Technical feasibility of a radioactive waste geological disposal facility in Boom Clay in the Netherlands

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1 What is radioactive waste and how much is there?
If you think about radioactive waste, what comes straight to your mind? Right, the spent fuel originating from nuclear power plants! However, beyond power generation a large portion of the radioactive waste, in either gaseous, liquid or solid form, results from applications and processes ranging from agriculture and industry up to research and medicine.

There exists no unique scheme for defining and classifying radioactive waste. Based on individual national regulations waste which contains, or is contaminated with, radionuclides and/or activities is radioactive waste and as such categorised by established clearance levels relating their properties to the risk posed to the public and/or the environment. In the Netherlands waste is divided into three main categories; Low- and Intermediate Level Waste (LILW), heat generating High Level Waste (HLW) and non heat generating HLW. The LILW may, (i) be naturally occurring material containing large quantities of a radioactivity concentration below the exemption level and thus suitable for reuse as additives for the preparation of building materials, e.g. for road construction; or (ii) be technically enhanced naturally occurring radioactive material including, for instance, depleted Uranium originating from the Uranium enrichment facility of URENCO in Almelo and material from phosphor production. Heat generating HLW consists of the vitrified waste from the reprocessed Spent Nuclear Fuel (SNF) from the two nuclear reactors in Borssele and Dodewaard (closed in 1997), SNF from the research reactors in Delft and Petten, and spent uranium targets of molybdenum production. Non heat generating HLW is mainly reprocessing waste other than the vitrified residues and some decommissioning waste.

So just how much waste is there? Radioactive waste inventories are very incomplete and comparison of quantities is difficult due to different national classification systems. The International Atomic Energy Agency IAEA (2008) estimated the total LILW to be about 7,300,000m³ and the HLW to be about 830,000m³. The 2010 national waste inventory showed that the Dutch share is rather minor, with 20,540.5m³ of LILW, 15.8m³ of non heat generating HLW and 35.8m³ of heat generating HLW (Kgd. of the Netherlands, 2011). Over a period of 100 years, the cumulative amount of LILW and HLW, including decommissioning waste, generated in the Netherlands is estimated to be about 188,000m³ and 3,200m³ respectively (NEA, 2007).

This leaves us with The question: ```What to do with it?```.

2 Why not shoot it into space?
Besides sea dumping, disposal in the seabed, deep boreholes or ice sheets, rock melting, subduction zone disposal and others, outer space has been discussed seriously as one
possible disposal option by some researchers (e.g. NIREX, 2002). However, besides violating numerous international legislative provisions, outer space disposal would be a highly unfeasible option. For instance, the outer space disposal of the UK’s radioactive HLW of about 4500t is estimated to cost about £330,000,000,000, to take 230-450 years to complete and to involve a launch failure probability of about 3.19% which is 26 failures out of 910 launches using a Space Shuttle and 253 failures out of 1820 launches using an Ariane type launch system (CoRWM, 2004).

Over recent decades the long-term deep geological disposal of radioactive waste was found to be the only feasible, safe and sustainable concept which gained an international consensus as well as scientific and societal support. Deep geological disposal facilities are systems of multiple engineered and natural barriers, designed to isolate the contaminant over the long term, and are adjustable to account for the local technical, environmental, safety, financial as well as societal and ethical boundary conditions.

Although the nuclear fuel cycles are becoming more advanced and transmutation may become practically feasible in the future, there will always be some radioactive waste we have to take care of. So why should we take care of it now and not just wait and see?

3 The Dutch concept of storage and disposal

With the Netherlands signing the United Nations Rio Declaration on Environment and Development in 1992, a possible wait-and-see tactic was no longer an option. Principle 15 of this declaration imposes the precautionary approach which states that; ```In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.´´ (UNCED, 1992).

Research on the storage and disposal of radioactive waste in the Netherland started in 1971. In 1979 the Interdepartementale Commissie voor de Kernenergie (ICK) as part of the Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer (VROM) recommended deep geological disposal, possibly in the rock salt formations in the north eastern part of the Netherlands (ICK, 1979), as shown in Figure 1. Following a public debate on energy policy starting in 1979, the Centrale Organisatie Voor Radioactief Afval (COVRA) was founded based on a report on the position of the Dutch government delivered to parliament in 1984 (VROM, 1984). In the same year the Dutch government formed the scientific steering committee OPberging te Land (OPLA) launching the first research programme to investigate the possibility of waste disposal in rock salt. Van den Broek et al. (1993) concluded in the final OPLA report that disposal in salt is feasible with the possibility of future retrievability.

In a position paper the Dutch Government outlined in 1993 its policy regarding the disposal of highly toxic and radioactive waste. Aiming at the general minimisation of waste it was decided that non-avoidable waste is to be recycled (reprocessed). Based on the outcome of the OPAL programme, as well as on the requirements of sustainable development, disposal in a deep geological repository was chosen to be the preferred approach under the premise that every
Step of the process is reversible so that any waste can be retrieved if and when deemed necessary. In order to oversee and coordinate all research related to radioactive waste disposal the Commission Disposal Radioactive Waste (CORA) research programme was initiated.

The CORA programme started in 1995, comprised 21 projects, cost around € 3.5 million with 20 research institutions (domestic as well as foreign) participating and was concluded in 2001. The research focused on the technical feasibility of a retrievable deep underground repository in salt rock, as well as on the suitability of Boom Clay as a host rock (Figure 1 right) and of long-term storage above ground; for each of these options the evaluation of retrievability, as well as safety, was key. The main conclusions from this project were that

- retrieval of radioactive waste from repositories in salt and clay is technically feasible with the disposal concept envisaging the construction of short, horizontal disposal cells each containing one HLW canister;
- safety criteria can be met;
- structural adjustments to the repository design are required to maintain accessibility. This applies particularly to a repository in clay, which needs additional support to prevent borehole convergence and eventual collapse of the disposal drifts; and
- costs are higher than those for a non-retrievable repository, mainly due to maintenance of accessibility of the disposal drifts

(CORA, 2001).

Figure 1: Potential host rock for the disposal of radioactive waste in the Netherlands: rock salt deposits (left) and layers of Boom Clay (right) (CORA 2001a).
In 2002, based on the outcomes of the CORA projects and previous investigations, the Dutch Ministry of Housing, Spatial Planning and the Environment submitted a statement to parliament (VROM, 2002) setting the current Dutch policy on radioactive waste, that is,

- to store all radioactive waste for a period of at least 100 years at COVRA;
- to perform research preferably in an international collaborative programme; and
- eventually to dispose of all radioactive waste retrievably in a deep geological facility (Haverkate, 2003).

However, further research is required to resolve outstanding issues, to preserve expertise and knowledge, as well as to prepare for site selection in case of any change in the current timetable (Kgd. of the Netherlands, 2011). Hence in September 2009 the third Research Programme for the Geological Disposal of Radioactive Waste, the Onderzoeks Programma Eindberging Radioactief Afval (OPERA¹), was launched for the 2011-2016 time frame. As the existing safety and feasibility studies for the disposal of radioactive waste are over 10 to 20 years old, the OPERA research programme aims to evaluate existing national and international safety and feasibility studies, to modify individual concepts, frameworks and analyses and to adopt this information when designing a generic waste repository in the Netherlands.

The development of a geological disposal facility takes place over several decades and to date no facility is in operation in which HLW has been finally disposed. Parallel to the OPERA programme the Dutch government is developing a national programme for the management of spent fuel and radioactive waste from generation to disposal. This roadmap which is expected around 2014 will contain the national policies, clear milestones and time frames, a detailed inventory and estimate of future waste, concepts and technical solutions for all processes from generation to disposal and beyond (long-term post-closure), set responsibilities and assess the costs (Kgd. of the Netherlands, 2011).

4 Feasibility of the current disposal concept in Boom Clay

A two year research project as part of the OPERA programme investigates the feasibility of a generic disposal concept in Boom Clay. It started in December 2012 and is led by Prof. M. A. Hicks of the TU Delft Geo-Engineering Section in collaboration with NRG and TNO.

Figure 2 outlines the repository concept proposed by Verhoef et al. (2011) on which this study is based. The repository is to be situated at a depth of approximately 500m in a Boom Clay stratum of approximately 100m thickness. Due to the small waste quantities projected for the Netherlands, all LILW and HLW is planned to be disposed of in one facility which leads to a total footprint size of about 3050m by 1300m. Based on the current Belgium Supercontainer concept the waste will be stored in horizontal drifts drilled perpendicular to the main galleries with varying diameters and length depending on the waste form.

¹ http://www.covra.nl//disposal/opera-disposal
The repository life-cycle can be considered in three phases: (i) the pre-operation phase, including the conceptual development, site investigation and selection, design and construction; (ii) the operational phase, including waste emplacement and any period of time prior to closure; and (iii) the post-operational phase.

Figure 2: Current OPERA repository concept in Boom Clay: (a) artist impression, (b) footprint and disposal sections and (c) Supercontainer for head-generating HLW (Verhoef et al., 2011)

Figure 3: *The repository life-cycle*
The research on the technical feasibility of the repository will investigate whether the repository can be constructed and whether it is able to perform the appropriate safety functions and meet safety requirements. The research will be based on 2D and 3D numerical studies of the disposal concept, as well as possible variations on that design. It will involve analyses of the staged excavation and construction of the repository, as well as pre- and post-closure assessments of repository performance; for example, in terms of (long term) stability, deformations, stress changes, structural integrity and water/gas pathways. A significant feature of the research is that it will take account of the considerable uncertainties in the clay properties and behaviour through a reliability-based design approach.

Probabilistic techniques will be used to quantify the influence of the considerable uncertainties arising from the gaps in current knowledge, especially with regard to clay properties and behaviour. However, as knowledge is gained through other national and international projects, including those within OPERA, the analyses may be refined as uncertainties reduce. For instance, the Belgian underground research facility HADES (High-Activity Disposal Experimental Site) in Mol is situated in the same stratum although at a shallower depth of about 223m. Results from numerous experiments conducted in boreholes and side galleries since it's construction in 1980 will be extrapolated for this research project and help us to understand the processes involved.

Note that, while the probabilistic approach is an appropriate tool for quantifying the effects of uncertainties and for determining critical factors, its effectiveness is greatly enhanced by narrower (less uncertain) parameter distributions arising from increased knowledge. Hence, this approach is not a substitute for lack of knowledge; rather, it is a means of quantifying lack of knowledge and its influence on predicted repository performance. The need for quality data for Boom Clay at depths exceeding 500m is clear and remains an urgent priority.

A project website with further information and updates on this research project will be available soon on the new Geo-Engineering website. For possible MSc (and Bsc) projects related to this research please contact me (p.arnold@tudelft.nl) or Dr. P. Vardon (p.j.vardon@tudelft.nl).

5 References


