Multinational European Nuclear Waste Disposal: Looking Off-Shore – 14099

Hans D.K. Codée and Ewoud V. Verhoef
COVRA N.V., P.O. Box 202, 4380 AE Vlissingen, The Netherlands
hans.codee@covra.nl and ewoud.verhoef@covra.nl

ABSTRACT

Radioactive waste generally has a small volume. Therefore it can easily be controlled and contained, but it has the disadvantage of a negative effect on the economy of scale. Geologic disposal facilities for long-lived waste are expensive to construct and operate for small quantities of waste. The economy of a national solution could strongly be improved by multinational co-operation.

For the long-term management of high-level waste only geologic disposal is acceptable. Hence, any country with whatever minute quantity of waste has to find a disposal site. Site selection has always been done for land based locations and within national borders. National borders are however meaningless on the timescale of a hundred thousand years to be taken into account for a disposal facility. Looking at land based locations only might be an unnecessary limitation, realizing that most of our globe is covered with water. For an off-shore site, a geologic disposal facility is meant here and not sub-seabed disposal.

In Europe there are quite some countries with small amounts of high-level waste, such as Denmark, Norway and the Netherlands all bordering the North Sea. These countries could co-operate with other countries with larger quantities of waste and create a European multi-national solution. The creation of an artificial island in the North Sea could be considered as entrance to the disposal facility and the island could host also other activities.

INTRODUCTION

The broad civilian use of nuclear power started in 1953 with the “Atoms for Peace” program. Many research reactors were built in the fifties and operation of power plants followed, starting in 1954. Apart from the waste related to military programs, waste has been produced at least during some 60 years.

In the same period important developments took place in environmental thinking. In the early years ‘dilute and disperse’ was generally used as an answer to emission and waste management. This unfortunately still is the case for worldwide CO_2-management. Since 1979 the Lansink’s ladder principle: “reduce-reuse-recycle-disposal” [1] and since 2002 the cradle to cradle principle [2] are leading concepts in waste management. Environmental footprints can generally be reduced when processes are optimized with respect to quantitative production elements.

The energy contained in fissionable elements is enormous. With just small volumes of material huge amounts of energy can be produced. The resulting waste is also small in volume, yet potentially very dangerous. The limited volume is an advantage because it can therefore easily be controlled and contained. But this has also a disadvantage because of the negative effect on the economy of scale.

Inherent with the manifestation of its dangerous radiation, radioactive waste will decay and hence lose its dangerous properties. The largest volume of waste, the low level waste, will lose its dangerous properties within some 300 years and can easily be kept out of our living environment. National solutions for this type of waste can be developed and operated economically. For the management of long-lived, intermediate, and high-level waste (this includes spent fuel declared as waste) there is no other option available than geologic disposal [3]. Hence any country with whatever minute quantity of this waste is obliged to find a disposal site. Geologic disposal facilities are expensive to develop and construct as well as expensive to operate. Managing the small quantities of long-lived, intermediate, and high-level waste presents large challenges in terms of economics.

Almost all elements of the nuclear fuel cycle are executed as international activities. Economics are strong drivers herein. Mining and milling of uranium, enrichment, fuel fabrication, nuclear electricity production, medical and other industrial isotope fabrication, recycling of used fuel, recycling of low contaminated metal scrap and a few other waste treatment options, all of them are operated cross-border. Radioactive waste disposal however is generally seen as a strictly national activity. This in spite of the fact that there are operating examples of disposal facilities for conventional, toxic waste that accept wastes from abroad.

EUROPEAN CONTEXT

All twenty-eight member states in the European Union (EU) have radioactive waste. Fifteen Member States have nuclear power plants. Twenty-two Member States have or had nuclear research reactors and all 28 Member States use radioactive materials in industry, health care and research. Hence, the quantities of radioactive waste per country show enormous variations, both in quantities and in characteristics. However, whether small and easy to manage in quantity and radiological risk, or large and multiple in risk, today’s generation has the moral obligation to take care of the waste. This means: to take actions that will prevent undue burdens to future generations. The responsibility to take actions is primarily the responsibility of each Member State, taking into account the polluter pays principle and international safety and security principles. In practice this means that programs are being developed at national level.

Since 2011 an overarching structure has been imposed in the EU. The EU Council Directive 2011/70/EURATOM, establishing a European Community framework ("Waste Directive") for the responsible and safe management of spent fuel and radioactive waste resulting from civilian activities, was adopted on 19 July 2011 and entered into force on 22 August 2011 [4].

As a key obligation under this Waste Directive, EU Member States shall ensure the establishment, maintenance and implementation of a National Program covering all aspects of spent fuel and radioactive waste management from generation to disposal. In short the National Program can be identified as an answer to the questions:

- *What radioactive waste and spent fuel do you have;*
- *What are you doing/going to do with it; and*
- *When are you going to do it?*

The main function of a National Program is to show how the national policy is transposed into practical solutions. For each Member State its national legislative, regulatory and organizational framework forms the "infrastructure" for the implementation of the program. Thus, policy-making, national framework and National Program are bound in a cohesive system.

The main role of a National Program is to serve as the key tool and basic reference for the respective national actors dealing with the practical implementation of national spent fuel and radioactive waste management policies.

TABLE I. Nuclear power in Europe and the US as of November 2013 [5]

Country	**Number of units**	**Nuclear capacity (MWe)**
Belgium	7	5,927
Bulgaria	2	1,906
Czech Republic	6	3,804
Finland	4	2,752
France	58	63,130
Germany	9	12,068
Hungary	4	1,889
Netherlands	1	482
Romania	2	1,300
Slovakia	4	1,816
Slovenia /Croatia	1	688
Spain	8	7,567
Sweden	10	9,474
Switzerland[a]	5	3,308
United Kingdom	16	9,231
Total Europe	**137**	**125,342**
United States	**100**	**98,560**

[a] Non EU member

US CONTEXT, THE BLUE RIBBON COMMISSION

In the US a development can be seen that parallels European developments. The 2012 advice of the Blue Ribbon Commission on America's Nuclear Future (BRC) [6] mentions comparable elements as the requirements for a National Program of the EU member states. The above given key question: *"What radioactive waste and spent fuel do you have and what are you doing / going to do with it and when?"* was answered by the Co-Chairman of the BRC as: *"We know what we have to do, we know we have to do it, and we even know how to do it."*

In the US in principle only one or perhaps two disposal sites are being considered. This is interesting to observe because the scale of use of nuclear power plants in Europe and in the US is comparable. In the US 104 nuclear power plants are in operation and 137 are in operation in Europe.

WHY MULTINATIONAL EUROPEAN DISPOSAL?

National activities in Europe are strongly influenced by the European context. Cultures vary widely but the national economies are not isolated and the European environment does not stop at national borders. As can be seen from table 1 seven countries have a modest nuclear power program with an installed capacity lower than 2000 MWe. Thirteen Member States of the EU do not have a nuclear power program and twenty-two have or had research reactors. Compared with both the physical size of the US and the nuclear power program in the US where only one repository might do, the conclusion could be drawn that also in Europe one single disposal facility would be sufficient. This would require an ultimate European attitude of all Member States. This in practice is not the case, but at least an effort could be made to share on a regional basis a disposal facility.

There are two main reasons to share a geologic disposal facility among European nations. Firstly: a multinational facility might be a better facility and secondly the timescales to be considered for a geologic disposal facility are so long that national boundaries or national entities are meaningless.

In Europe there are twenty countries with a modest nuclear power program, or with a limited and decisively ending program, or with only medical and research activities. These twenty countries will be called hereafter 'modest nuclear countries'. For these modest nuclear countries a multinational facility will most likely be a better facility with respect to:

- ***Economy***
  International practice until now has shown that R&D for a period of at least 30 years, siting, construction, commissioning and operation of a geologic disposal facility is very costly and will cost at least a few billion Euros (or US dollars). A simple calculation shows that 30 years operation of 1000 MWe with an operational efficiency of 80% and a fee of 0.1 cent per kWh for financing disposal will result in a fund of only 0.2 billion of Euros or US dollars. Clearly this is not enough to finance a geologic disposal facility. Thus a nuclear power program of 1000 MWe cannot afford a disposal facility after 30 years. An increase of at least a factor 10 has to be found. Solutions can be: increasing the installed capacity, increasing the operational lifetime, increasing substantially the cost per kWh and increasing the interim storage period while the obtained capital really grows in a capital fund. The economy of scale for a national solution could be strongly improved by

multinational co-operation and sharing the costs of a disposal facility. For modest nuclear countries the economy of scale cannot only be improved for disposal of high-level waste and spent fuel but also for other provisions in the management system. When taking an inclusive view on the nationally required provisions for waste management, this means including treatment facilities, temporary storage facilities and disposal facilities for low level waste as well as intermediate- and high-level waste, then multinational co-operation could mean that more facilities are shared and divided over the participating countries.

- ***Technology***
  The technological knowhow and capabilities will be limited for the modest nuclear countries, but are required for a long time for the implementing organization, supporting organizations, regulatory infrastructure and inspectorate. Maintaining the knowledge and competences will be especially difficult when the nuclear power activities come to an end while dismantling as well as preparing for a disposal facility is still to be done. The commissioning and operation of the disposal facility might take place in a period that practical knowhow in nuclear facilities has disappeared. Knowledge management and conservation of knowledge in the years directly after closure of the facility has possibly to be done by a workforce with no practical experience in a nuclear environment. The national solution will then have to rely heavily on expertise from other nations. Such a policy might be scrutinized for its credibility.
- ***Safety***
  The chain of nuclear safety is only as strong as the weakest link. Not only national, but global nuclear safety must be ensured. The limited resources in modest nuclear countries may not always sufficient to ensure the highest standards in safety design. Other countries even might not have suitable geology for a disposal facility. Sharing a facility is then a must to maintain global safety. In a multinational facility standards of participating countries will be harmonized to the highest level and so improving achievable safety levels. With a wider choice of geological conditions and increased technical potential the safety will be improved and environmental impact will be decreased.
- ***Security and non-proliferation***
  What was written above for global safety is also applicable for security and non-proliferation. Security and non-proliferation need a multinational approach. This is automatically ensured in a shared facility. If all intermediate and high-level waste ends up worldwide in a limited amount of facilities this will release the burden on international control for the long term, surveillance will be simplified.

The second argument why multinational disposal should be a preferred option for modest nuclear countries is that state boundaries and national entities are meaningless on the time scales considered for disposal. How boundaries changed within the period 0 – 2000 is shown in figure 1.

The EU Waste Directive mentions in its preamble:

“Some Member States consider that the sharing of facilities for spent fuel and radioactive waste management, including disposal facilities, is a potentially beneficial, safe and cost effective option when based on an agreement between Member States concerned.”

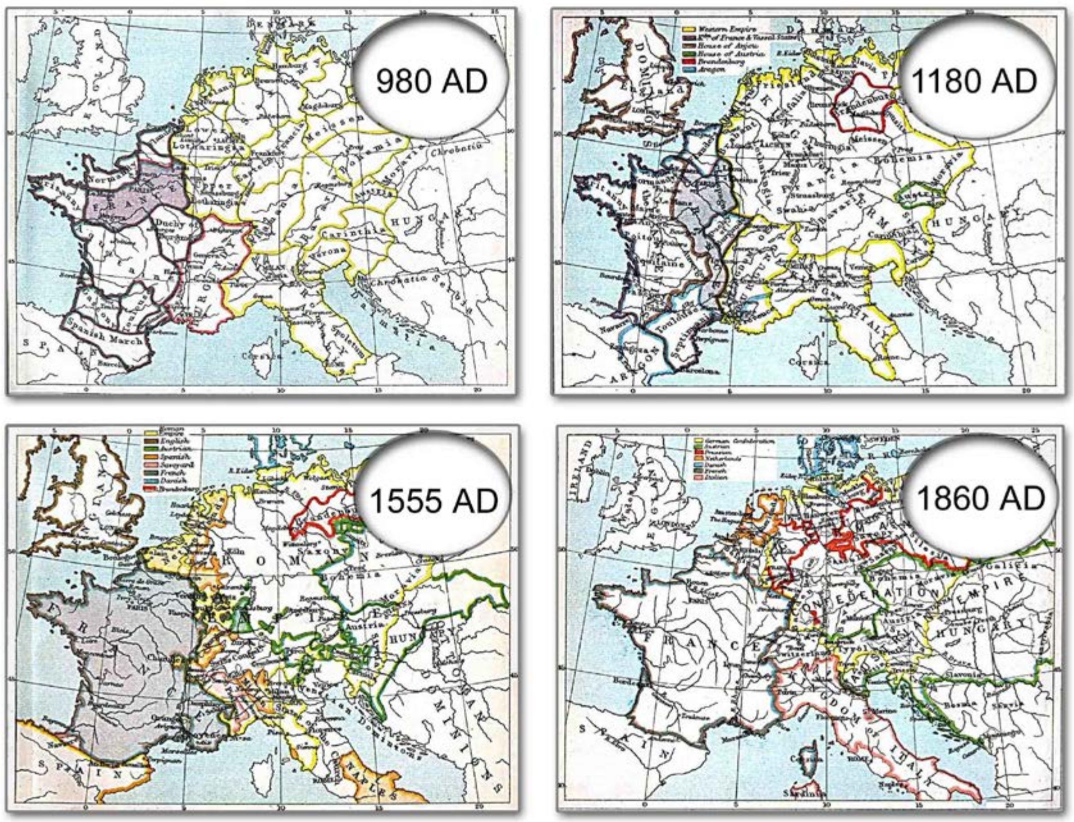

Fig. 1. Maps of Central Europe in 980, 1180, 1555 and 1860 AD showing the changes of national borders in time [7]

In article 4 of the Waste Directive this is translated in legal requirements. In the National Program shared disposal can be included as an option. Various actions have taken place in the past to study the merits and challenges of shared solutions. ARIUS and SAPPIER can be mentioned here [8]. The working group ERDO (European Repository Development Organization) promotes and assists to set up a dual track approach in the National Programs [9]. In such an approach Member States take their responsibility by working on a national solution as a first track, but this can be optimized in the second track with a multinational shared solution.

To be successful in sharing a disposal facility, agreement between participants is needed on technical issues such as clarifying that the import of waste is for disposal and not just for storage. Disposal will not be restricted to spent fuel but must also be foreseen for all long-lived wastes. Furthermore there should be economic advantages to all partners and disposal services should be continuously guaranteed. Partners need to agree on financing, management structure, responsibility, use of knowledge and experience among many other things. Although not easy, these practical things can be arranged between nations. Even more challenging will be the site selection process.

WHY LOOKING OFF SHORE?

For the site selection the multinational use has to be accepted by the local as well as by the national and global community. Full support of the EU and other international organizations such as IAEA is a prerequisite.

Finding a site for a nuclear activity is generally not an easy task, neither for a national solution nor for a multinational solution. When the whole cycle of waste management facilities is taken into account then sharing different facilities in a multinational setting can also mean that the burden, as it is felt in society, is shared by all. Both burdens and benefits can be shared, which can enhance the feeling of fairness. Treatment can be done in country A, disposal of low level waste in country B, long-term storage for cooling of spent fuel in country C and disposal of high-level waste in country D.

Specifically when siting a geologic disposal facility, the local community will look for benefits to them. It is seldom enough to get just acknowledgement that there are many activities needed on a national level that will bring locally some disadvantages and that these activities have to be spread over the country. Apart from just financial compensation it is not easy to find long lasting site specific benefits.

Up to now, site selection has always been done for land based locations and within national borders. As described earlier national borders are however meaningless on the timescale of a hundred thousand years and more to be taken into account for a disposal facility. For the land based locations there is the alternative to look off shore. Realizing that some 70 per cent of our globe is covered with water, this might result in attractive options for site selection. Furthermore, for an off shore location there will not be a single local community affected directly but the burden will be felt more as a national burden and hence as a national solution needed. A better feeling of fairness might be the result. It goes without saying that if an off-shore site is considered, this may in no way mean a concession to the safety case compared to an on-shore location.

Using an off-shore location could be executed as sub-seabed disposal. This however is forbidden by the 1972 Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, also known as the London Convention and by the 1996 update, known as the London Protocol . Furthermore the OSPAR convention has to be respected . The concept proposed in this paper is to create a geological disposal facility in the same way as can be done on land in a deep and stable geologic formation but the site of this formation is chosen off-shore. This means that the formation has overlaying geologic strata as well as a shallow sea. Potentially suitable geologic formations for disposal in Europe on land are clay and salt formations. Research programs on these formations are ongoing in many European countries, including France, Belgium, Switzerland, Germany and the Netherlands. The same clay and salt formations extend under the North Sea and hence offer an off-shore alternative.

Fig. 2. Potentially suitable salt formations in the north-western part of Europe including the North Sea. The red area is of potential interest [10].

Access to the geology off-shore can be done from land with a tunnel. This is not fundamentally different than having an on land site for the whole disposal facility. The acceptable length of a tunnel will limit the off-shore locations to be considered. Off-shore activities can also be operated from an artificial island. Such an island can be constructed directly above the geologic formation selected as disposal site. Creation of artificial islands and reclaiming land from the sea is a well-known practice especially in the Netherlands. This has historical roots because the Netherlands is largely laying below sea-level. Over many centuries the Dutch had to protect their country against the water from the North Sea. Located in a delta of important European rivers the country also had to be protected against flooding from these rivers. Civil and hydraulic engineering as well as water management are Dutch skills. Artificial islands are not new and can be found all over the world. In the Stone Age they were created in Scotland and Iceland: the crannogs. Modern examples are Kansai airport in Japan and the astonishingly beautiful islands in Dubai: “the World” and “Palm” [11].

In the Netherlands proposals have been made to protect our country against harmful effects of sea-level rise. The creation of an island in the shape of a tulip in the North Sea has been proposed (Fig. 3). Because of its fundamental function for the safety of the Netherlands’ dikes and dunes and also such an island will be maintained by the Dutch society “forever”. If an entrance to an underground disposal facility is created on an artificial island as described, the knowledge of the disposal site will also be kept “forever”. It would also be easier to protect the facility against unauthorized human intrusions.

There are quite some countries in Europe with small and very small amounts of high-level waste, all of them having to find a solution for the waste that need geologic disposal. Some of these countries, such as Denmark, Norway and the Netherlands are bordering the North Sea. These countries could co-operate with some other countries with larger quantities of waste and create a European solution. An off-shore option could be explored including the creation of an artificial island in the North Sea. It is clear that such an island could also host other activities such as an airport, wind farm services or even recreational activities.

Fig. 3. “Tulip Island” in the North Sea [12]

CONCLUSION

Although being very hazardous, radioactive waste has the advantage that the volume is small and that the hazard will ultimately disappear because of decay. Long-term isolation from the biosphere is foreseen by disposal in deep, stable geologic formations. This is a costly operation, difficult to realize for countries with low volumes of waste. European multi-national co-operation can strongly improve the economics and also enhance safety and security. When countries join with larger waste volumes then tens of billions of Euros become available.

Suitable geology researched on land also exists under the North Sea. When co-operation is pursued between countries neighboring the North Sea, an off-shore site could be chosen, for which an artificial island as entrance can be created. Such a European multinational disposal concept could enhance the feeling that the burden is really spread over the participating countries and not imposed on one local national community. With an artificial island also something of astonishing technology as well as astonishing beauty could be created that will obtain general support by the public. The project will be appealing and result in proudness of all involved. Prerequisite is out of the box thinking and enthusiasm at political level for such European collaboration.

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