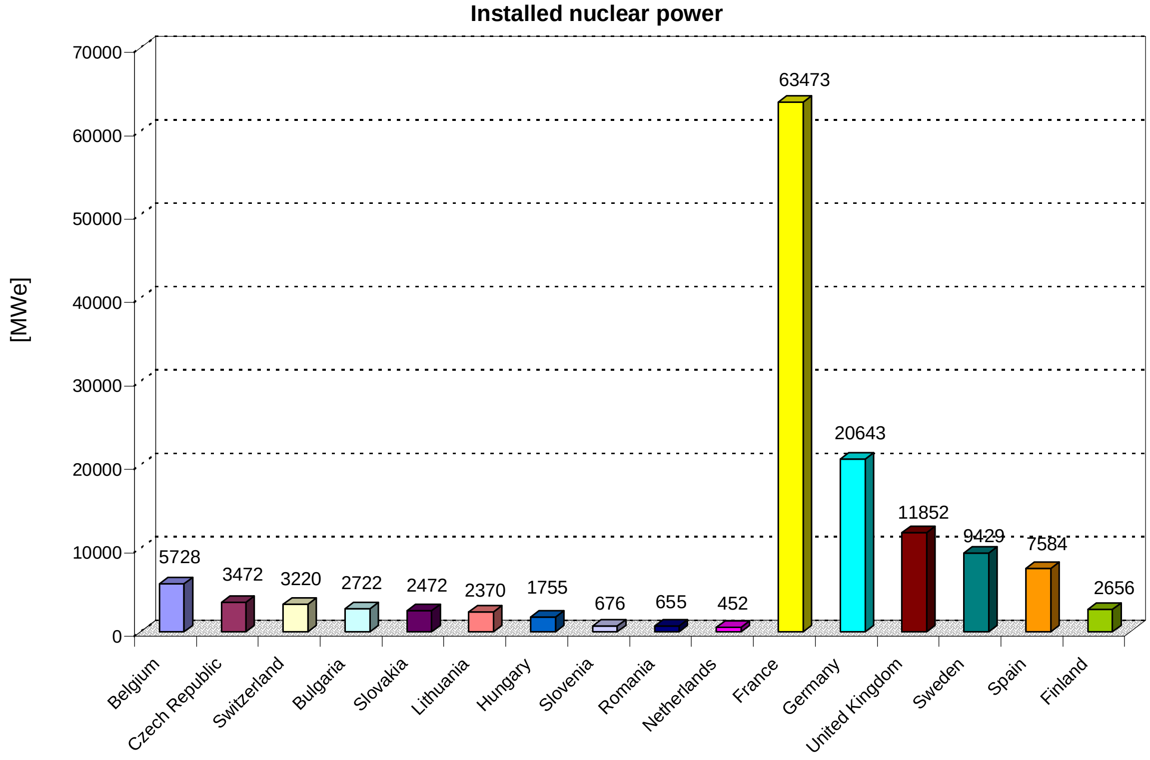

Figure 1 Installed nuclear power in EU countries + Switzerland

When examining Figure 1, it is notable that the most advanced national programmes for deep geological repository development are in Finland and Sweden, which are not the countries with the largest nuclear power industries.

Further analysis of the European electricity market reveals that the combined size of the nuclear industry in the SAPIERR countries versus non-SAPIERR countries provides an obvious justification for the European regional repository concept. This comparison is highlighted in Figure 2. The graph in Figure 2 shows that the 10 SAPIERR countries with a nuclear power industry represent only 17 percent of the installed power in EU (with Switzerland being included with the EU countries in this context.) The combined size of nuclear power industries in all 14 SAPIERR countries is less than that of France or approximately equal to that of Germany.

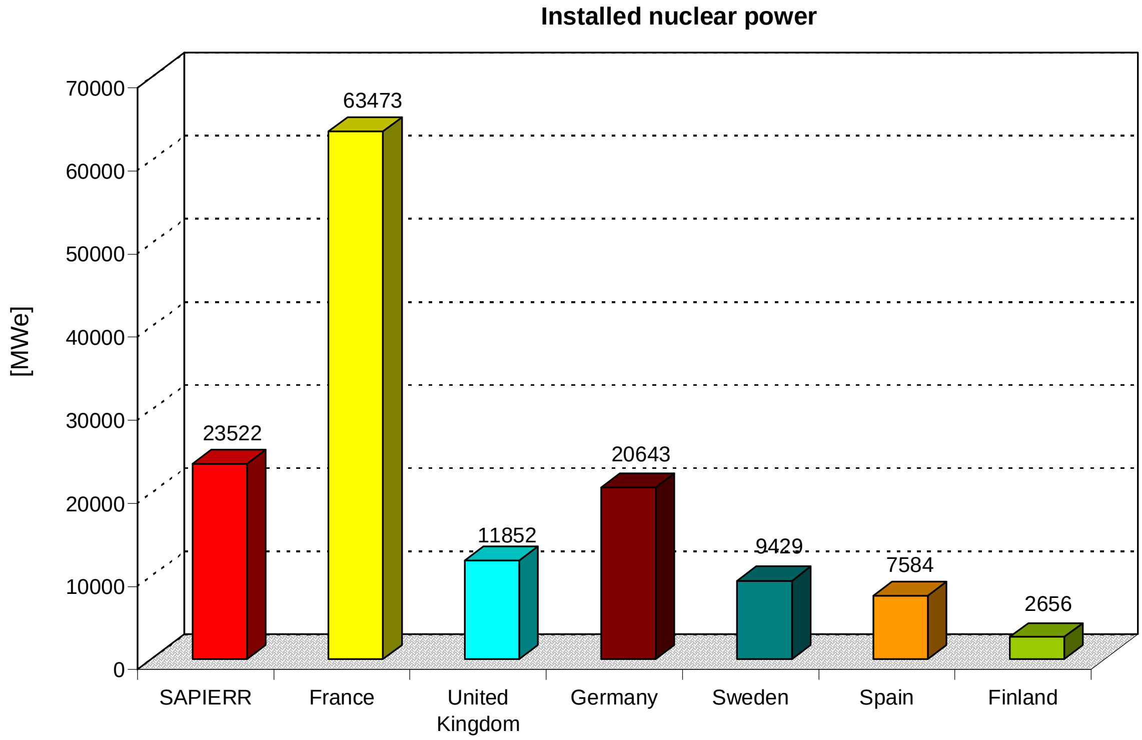

Figure 2 Installed nuclear power in SAPIERR countries in comparison with other EU countries

Out of 14 SAPIERR countries, 10 operate commercial nuclear power plants and another one – Italy – has done so in the past. There is no history of utilisation of nuclear power for electricity production and no plans to do so in future in Austria, Latvia, or Croatia (except formal ownership of 50% of the Krsko nuclear power plant at Slovenian territory).

In order to assess the combined inventory of spent nuclear fuel, high-level radioactive waste, and long-lived intermediate-level radioactive waste from all the SAPIERR countries, certain simplifying assumptions have been made:

- No new nuclear power reactors will be built in the SAPIERR countries.
- The existing ones will operate by the end of their operational lifetimes and will be decommissioned immediately afterwards.
- There will be no plant life extension at the operating reactors.

These assumptions are intended only to give a reference case, and not to reflect expected developments.

3.1 SAPIERR CUMULATIVE INVENTORY OF SPENT FUEL

With the above assumptions, the total spent fuel inventory of all the SAPIERR countries for a potential shared deep geological repository is shown in Figure 3. At present it amounts to 9 260 tHM and on the basis of predictions for individual SAPIERR countries it is estimated that their total spent fuel inventory will be equal to 25 637 tHM in 2040. Country-wise break-down of the total spent fuel inventory available in the SAPIERR countries in 2040 is shown in Table 1.

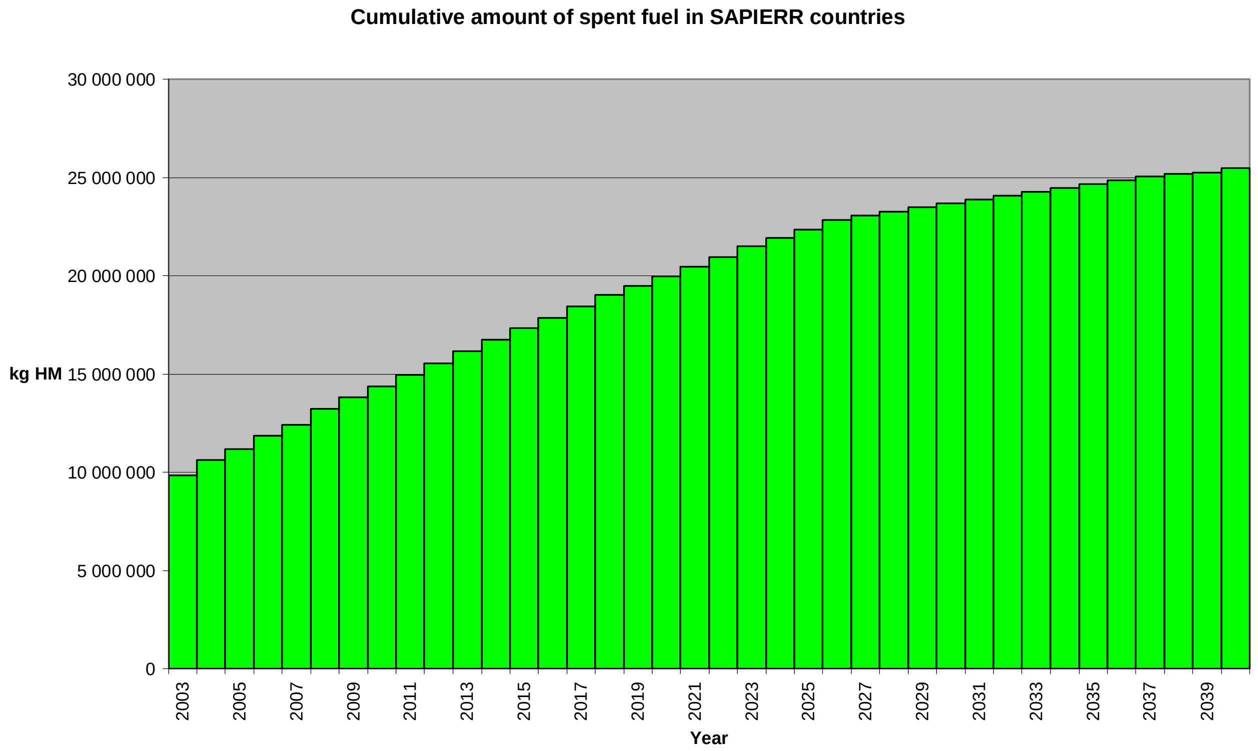

Figure 3 SNF inventory in SAPIERR countries

Table 1: Inventory of spent fuel stored in SAPIERR countries in 2040

Country	Spent fuel inventory [tHM]
Belgium	4 300
Bulgaria	2 039
Czech Republic	3 496
Hungary	1 314
Italy	299
Lithuania	2 504
Romania	5 570
Slovakia	2 375
Slovenia	620
Switzerland	3 120
Total	**25 637**

The combined spent fuel inventory of the SAPIERR countries can be compared to the inventories of the countries with large nuclear programmes, for example France or Germany. At the end of 2002, about 7 200 tonnes of French fuel was stored at La Hague and 3 600 tonnes in EDF's nuclear power plants. An estimate of the amount of radioactive waste generated in Germany is that 9 000 tonnes of spent nuclear fuel will have been generated by around 2020. The total amount of 10 800 tHM of French spent fuel is 10% larger than the current inventory of spent fuel in all SAPIERR countries. Taking into account the policies of individual SAPIERR countries described in the Inventory report [2], it can be expected that also in 2040 the spent fuel inventory of all SAPIERR countries together will be still less than the spent fuel inventory of France alone and will be only about twice as big as the spent fuel inventory of Germany.

Another example of a large size deep geological repository for spent fuel is the facility planned at Yucca Mountain in the USA. The US Department of Energy currently is preparing to submit a license application to the US Nuclear Regulatory Commission for repository construction authorization. The US legislation limits the emplacement of waste at the first geologic repository to 70 000 tHM until such time as a second repository is in operation. The materials that may be disposed at Yucca Mountain include about 63 000 tHM of commercial spent fuel; about 2 333 tHM of defence programme spent fuel; and about 4 667 tHM of defence programme high-level radioactive waste.

The important messages given by the above figures are that all of the SAPIERR reference spent fuel could fit into a single repository smaller than that which France or the USA will need, but that the quantities are high enough to suggest that it could still be economical to implement more than one repository for regional use.

3.2 HIGH-LEVEL WASTE

Five out of the fourteen SAPIERR countries have at least a part of their spent fuel reprocessed. They are namely Belgium, Bulgaria, Italy, the Netherlands, and Switzerland. In all cases, the vitrified high-level waste from the spent fuel reprocessing has been or will be repatriated. For the purpose of this pilot initiative, the volumetric inventory of these vitrification products is estimated.

The total volume of HLW from reprocessing is summarized in Table 2. A relatively small volume of 355 m^3 (excluding container and backfill) would be needed in the potential SAPIERR repository for this type of heat-producing waste.

Table 2: Volume of heat-producing HLW from spent fuel reprocessing in SAPIERR countries in 2040

Country	Volume of HLW reprocessing waste [m^3]
Belgium	75
Bulgaria	30
Italy	10
Netherlands	110
Switzerland	130
TOTAL	**355**

3.3 LONG-LIVED INTERMEDIATE-LEVEL WASTE

In addition to the spent fuel and high-level waste from spent fuel reprocessing, there are some other categories of radioactive waste which are unacceptable for disposal together with short-lived low and intermediate-level radioactive waste. These categories include:

- long-lived waste from operation of nuclear reactors
- long-lived waste from decommissioning of nuclear reactors
- some institutional radioactive waste
- waste from operation of the spent fuel encapsulation facility
- long-lived intermediate-level residues from spent fuel reprocessing.

It is important to have some estimate of the total inventory of such wastes since it would be of little use to SAPIERR countries to have a shared disposal route for HLW and spent fuel – but to still require a national geological facility for other wastes.

Based on these known data, the volumes of other radioactive waste to be disposed of in the potential SAPIERR repository are estimated according to the size of the nuclear industry in individual SAPIERR countries. The data obtained are not fully congruent. This is most probably caused by varying definitions of the waste destined for the deep geological repository, and by whether conditioning and packing has been considered, whether reprocessing wastes are returned, etc. Therefore certain assumptions have been made in the table for some of the countries (higher values than those reported in the questionnaires are shown in Table 3 if the size of the nuclear industry indicates the original value might have been underestimated). These estimates are summarized in the following table.

Table 3: Estimated volumes in 2040 of SAPIERR countries' other wastes requiring geological disposal

Country	Reactors in operation	Reactors in construction	Reactors under decommissioning	Research reactors	Volume of other waste [m^3]
Austria	0	0	0	3	300
Belgium	7	0	0	5	5 000
Bulgaria	4	0	2	1	3 500
Croatia	0.5	0	0	0	200
Czech Republic	6	0	0	5	4 000
Hungary	4	0	0	2	1 500
Italy	0	0	4	5	4 000
Latvia	0	0	0	1	200
Lithuania	2	0	0	0	1 500
Netherlands	1	0	1	3	3 000
Romania	1	1	0	2	2 000
Slovakia	6	0	1	0	2 600
Slovenia	0.5	0	0	1	300
Switzerland	5	0	0	6	2 900
TOTAL	**37**	**1**	**8**	**34**	**31 000**

Based on these considerations, a very approximate figure of 31 000 m^3 of additional space would be required in the potential SAPIERR repository for radioactive wastes other than spent fuel or HLW. Compared to 355 m^3 of heat-producing HLW from spent fuel reprocessing, the volume of these wastes is two orders of magnitude higher. Although the inventory of other waste is significantly lower in terms of radioactivity than the one of spent fuel, its total volume will significantly contribute to determination of the potential SAPIERR repository size.

3.4 DISPOSAL CONTAINERS FOR SPENT FUEL

If the idea of the European regional repository is to be attractive for decision makers, it will have to be not only safe and environmentally acceptable, but also economically advantageous. It has been shown that the costs of the encapsulation of spent fuel assemblies represent a significant portion of the total costs of disposal. Therefore, one of the most important aspects influencing the economy of spent fuel disposal in the European regional repository is cost-effective encapsulation. The possibilities of unifying or standardizing the disposal containers for all spent fuel assemblies types from the SAPIERR countries have been examined. It has been proposed that all the spent fuel assemblies might be loaded into a limited number of disposal containers types, thus potentially reducing enormously the costs of research and development as well as manufacturing.

The analysis showed that all the types of spent fuel from the commercial reactors may be encapsulated into three types of disposal containers. All three of them have the same diameter and wall thickness and they differ only in the length. Consequently, the costs of designing and fabrication of these standard containers should be very effective. It is only the internal spacing grid which is unique for each type of spent fuel assemblies. The standard disposal container is based on the existing preliminary design of the Swiss canister depicted on the Figure 4.

Figure 4: Preliminary design of the Swiss canister for the disposal of spent BWR fuel – possible reference design for SAPIERR disposal container

Assuming various internal profiles of the disposal containers and taking into account the lengths of the fuel assemblies (for details see [3]), the individual spent fuel types could be packaged in an encapsulation plant into three types of disposal containers, with differing lengths. A model calculation of year by year generation of spent fuel disposal packages has been performed. A unified cooling period of 50 years has been taken as input into the calculation. Thus, the oldest fuel from the Beznau I reactor (start-up 1969) will be available for packaging into the disposal containers in 2020 and the newest fuel from Temelín 2 and from Leibstadt will be available for packaging into the disposal containers in 2093. This long time span shows how demanding European repository projects can be, whether they are regional or national. The numbers of all three types of spent fuel disposal packages from SAPIERR countries obtained from the model are depicted in Figure 5.

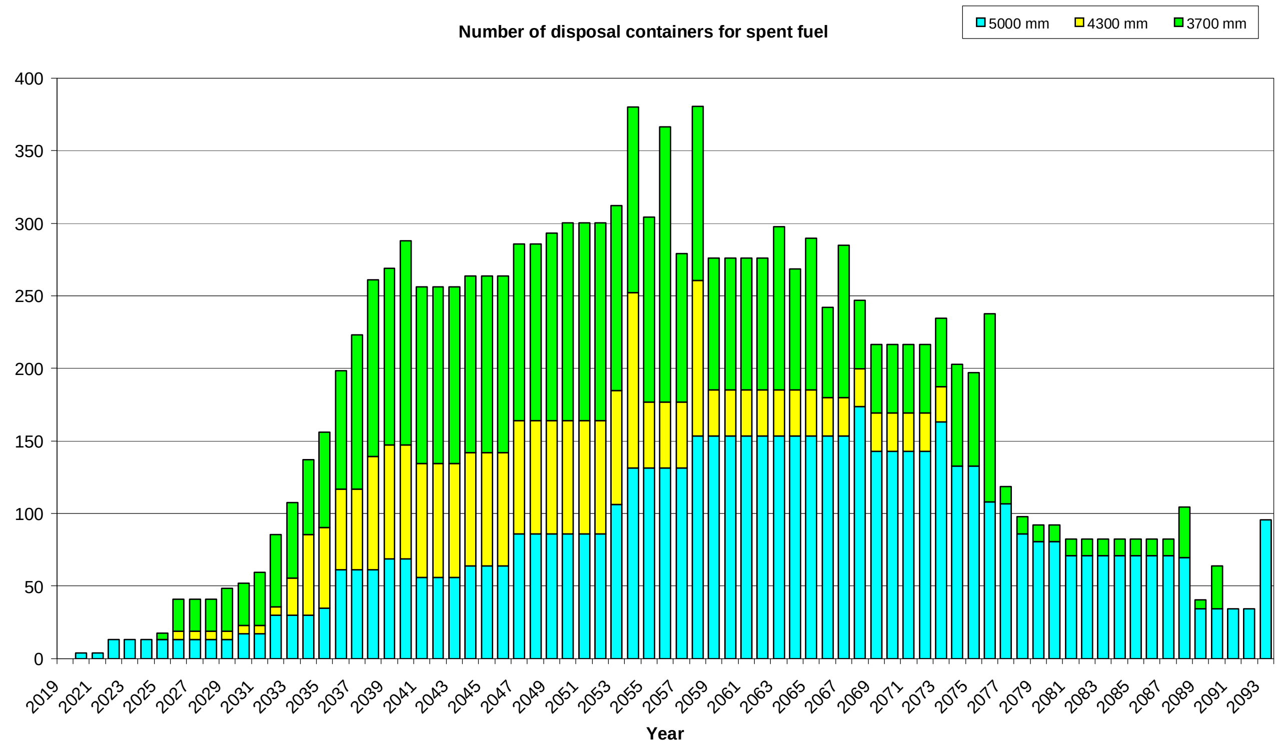

Figure 5: Throughput of encapsulation plant if all SAPIERR spent fuel is packaged after 50 year cooling period

All spent fuel from the SAPIERR countries (under the above mentioned assumptions) can be packaged into altogether 6 061 disposal containers of 5 000 mm length, 2 341 disposal containers of 4 300 mm length and 4 844 disposal containers of 3 700 mm length. The total number of disposal containers of all lengths equals to 13 246.

Similar standardization of packages for HLW and partially also for ILW was assumed in order to analyze options for a single repository for all the waste and separate repositories for spent fuel and ILW in terms of optimum point in time when they should be available and in terms of size and costs.

4. TECHNICAL OPTIONS CONSIDERED

Two possible overarching scenarios exist for the development of a multinational repository. These were described by the IAEA as:

- cooperation scenarios: where several countries agree to develop a shared facility in the territory of one of them;
- add-on scenarios: where an existing and well-advanced national programme offers space in its repository for other countries.

The SAPIERR project has considered only the first of these. It is likely to prove the most appropriate approach for the members of the SAPIERR project. The larger European radioactive waste management programmes have chosen purely national approaches and several European countries have legally excluded the possibility of accepting waste from other countries. International repositories may be conceivable outside the EU; the policy of the EU is, however, to dispose of its radioactive wastes within the Union, so that export to third countries is not a preferred option.

Consequently, the outline designs presented here are for new, shared facilities. Although the designs are based on the concepts and designs of the Swedish, Finnish, Swiss and Belgian repository projects, there is no connection with these national programmes. The possible variants considered for implementation of shared disposal facilities are:

- a single repository for all spent fuel (SNF) and HLW
- a single repository for the above wastes and also for long-lived intermediate level wastes (LL-ILW)
- two separate repositories for SNF/HLW
- one repository for SNF/HLW and a separate repository for LL-ILW.

The option that would be finally chosen would depend upon the size of the inventories, the locations where wastes arise, the possibilities for optimising transports, the economics and the political and ethical issues associated with ensuring fairness to host countries and communities.

Two repository design alternatives have been considered in the study – one for hard rocks (such as granites, gneisses and hard volcanic and sedimentary formations) and one for softer sedimentary rocks (such as less indurated clays and mudrocks). For simplicity, we have used existing designs and considered the issues arising from adapting them to accommodate the large SAPIERR inventory:

- Hard Rocks: the SKB 'KBS-3' repository design for granite and crystalline basement rocks, modified for horizontal package emplacement, as developed in NAGRA project work and also envisaged in the KBS-3H design currently under development at SKB.
- Sediments: the NAGRA Entsorgungsnachweis project concept for horizontal emplacement in clay marls.

4.1 REFERENCE DESIGN: SINGLE SNF/HLW REPOSITORY

Based on the NAGRA concept and SKB concept, assuming reasonable disposal tunnel length (this study has not looked into the specific thermal properties of the SAPIERR inventory) and tunnel plugging at both ends, we have estimated the total disposal tunnel lengths:

- 147 km for sediment: this is equivalent to 491 tunnels of 300 m length;
- 116 km for hard rocks: this is equivalent to 386 tunnels of 300 m length.

Thus the spent fuel and HLW disposal tunnels in the reference model occupy about 5 km^2 and the access and other works could occupy a further 0.5 to 1 km^2, depending upon the most appropriate means of access (shafts or inclines, or a combination).

The SAPIERR reference repository is relatively large at 5+ km^2, so it is likely that this type of geometrical constraint will affect the potential suitability of European sites, especially in complex or laterally discontinuous rock formations and geological environments. Clearly, simpler structural situations would be preferable.

For a regional repository in Europe, as for any national facility, the key siting issues will be more societal than technical. Accordingly, a successful siting strategy must consider both aspects. Learning from national programme successes and failures, some general guidelines for a siting strategy can be laid down.

These include:

1) before trying to identify specific sites, ensure that a consensus has been reached by participants that implementing one or more shared repositories is a common goal;
2) establish the structures and the processes required to assure the agreed level of stakeholder involvement;
3) develop, agree and document – in advance – the broad criteria that the repository must fulfil; avoid, however, over-specification of detailed parameter values;
4) make clear that there is no “safest” option to be found; all alternatives considered must be shown to offer the required high levels of safety; selection of preferred options will be based on simultaneous evaluation of a multiplicity of siting factors;
5) develop, agree and document the technical and non-technical impacts that a repository will have on the host country and community;
6) keep options open (both geological and geographical) far into the process until the chances of successful implementation at the preferred site(s) are very high.

Examination of Figure 5 suggests that, by the middle years of the century, SNF packages might be produced at the rate of 250 – 350 per year, and the repository would need to handle them at this rate to dispose of the whole inventory over a period of 50 – 60 years.

Consideration of the rate of spent fuel arisings shown in Figure 5 suggests that a reference repository operational date should be set at some point on the upward slope that indicates a rapid increase in waste package production, before it reaches its more-or-less constant rate of 250 – 350 containers ‘ready for disposal’ each year (assuming that an encapsulation facility is on stream) – this would thus be between 2031 and 2038. The HLW inventory does not influence a decision on operational date, owing to the comparatively small number of packages.

The approach proposed in the SAPIERR pilot project would avoid the need for a large buffer storage facility for spent fuel. By 2035, about 850 spent fuel packages could be ready for disposal if encapsulation was already available – implying significant storage requirements if no repository is available. A date of 2030 for commissioning of an encapsulation facility thus appears appropriate, allowing 5 years to gain operational experience and handle the small backlog of cooled spent fuel (~300 packages) that will then be available. However, it should be noted that there are already more than 1 100 containers of HLW requiring storage until 2053 and a further ~1 000 will be produce over the next 20 years. There is thus potential for considering a centralised storage facility for HLW that could also accommodate the small backlog of spent fuel packages discussed above.

A reference operational date for the repository of 2035, allowing a reasonable time for site selection, site investigation, construction and licensing of 20 - 25 years (based on experience from those countries with advanced programmes), indicates that the siting programme should be underway by 2010 - 2015. It is clearly not too early today to be thinking about the steps that will be required before that to plan the approach and establish the terms of co-operation between partners in a shared repository project.

Three main options present themselves for the location of encapsulation facilities:

- at the repository site(s);
- at a separate facility or facilities, not at the repository site(s);
- at the reactor or storage sites, if encapsulation is in multi-purpose containers.

For an encapsulation facility at the repository site, packages can be manufactured, stored in an adjacent buffer storage building and transferred directly to the repository at the appropriate time. The whole complex can be designed so that no off-site movement of waste packages is required. SNF/HLW need only be transported once – from reactor/store to encapsulation plant.

Separating the encapsulation facility from the repository site has the potential advantage of uncoupling the encapsulation programme from the selection and licensing of the site of the repository, which is often a difficult step in overall disposal programmes. Providing that an encapsulation system can be identified that is suitable for any of the potential sites, encapsulation can commence at a time, and proceed at a pace, that accounts for practical and economic considerations of waste arising rate and storage needs. The option of multiple encapsulation plants could facilitate production of different packages at different plants – to serve different regional requirements, for example. In this option, waste would have to be transported twice: from reactor/store to encapsulation plant and then on to the repository site.

If a repository design option is selected in which SNF/HLW are disposed of in multi-purpose containers (MPC) – for example, in caverns that are subsequently backfilled – then 'encapsulation' in MPCs can take place at each reactor site or HLW waste store. Disposable MPCs that could be used for storage, transport and disposal would need to be developed and the cost implications of this option (development and container costs) have not been considered in this project. SNF/HLW need only be transported once – from reactor/store to repository site.

In all of the above models, all SNF and HLW must be brought to the encapsulation plant and/or repository from nuclear power plants and stores across Europe. Locating the repository and encapsulation facility so as to take advantage of a harbour and good links to the European rail network is obviously advantageous. The flow of SNF transports into the facilities would be almost continuous – a daily occurrence – for several decades. Given this volume of traffic, rail and sea (or river) transport is preferable to road transport in terms of environmental impact and social acceptability.

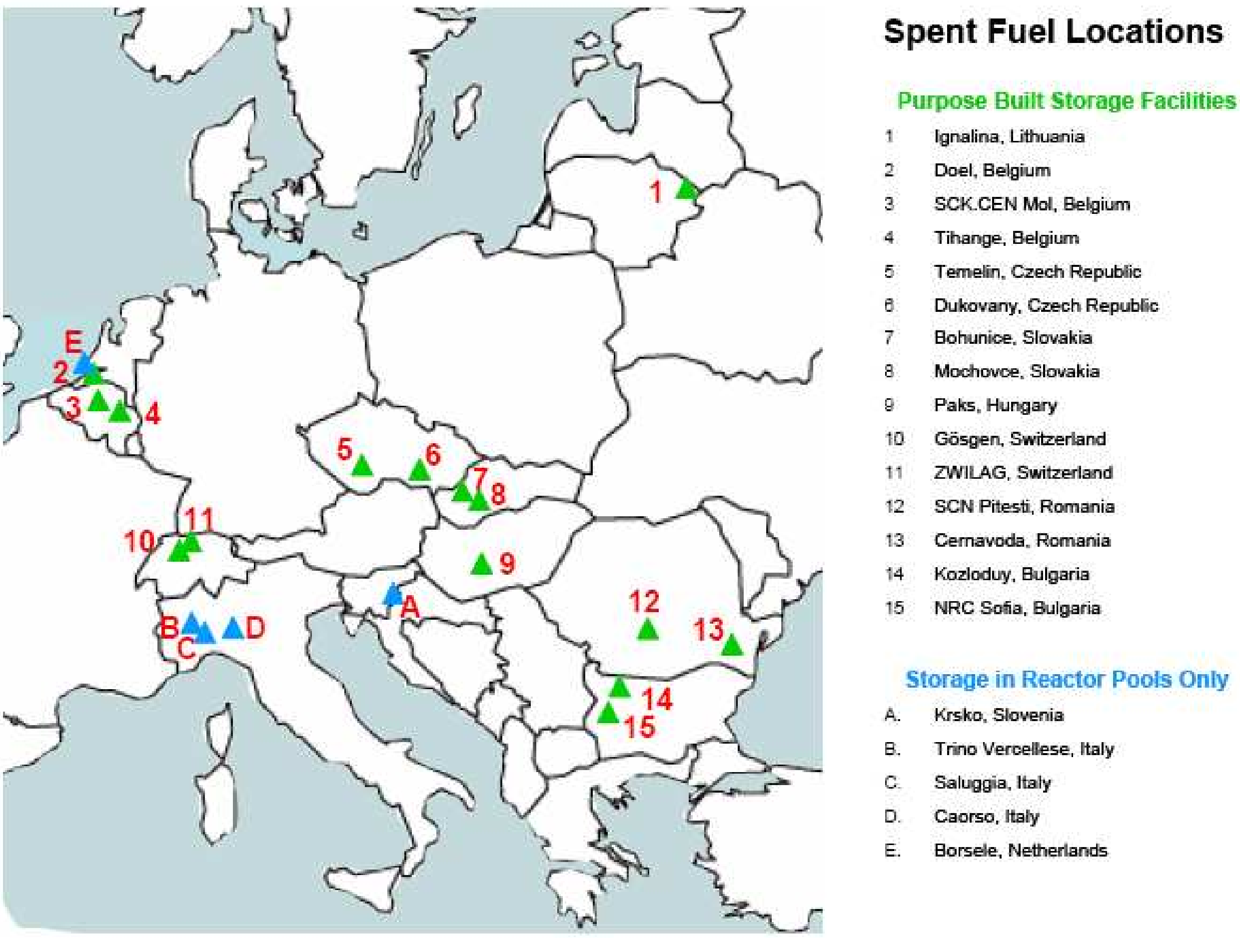

Figure 6: Location of SNF stores in the SAPIERR countries. Note that only sites where extended storage is foreseen are shown. Power reactor sites with fuel cooling in ponds and research reactors where the fuel is moved off-site are not shown.

Figure 6 shows the location of SNF stores in the SAPIERR countries. It is clear that the sources are widely spread and it would be impossible to make use of only one mode of transport. Although it could be possible to use local transfer stations for sea transport for some countries (or groups of countries), this would only be useful if the repository itself (or encapsulation facility) had good rail links with a harbour or was located near the coast.

The rough costs of a SAPIERR repository have been estimated by scaling from mixed data from other national programmes. This is of course approximate since national programmes include differing cost items. The indicative repository costs (excluding encapsulation) for the SAPIERR SNF and HLW inventory are:

- 5 billion EUR (hard rock)
- 6.5 billion EUR (sediment)

4.2 REFERENCE DESIGN: SEPARATE ILW REPOSITORY

The SAPIERR LL-ILW inventory comprises 31 000 m^3 of conditioned wastes. SKB hard rock design suggests that a rough factor of between 3.5 and 6 could be used to convert waste volume to cavern volume. For the SAPIERR inventory, a factor of 5 would lead to a requirement for about 150 000 m^3 of cavern space, or approximately four SFL3-type caverns of ~140 m length (560 m total).

The NAGRA LMA-1 design for clay suggests a factor of about 2 (cavern / waste volume) to be more appropriate. A more direct comparison of just the waste volume with that of NAGRA shows a total length of disposal cavern of about 1 050 m would be required for the SAPIERR inventory.

The hard rock design requires a smaller length of tunnel but a larger excavated volume than the sediment design. Construction (excavation and rock support) in hard rocks is more straightforward than in many argillaceous environments. The difference between a 560 m length of cavern in hard rock and a 1 050 m cavern length in sedimentary formations is thus a significant discriminator on the grounds of practicality. A design similar to that of NAGRA with, say, ten 105 m long caverns accessed from a single, long operational tunnel for the SAPIERR inventory would occupy an area of about 192 000 m^2, a factor of 2.3 times larger than for the hard rock design. Owing to the requirement for gently curved and angled tunnel designs in sediments (compared to the orthogonal intersections possible in stronger rocks), the access works for a sedimentary rock repository are also likely to occupy more space.

The times of arising of LL-ILW from reactor operation and decommissioning (and the operation of HLW/SNF stores and encapsulation plants), will be spread widely over the next decades and are dependent on the planned operational lives of facilities, refurbishment and plant-life extension possibilities. In the SAPIERR project, we have not attempted to produce a time sequence plot of arisings, as we did for HLW and SNF.

From the viewpoint of timing, it would be preferable to have a disposal facility available at the time of waste arising, in order to avoid having to provide national storage. Significant 'new' waste arising comes with NPP decommissioning: national stores exist for operational wastes. The shielded storage buildings that are needed for some of these wastes (e.g. HABOG in the Netherlands and ZWILAG in Switzerland) represent major investments and present possible siting problems. If these problems and costs can be avoided by provision of a shared repository, this would benefit all user countries.

Consequently, we assumed that it would be of most value to have an operational LL-ILW repository before any substantial decommissioning starts to occur. Section 4.3 suggested an operational date for a SNF/HLW repository of 2035, with the likely requirement for a centralised storage facility for the earlier HLW arisings and a small backlog of SNF that would exist by then. A much earlier timescale would be appropriate for a LL-ILW repository as most of the SAPIERR countries nuclear power plants will be in decommissioning long before 2035 (see Figure 7).

This figure suggests a fairly steady rate of LL-ILW waste arisings from decommissioning over at least the next 20 years, at which point there is a peak, as seven NPPs finish operation in 2025. If a repository is not available, then the wastes (both accumulated operational wastes and those from past and near-future decommissioning) will have to continue to be stored in a dispersed fashion (possibly with requirements for extended size in future at existing stores) or making use of the suggested central store for HLW-SNF.

There is thus an argument for considering a shared LL-ILW repository immediately, if future storage costs are to be reduced. This suggests early implementation of a LL-ILW repository may be useful, even if a later HLW/SNF repository also includes LL-ILW.

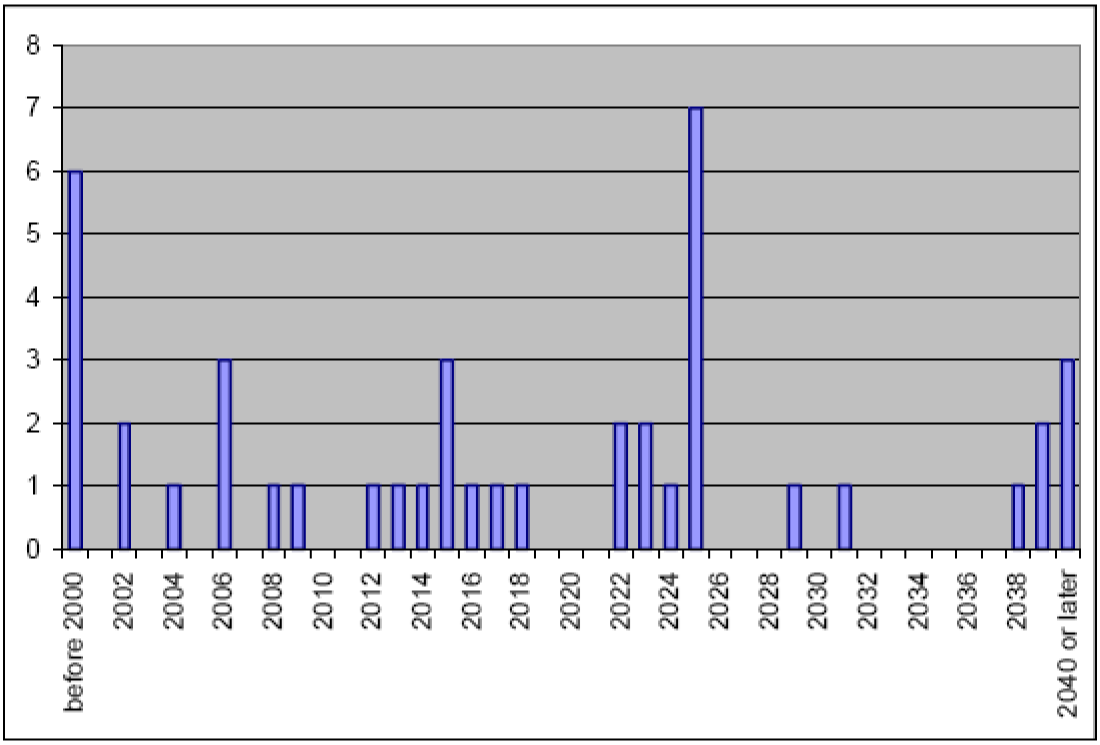

Figure 7: Number of nuclear power plants in SAPIERR countries ceasing operation and assumed, for the purposes of this study, to enter decommissioning immediately.

Since only SKB data have been used to develop a scaled estimate of the costs for the LL-ILW repository, only costs for the hard rock option have been calculated. Within the project constraints we have not been able to obtain sufficiently clear data on the sediment option.

The SKB data for the SFL 3-5 facility are complicated as they assume that it is co-located with the spent fuel repository. Consequently, the siting and some of the access costs are convoluted with those of SFL 1. Nevertheless, using the data that are applicable, making some assumptions about costs shared between SNF and LL-ILW repository development, and scaling by waste volume, we derived an estimate of the total cost of about 804M EUR for SAPIERR wastes.

This compares with the incremental cost provided by SKB for co-disposal with SNF, of about 63M EUR. However, the latter appears simply to cover underground construction, operation and closure and it is not known whether this number includes any R&D costs (it does not include any underground access or surface facilities). Nevertheless the considerable cost savings of co-location are apparent, despite these uncertainties. The main saving is clearly siting costs – about 27% of the estimated total for SAPIERR. For the co-location increment on stand-alone HLW/SF repository cost, we thus assumed a reasonably conservative figure of 25% of the stand-alone LL-ILW repository cost (i.e. about 200M EUR).

It can be seen that, when scaling with the SKB data, the cost of a stand-alone LL-ILW repository for the SAPIERR waste is 12-16% of the cost of a SAPIERR SNF/HLW repository, for the hard rock and sediment options.

4.3 ECONOMIC ASPECTS

One of the strongest drivers for shared repository concepts is the potential economic advantage. The economics of scale are obvious both for encapsulation plants and, even more so, for repositories. In both cases the fixed costs are high and can be better amortised with a high throughput.

We have compared diverse international cost estimates that have been published for spent fuel and found a broad consistency. The unit cost of disposal of SNF ranges from 80’000 to 1’200’000 EUR/t with the most common values from 300 000 - 600 000 EUR/t.

Of course, the unit costs vary with the size of the inventory, i.e. there are economies of scale. To illustrate the economy of scale in large repositories, one can plot the total costs against SNF inventory on a double logarithmic scale (Figure 8) and then fit an approximate straight line which indicates that the costs increase with the n^{th} power of the tonnage, where n is 0.6, i.e. less than directly proportionally. The figures plotted have removed the allowances for R&D and for contingencies. Of course, extrapolating linearly to very low tonnages of SNF will become increasingly unrealistic, since the fixed costs associated with a repository programme will become increasingly important at low inventories. Nevertheless, the derived relationship indicates that doubling the inventory will increase the costs only by a factor $2^{0.6} = 1.5$. The scaling results from these rather diverse cost estimates are confirmed broadly by specific cost calculations done in Canada. For a repository in which only the inventory changes, doubling the number of spent fuel bundles to be disposed of from 5M to 10M increased the overall costs from 10.2B CAD to 15.3B CAD i.e. by a factor 1.5.

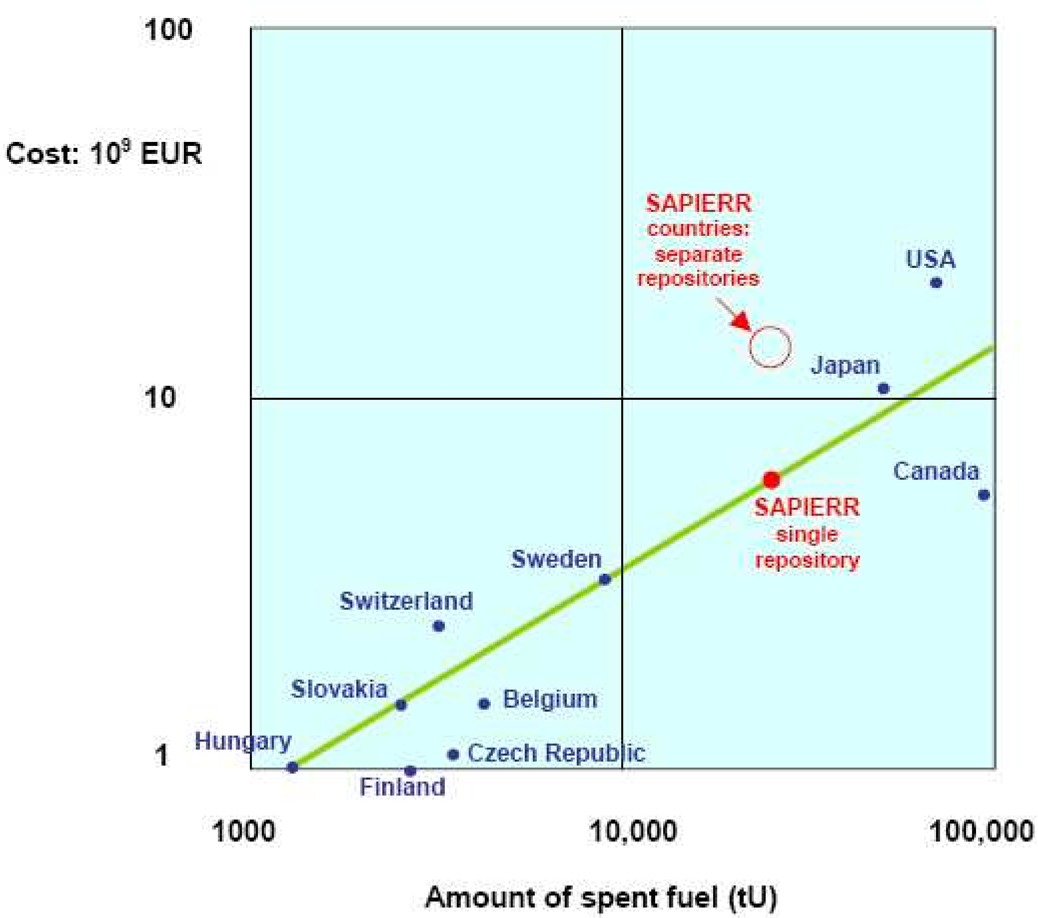

Figure 8: Deep Repository Costs as a Function of Quantity (Spent Fuel only)

Plotting the 10 SAPIERR countries with nuclear power independently on the averaged straight line of Figure 8 and summing the costs gives a total of 14B EUR. Using the same approximate relationship a single repository for the 25 637 tonnes of SAPIERR country spent fuel gives a cost of 6B EUR. This figure agrees fairly well with the specific estimates of 5.0B and 6.5B EUR derived for a single SNF/HLW SAPIERR repository. The apparent savings by implementing one rather than 10 repositories are thus 7-9B EUR in this approximation. These substantial savings could result from cooperative initiatives to implement a common repository. A further key point is that the multiple purely national facilities approach still leaves the non-nuclear power countries looking for a solution for disposal of long-lived wastes.

5. A POTENTIAL SCENARIO FOR REALISATION OF A REGIONAL REPOSITORY IN EUROPE

A potential scenario for realisation of a European regional repository has been postulated by the SAPIERR project. It is a "partner scenario" which is laid out below as a series of sequential steps. It is interesting that they do not differ greatly from steps taken within a federally organised state to seek a national disposal solution. A very preliminary timescale is suggested for each step.

Step 1: Pilot feasibility studies (now – 2010)

Step 2: A formalised study consortium (2008 – 2012)

Step 3: A dedicated Regional Repository Project Team (2010 – 2015)

Step 4: Siting studies leading to candidate siting areas in different partner countries (2015 – 2025)

Step 5: Establishment of a Business Consortium or a Joint Venture (2020)

Step 6: Establish a construction and operation company (2025)

Step 7: Repository operation (2035 – 2095)

Step 8: Closure and post-closure (2095 – indefinite)

The kernel of the problem lies of course in the siting issue. However, this is also a difficult problem in national programmes – but has not prevented local communities in some countries agreeing to host repositories. In Europe, exchanges of all goods and of people are continually increasing between EU Member States. Industrial facilities providing services to all countries are not uniformly spread across the community; nor are mining operations nor even toxic waste disposal facilities. It is conceivable that well designed, high-tech, safe repositories could ultimately be implemented on a multi-national basis. It is important to ensure that partnering concepts do not fail at an early stage by trying to force the premature identification of a site or sites. As in successful national programmes, multiple siting options should be maintained over a long time and the ultimate selection of preferred sites should be an open process in which all technical, societal, economic and political issues are tabled simultaneously. This is why SAPIERR has been a "Siteless Pilot Project".

6. RTD REQUIREMENTS

A major objective of the SAPIERR pilot study was to identify areas in which further research and technology development could help to progress further multinational repository concepts in Europe. The proposals developed can then be assessed, evaluated and ranked within the EC framework in order to allocate future support funding.

It is acknowledged that various technical activities proposed are already being tackled at national level in countries interested in region approaches. They are, nevertheless, included here if it appears that they could be effectively coordinated in a co-operative regional European approach. It is also recognised that some of the cooperative efforts mentioned have already been identified within the EC as being of value for all EU countries involved in geological disposal, independently of whether they are pursuing national, dual-track or purely regional strategies towards final disposal.

The following requirements have been defined:

- TECHNICAL AND ENGINEERING REQUIREMENTS
  - Improvement/coordination of national inventories
  - Encapsulation of spent fuel or HLW
  - Conditioning and packaging of other long-lived wastes
  - Design of repository systems for multinational use
  - Transportation studies
- GEOLOGICAL AND ENVIRONMENTAL STUDIES
  - Safety Studies
  - Compilation of siting criteria for geological repositories
  - Integrate geological screening studies from SAPIERR countries
  - Contribution of investigations in underground laboratories
- SOCIO-POLITICAL STUDIES
  - Public attitudes to geological disposal and to shared repositories
  - Harmonisation of legal and regulatory issues
  - Compensation of hosts
  - Review of current exchanges of toxic wastes in the EU
- INSTITUTIONAL FRAMEWORK
  - Security of storage and disposal facilities
  - EU legal and legislative study
  - Structures for a multinational disposal organisation
  - Costs and Financing
  - Coordinated project planning

The top priority items are related to the institutional framework to be established since increased activities could then be set into an overall systematic approach. Thus, the top priorities are the proposals to coordinate national plans of countries interested in regional solutions and to establish efficient, transparent structures for guiding and executing future project work. At the closing seminar of SAPIERR in Brussels in November 2005, these suggestions were discussed, based on the more extended explanations in Reference 3. A selection of the possible research topics was included in a draft proposal for a follow up project to SAPIERR. The exchange of views at the meeting indicated that there was significant support for moving ahead to structure a true multinational disposal organisation. However, there were still reservations about becoming too site specific in the next phase of work; integrating geological studies from EU countries was therefore judged to have lower priority. Items that were thought more urgent were assessment of public attitudes to multinational repositories and better quantification of the financial issues involved. Undisputed is the view that a structured formalised EU project organisation studying the possible implementation of a European repository should have a secured place on the international stage alongside the waste management agencies of countries with purely national disposal programmes.

7. CONCLUSIONS

The following points highlight the top level conclusions to be drawn from the SAPIERR project.

- The potential benefits of multinational, regional repositories are recognized widely throughout the EU, as evidenced by the participation in SAPIERR of numerous organisations from 14 different countries in Europe.
- The most obvious benefits are in the economic area where shared repositories would lead to substantial reduction in expenditures throughout the Community. Even with the current rough estimates of disposal costs, it is apparent that savings of several billion Euros could be achieved or that the total costs may be reduced by about half.
- Many or most of the problems faced by regional repository initiatives are common to those to be tackled by national disposal programmes. In particular the task of siting the facility is, in both cases, challenging. Time must be allowed not only for technical preparations but also for achieving the necessary degree of public and political consensus.
- If shared regional repositories are to be implemented, efforts must be increased already now. The optimal dates for implementation of shared facilities are around 2030 for an encapsulation plant and 2035 for the repository operation. Experience in national programmes show that the implied 3 decade lead time has been often necessary. If earlier implementation is the goal (as suggested in first Waste Directive drafts) then correspondingly greater efforts are required.
- Before greatly enlarging the scale of the work on regional repositories, a structured framework should be established. This can, in principle, be done by cooperation of individual Member States in the EU. However, start-up funding, organisational support and guidance by the Commission would greatly ease this process and bring forward the date at which a self-sufficient, joint undertaking type of organisation could be established.
- The EU countries with small nuclear power programmes, or only radioactive wastes from other sources, should continue their efforts within the EU to establish the shared regional repository concept as being no less valid, important or urgent than the purely national disposal projects being pursued in some Member States.

SAPIERR succeeded in its objectives to bring together the interested representatives from multiple countries and to outline the issues associated with the potential European regional repository including the proposal for further RTD under the European Commission Framework Programmes. More information on the SAPIERR project, its history, events, and all published documents can be found on the project dedicated website: **www.sapierr.net**.

REFERENCES

[1] Christina Boutellier, Charles McCombie: Legal Aspects, SAPIERR report – deliverable No.2, August 2004, http://www.sapierr.net

[2] Vladan Stefula: Inventory, SAPIERR report – deliverable No.1, September 2004, http://www.sapierr.net

[3] Neil Chapman, Charles McCombie, Vladan Stefula: Possible Options and Scenarios of Regional Disposal and Future RTD Recommendations, SAPIERR report – deliverable No.3, September 2005, http://www.sapierr.net