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Foreword

E.V. Verhoef & E.A.C. Neeft*

P.O. Box 202, 4380 AE Vlissingen, The Netherlands

* Corresponding author. Email: erika.neeft@covra.nl

Radioactive substances and ionising radiation are used in medicine, industry, agriculture, research, education and electricity production. This generates radioactive waste. In the Netherlands, this waste is collected, treated and stored by COVRA (Centrale Organisatie Voor Radioactief Afval). After interim storage for a period of at least 100 years, radioactive waste is intended for disposal. There is a world-wide scientific and technical consensus that geological disposal represents the safest and most sustainable end point for the management of radioactive waste (e.g. Council Directive, 2011).

Geological disposal is the emplacement of radioactive waste in deep underground formations. The goal is long-term isolation and containment of radioactive waste in order to protect people and the environment from the harmful effects of ionising radiation from this waste. OPERA (OnderzoeksProgramma Eindberging Radioactief Afval) is the third Dutch research programme on geological disposal of radioactive waste and started in 2011. In this programme, researchers of different organisations and different disciplines work together to study the feasibility of a disposal facility in the Boom Clay (Rupel) or the Zechstein rock salt formation in the Netherlands. OPERA is the first Dutch research programme coordinated by a waste management agency. Since the 1980s, the Belgium waste management agency has coordinated research on geological disposal of radioactive waste (ONDRAF/NIRAS, 2013) in Boom Clay. Outcomes of the Belgian research are important to OPERA. Accordingly, this issue also includes outcomes of the Belgian research programme.

Figure 1 shows the disposal facility in clay that is investigated in OPERA (Verhoef et al., 2014). The facility consists of both surface and underground facilities that are connected by vertical shafts and (optionally) an inclined ramp for the emplacement of waste. The underground facilities include separate disposal sections for different types of waste. The total area of the underground facilities is estimated to be 3.2 km^2. After closure, the connection between the surface and underground facility is removed by backfilling of the shafts and ramp. The disposal concept should provide sufficient confidence that the waste is contained inside and isolated from the surface for very long periods, up to 1 million years. Such periods allow the waste to decay such that protection from the harmful effects of ionising radiation is no longer required.

The results of OPERA are presented in a so-called 'safety case'. A safety case is an integration of arguments, at a given stage of geological disposal development, in support of the safety of disposal of radioactive waste. A safety case comprises the findings of a safety assessment. It should acknowledge the existence of any unresolved issues that may have an impact on the safety of the geological disposal facility and provide guidance for work to resolve these issues in future development stages. As the radioactive waste disposal process in the Netherlands is at an early, conceptual stage and the previous research programme ended more than a decade ago, a preliminary, generic and conditional safety case will be developed in OPERA to structure the research necessary for the eventual development of a disposal facility in the Netherlands. The OPERA safety case is generic, because a choice for host formation or location is not expected before 2100. The safety case is conditional since plausible assumptions must later be confirmed in a specific safety case, for example for site selection. Some of these plausible assumptions are discussed in this special issue.

Site characteristics

In the spatial planning of the underground in the Netherlands, no specific areas need to be reserved for geological disposal. Considering the disposal concept investigated, there are ample opportunities to dispose of radioactive waste in the Rupel Clay with the occurrence described by Vis et al. (2016) in this issue. The projected disposal area of 3.2 km^2 is smaller than the visualised locations of boreholes in the description of the thickness of the Rupel Clay by Vis et al. (2016). In addition, there are also other potential host rocks available such as other Palaeogene clay formations and Zechstein rock salt.

Considering the long-term planning of a disposal facility, development of measurement techniques and data analysis for a site characterisation is not necessary in in the Netherlands. In

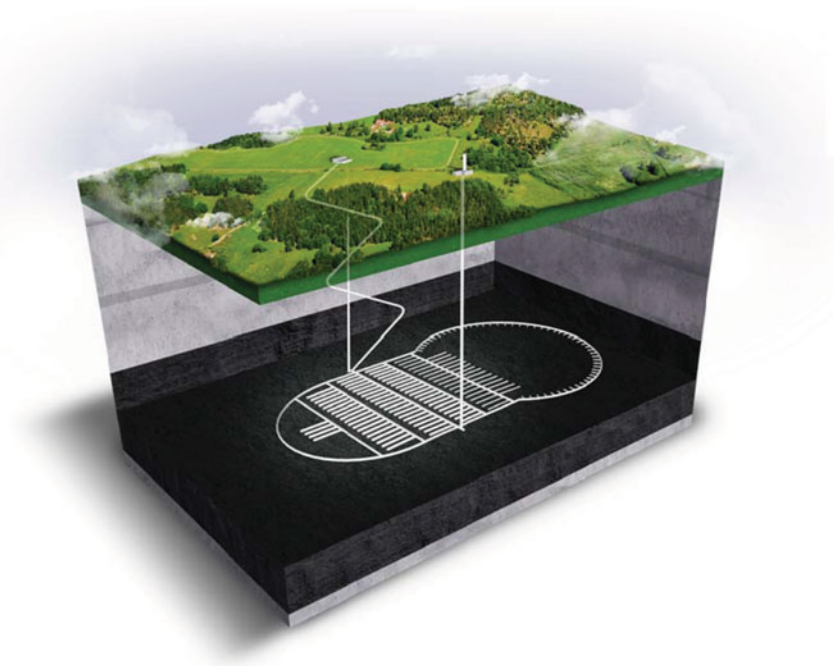

Figure 1. Artist's impression of a geological disposal facility in Rupel Clay to emplace radioactive waste in the Netherlands.

Belgium, a disposal facility is expected decades earlier than in the Netherlands. Consequently, developing measurement techniques and data analysis for a site characterization is of more interest to the Belgian programme. An example of such development is the non-destructive imaging of the underground for a range in depths and detail relevant for geological disposal in Belgium (Carcione et al. 2016).

In the post-closure safety assessment, the potential transport of radionuclides is calculated from the waste after closure of the disposal facility. In a disposal facility, waste is contained by different barriers, both engineered and natural. Engineered barriers can be waste matrices, waste packages and backfill. Radionuclides need to pass the engineered and natural barriers before they reach the biosphere. Rupel Clay is the only natural barrier considered. It is an aquitard in which water flow is limited. The slow movement of water through the host rock and the clay pore water chemistry are used as input to predict the potential transport of radionuclides to surface. This then allows estimation of the level of safety, i.e., the protection against radiation risks provided by the disposal concept.

Diffusion-dominated transport

A condition for the safety case is that waste is disposed of at a site where the pore water is effectively stagnant and consequently the transport of radionuclides is dominated by diffusion. No direct measurements of water flow within Rupel Clay at relevant disposal depth in the Netherlands are available. Verweij et al. (2016) describe how permeability values for Rupel Clay in the Netherlands were derived. They also tested their methodology with measured values in Belgium and consequently a reliability of the values for the Netherlands was obtained. Their description of the uncertainties (determination of clay content, variation in mineralogy, anisotropy and burial history) provides sufficient arguments for the added value of geohydrological measurements in determining whether diffusion-dominated transport can plausibly be assumed within the Rupel Clay at relevant depth for disposal of waste in the Netherlands.

Geohydrological measurements for geological disposal have been taken frequently in the framework of the Belgian programme. Currently, more fundamental research is carried out to understand how measured permeability values relate to the observed microstructure (grain fabric, pore size and shape) of poorly indurated clays, such as Ypresian clay and Rupel Clay. This requires a careful coring and preparation of the samples. Hemes et al. (2016) show images of the microstructure of poorly indurated clays with the latest sample preparation methods available.

Sorption and retardation

Another condition for the safety case deals with chemically influenced processes in the Rupel Clay that limit the potential release of radionuclides. Depending on pore water chemistry and mineralogy, Rupel Clay can sorb and retard radionuclides, further slowing down their transport. Koenen & Griffioen (2016) and Behrends et al. (2016) show that in order to reliably estimate the reactive solid phases that are relevant for sorption and retardation, the clay mineralogy needs to be determined from fresh or carefully preserved clay cores from the deep

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underground. Their research provides insight into the clay mineralogy and will help any Rupel Clay sampling for research in the future.

Travel times for a generic safety case

The transport of radionuclides from the Rupel Clay to the biosphere depends on the surrounding formations. The formations surrounding the Rupel Clay differ throughout the Netherlands. As a generic safety case is developed in OPERA, the location of the disposal facility and thus the surrounding formations cannot be defined. The Netherlands Hydrological Instrument is a hydrological model in the Netherlands. Valstar & Goorden (2016) describe the necessary extensions for the groundwater part of this model and the underlying assumptions to model the transport and estimate a range of travel times to the surface. Griffioen et al. (2016) collected and interpreted groundwater quality data of Palaeogene and older formations. This information may be used to validate the extended hydrological instrument in the future.

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