MCM McCombie Chapman McKinley Consulting
Täfernstrasse 11, 5405 Baden-Dättwil, Switzerland

Summary of the Safety Case for the Proposed HLW-ILW Repository in Belgium

Report prepared for the South Australia Royal Commission

Neil Chapman and Charles McCombie

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Foreword

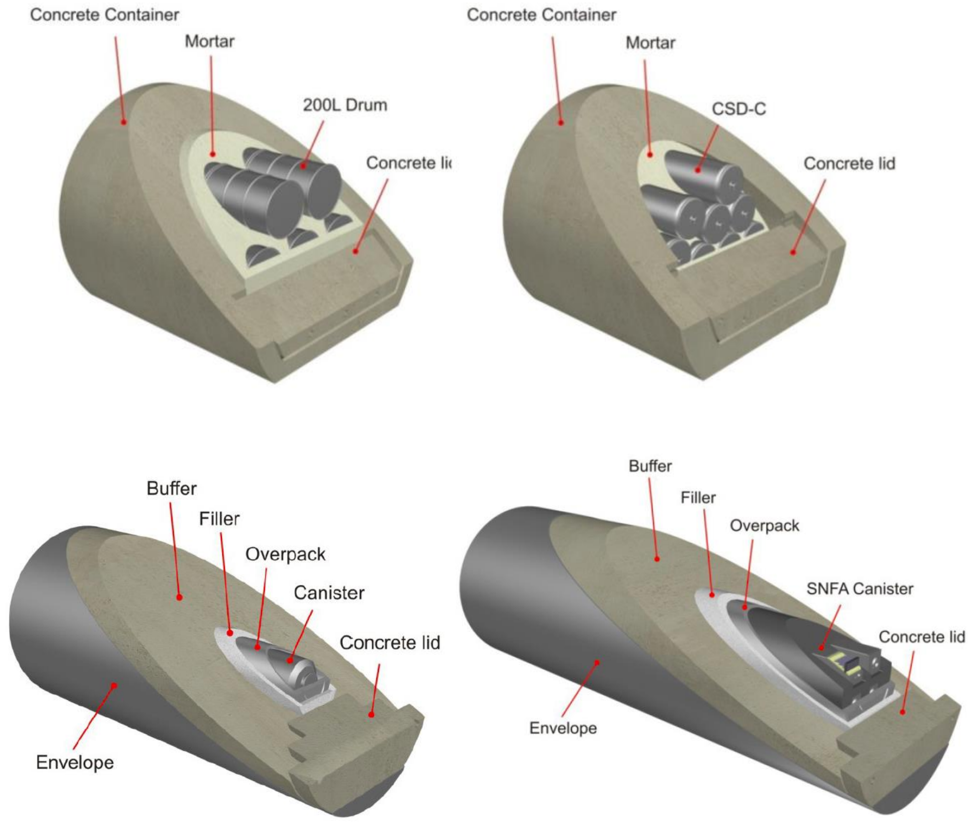
Belgium has a relatively small nuclear power programme but has been involved in the development of nuclear energy technologies in Europe since the earliest days, with a sustained programme of R&D into disposal of radioactive wastes in deep clay formations since the 1970s. The Belgian programme led international R&D on clay host rocks for many decades. Part of this work has been the development of disposal concepts and associated safety evaluations for spent fuel, vitrified HLW and long-lived ILW disposal in the Boom Clay formation and other, related clays. This work is led by the Belgian Agency for Radioactive Waste and Enriched Fissile Materials, ONDRAF/NIRAS and is supported by R&D carried out by the Belgian Nuclear Research Centre, SCK•CEN, including information from the underground research laboratory at Mol. The most recent comprehensive safety case, called SAFIR 2, was published in 2001 and a broad programme of work by ONDRAF/NIRAS is currently aimed at updating this. The final site for the national deep geological repository has not yet been selected. The safe management of radioactive wastes is overseen by the regulatory authority, the Federal Agency for Nuclear Control (FANC/AFCN).

1 Outline of the GDF Project and the Disposal Concept

Belgium has been involved in the development of nuclear power and associated technologies since the early decades of nuclear energy in Europe. As a result, it has a complex inventory of historic wastes from developmental and manufacturing facilities, plus those from its nuclear power plants, other reactors and nuclear research and industrial facilities. It has been involved in the development of geological disposal in Europe since the initiation of joint European Community projects in the 1970s, with a deep underground research facility at Mol in the Boom Clay, one of the target geological formations being considered for the GDF. No site is yet selected for the GDF and other clay formations (e.g. the Ypresian clays) may be possible hosts. The Boom and Ypresian clay formations are between about 28 and 56 million years old.

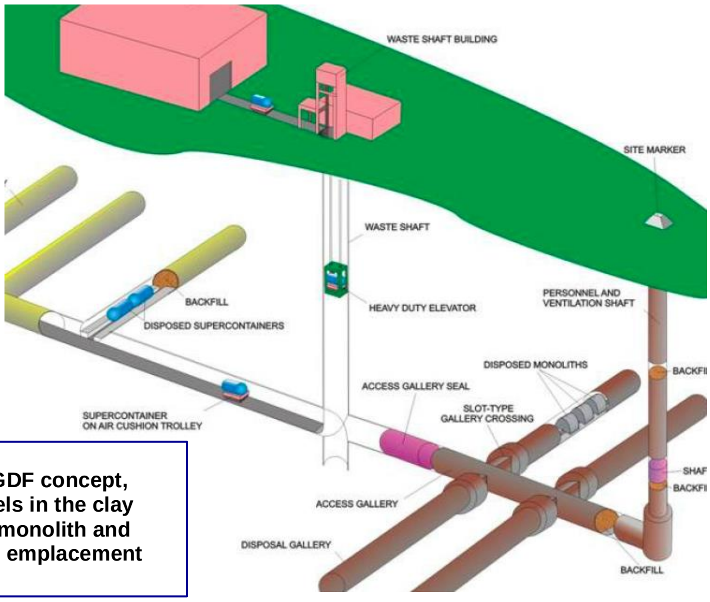
The wastes destined for geological disposal by 2070 are principally about 10,000 to 11,000 m^3 of 'Category B' cemented, vitrified and bituminised intermediate level waste (ILW: a mix of operational, reprocessing and decommissioning wastes), plus 600 to 4500 m^3 of 'Category C' vitrified high-level waste (HLW) from reprocessing spent nuclear fuel. The amount of HLW depends on future policy on fuel reprocessing, so there may also be some spent fuel (SF) to dispose of in the GDF (also in Category C).

The disposal concept involves placing the Category B and C waste containers into massive 'monoliths' and 'supercontainers', respectively (illustrated below)[1]. These containers will be emplaced in tunnels constructed in the deep clay formation and the GDF will then be backfilled and sealed. A conceptual illustration of the GDF is shown on the following page.



Monoliths for ILW (top) and supercontainers for HLW and spent fuel (bottom)

[1] ONDRAF/NIRAS Research, Development and Demonstration (RD&D) plan for the geological disposal of high-level and/or long-lived radioactive waste, including irradiated fuel if considered as waste. State-of-the-art report as of December 2012. Belgian Agency for Radioactive Waste and Enriched Fissile Materials: Report No. NIROND-TR 2013-12 E December 2013.



Detail of the GDF concept, showing tunnels in the clay formation for monolith and supercontainer emplacement

2 Safety Case Requirements

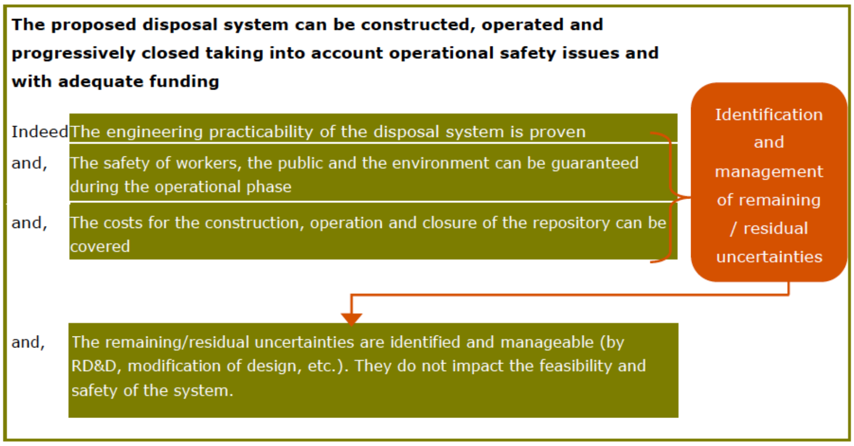
ONDRAF/NIRAS (the organisation responsible for managing Belgium's radioactive wastes) has carried out considerable RD&D since 1974, including several detailed evaluations of the safety of the GDF. The most recent comprehensive analysis was SAFIR 2, in 2001. In its next stage of work, it will present the Belgian government and regulatory authority[2] with a **Safety and Feasibility Case (SFC)**, a synthesis of evidence, analyses and arguments that quantify and substantiate the ONDRAF/NIRAS claim that the GDF can be constructed and be safe after closure, and beyond the time when active control of the facility can be relied upon. At present, FANC is developing the safety regulations that will apply to the Belgian GDF.

The SFC will become more comprehensive as the programme progresses and is a key input to decision making at several steps in GDF planning and implementation. In addition to the safety arguments and feasibility specifications, the SFC encompasses environmental policies and their implementation, as well as mechanisms to ensure appropriate public information and participation. The SFC can also be used as a platform for informed discussion, whereby interested parties can assess their own levels of confidence in the project and issues that may be a cause for concern can be identified for further work.

ONDRAF/NIRAS bases its approach on a **Safety Strategy**, which uses Safety and Feasibility Statements, in the form of 'trees', containing a hierarchical set of claims that ONDRAF/NIRAS considers to be correct, but which must be substantiated by their RD&D work. The 'Safety Tree' and the 'Feasibility Tree' are illustrated below.

We have confidence in the long-term safety		
Indeed,	The system is known	
	Indeed,	The system components can be characterised
	and,	The evolution can be bounded
and,	The safety functions that have been defined are relied upon	
	Indeed,	Isolation of the system is ensured during the period of concern
	and,	Containment is ensured during at least the thermal phase
	and,	Rate of radionuclides transport is low and some radionuclides are delayed
and,	The performance of the disposal system meets the requirements	
and,	The remaining/residual uncertainties are identified and manageable (by RD&D, conservative assumptions, scenarios, etc.). The irreducible uncertainties do not impact the overall knowledge, understanding and safety of the disposal system.	

[2] Federal Agency for Nuclear Control (FANC).



ONDRAF/NIRAS follows the commonly accepted and applied strategy for radioactive waste management of **concentration and containment** of waste, with **isolation** from the biosphere. A safe disposal system protects people and the environment now and in the future from the harmful effects of ionising radiation and chemically toxic contaminants associated with the waste. Protection must be provided at all stages over the lifetime of a repository, without imposing undue burdens on future generations.

ONDRAF/NIRAS has adopted the following set of **Safety Principles**: *robustness, demonstrability, passive safety, defence-in-depth, use of best available techniques and optimisation of protection (and safety),* based on international standards and recommendations by the IAEA.

The safety of the GDF is characterized by attributing **Safety Functions** to the various components of the system, natural and engineered. It can be seen below that the components have specific functions, but all the Safety Functions are dependent to varying extents on the natural (geological) and engineered barriers working together.

Engineered containment (C) (for heat-emitting Category C waste) prevents the release of contaminants from the disposal package during the 'thermal phase' (the first thousand years or so, during which the GDF and immediately surrounding clay formation are significantly heated by the HLW or SF) by using one or several **engineered barriers**. The component contributing to this Safety Function is the supercontainer, illustrated above.

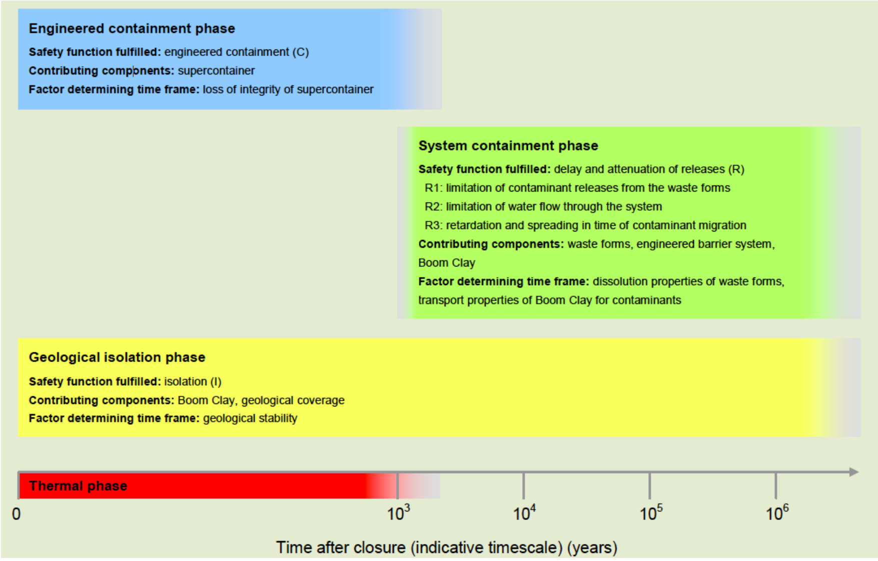
Delay and attenuation of releases (R) to retain contaminants within the disposal system. The components contributing to this Safety Function are the solid waste materials, the engineered barrier system and the host clay formation which, together:

- limit and spread in time any releases of contaminants from the waste packages
- limit the flow of water through the disposal system, to prevent or limit transport of contaminants to the environment in flowing groundwaters
- retard and spread in time the migration of contaminants to the environment

Isolation (I) of the waste from people and the environment by preventing direct access to the waste and protecting the GDF from potentially detrimental processes. The host clay formation and overlying geological formations provide this Safety Function by:

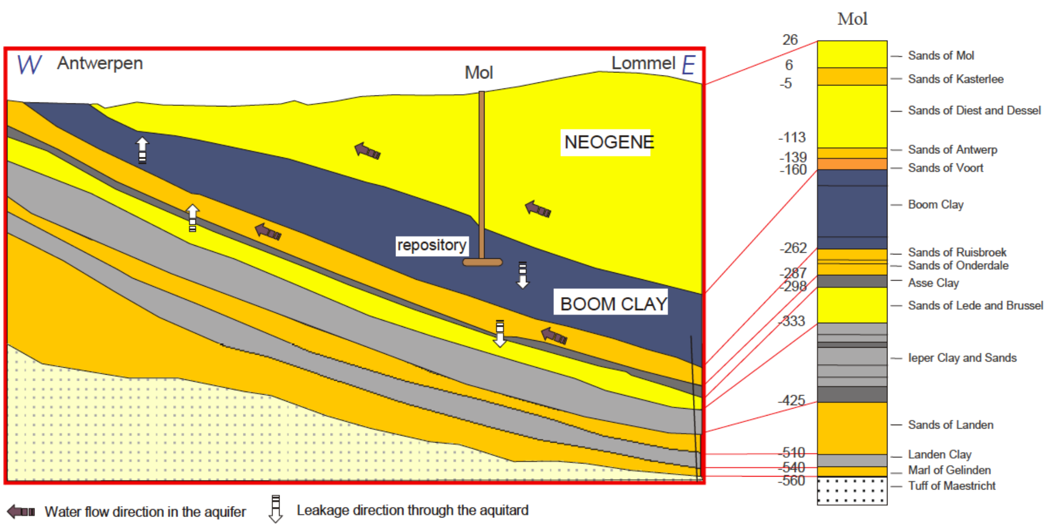
- limiting the likelihood of inadvertent human intrusion and, in case such intrusion does occur, of limiting its radiological and chemical impacts on people and the environment
- protecting the waste and the engineered barrier system from natural changes and perturbations in the environment of the GDF, such as major climate variations, erosion, uplift, seismic events or rapid changes in chemical and physical conditions.

The illustration below shows how these Safety Functions operate at different times into the far future, from the time of disposal out to more than a million years.



3 Role of the Geological Environment in Safety

The Boom Clay is a relatively plastic and highly impermeable formation, which gives it good containment properties. The formation is some tens of metres thick, being present below much of Belgium, dipping gently from the surface in the SW, down to depths of some hundreds of metres in the NE. The illustrations below show the uniform structure of the Boom Clay where it is exposed near the surface and the general geological structure in which it lies[3].



[3] Preparatory Safety Assessment: Conceptual model description of the reference case. Eef Weetjens, Jan Marivoet and Joan Govaerts. External Report of the Belgian Nuclear Research Centre (SCK•CEN): SCK•CEN-ER-215, 2012.

The Boom Clay is an efficient natural barrier to the migration of radionuclides and chemical contaminants towards the surface environment because it has:

- Very low permeability, allowing practically no water movement. Movement of contaminants through the clay is thus essentially by the extremely slow process of diffusion.
- Strong physical and chemical retention capacity for many radionuclides and chemical contaminants, meaning that migration through the clay is considerably delayed.
- A capacity for self-sealing: any fractures induced by excavation works seal within weeks.

These properties have been studied and demonstrated in numerous experiments and observations over decades in the laboratory and in the deep underground research laboratory at Mol, where large-scale tests and experiments have been carried out since 1974. In addition, the isolation and containment effectiveness of clay has been shown to protect even biodegradable material such as wood from degradation for millions of years. ONDRAF/NIRAS cite examples such as the 1.5 million year old preserved woods of the Dunarobba 'fossil forest' in Italy and the even older 'fossil' woods of the Entre-Sambre-et-Meuse region.

Overall, a large part of the safety provided by the disposal system comes from the geological barrier, which protects the engineered barriers during the early period after closure so that they can provide their isolation and containment functions and then continues to isolate and contain the waste far out into the future.

4 Role of Engineered Barriers in Safety

The engineered barrier system (EBS) limits perturbations of the host clay formation by repository construction, operation and closure and provides complete containment within the GDF for Category C waste during the early thermal phase. It also contributes to the delay and attenuation of the releases, as outlined in Section 2. Backfill and seals in the GDF will ensure that, after closure, contaminant movement within the GDF will be diffusion-dominated.

After the first 1000 years or so, the EBS is assumed to become degraded and to have only a limited role in containment and isolation compared to the geological barrier provided by the clay, which dominates the overall safety provided by the GDF system.

The performance of the engineered barrier materials has been tested over many years in laboratory experiments and *in situ,* in the Mol underground laboratory. Analogues of materials found in nature also provide evidence for the safety case. For example, basaltic volcanic glasses, which have been shown to behave similarly to vitrified HLW glasses, have been found in the Boom Clay, and show no evidence of dissolution, despite being buried for almost 30 million years.

5 Risk Assessment under Potential Future Scenarios

Safety assessment in the SFC systematically analyses the hazards associated with the GDF and its ability to fulfil Safety Functions and meet requirements from the regulatory body.

Practically, safety assessment evaluates the performance of the GDF system across a large spectrum of **scenarios** and **calculation cases** to show that the disposal system will perform safely, if built as intended. It also highlights residual uncertainties and outstanding issues to be tackled as the programme moves forward.

In the ONDRAF/NIRAS safety assessment, scenarios include:

- **Reference scenario:** based on a 'reference case' and several alternative cases that make different assumptions. In the reference case, the system is implemented according to the specified design, and the assumptions made tend to be conservative. Alternative cases elucidate the impact of uncertainties or are used to evaluate the impact of different GDF design options.
- **Altered scenarios:** representing alternative 'futures' of the disposal system that have a lower probability of occurrence than the reference scenario and which result from

natural events or processes that might significantly impair one or more Safety Functions. In the most recent (SAFIR 2) safety evaluation[4], these scenarios included the impacts of future greenhouse or severe glacial climates, poor sealing of the GDF, the premature failure of an engineered barrier and the possibility of radioactivity being transported by gases produced in the GDF.

- **'Human intrusion' scenarios:** represent alternative 'futures' of the disposal system resulting from future human actions. Their probability of occurrence cannot reliably be quantified over the time frame covered by safety assessment, but is kept low by siting and design measures. Human intrusion scenarios will be developed in interaction with the regulators. In the SAFIR 2 safety evaluation, these scenarios included drilling and pumping a water exploitation well near the GDF and the drilling of a borehole directly through the GDF and the wastes.

In the current reference scenario, the Boom Clay is stable and no human or natural events alter the isolation provided by the disposal system. The containment of radioactive and chemical contaminants within the overpack lasts until at least the end of the thermal phase (a few thousands years after waste disposal). Water in the clay pore spaces will diffuse slowly into the EBS and eventually start to corrode the monoliths and supercontainers, and finally the primary waste packages. The waste will begin to dissolve in the pore waters and release contaminants that will diffuse into the host clay formation. The Boom Clay around the repository will have been disturbed by the excavation, construction, operation and post-closure evolution of the GDF, but the spatial extent of these perturbations is limited. Movement of contaminants is diffusion-dominated and further delayed by retention processes in the clay. After the slow diffusive transport through the Boom Clay formation, during which a large fraction of the radioactivity will have been removed, owing to the natural process of radioactive decay, only a minor fraction will reach groundwater in surrounding geological formations and the biosphere.

These processes are evaluated using simulations of radioactivity release and movement. The outcomes of these simulations (called 'safety indicators') are compared with the appropriate limits specified by the regulatory authorities, or with reference values. The most commonly used indicator is the radiation dose rate to hypothetical individuals exposed to releases in the distant future. The uncertainty in dose rate calculations increases with time so additional indicators are used to improve the reliability of the safety assessment. Some indicators are used explain the functioning of the disposal system by quantifying the contribution of its main barriers or Safety Functions at different times; such indicators are called 'performance indicators'.

The main way that dose rates to people are calculated is to simulate the migration of radioactivity into and through the aquifer in geological formations overlying the GDF and the Boom Clay. Concentrations of radioactivity in water taken from a well located just above the disposal facility are calculated, along with radioactivity fluxes towards rivers. These concentrations are used to evaluate radiation doses to people using the water for drinking and agricultural purposes.

The results of the safety assessments in SAFIR 2 showed doses below the envisaged regulatory constraint for all wastes considered and for most analysed cases[5]. These assessments showed that the Boom Clay is the dominant contributor to overall safety in the reference scenario and other plausible evolution scenarios. Preparatory safety assessments performed in the frame of the current RD&D programme for the SFC confirm these results.

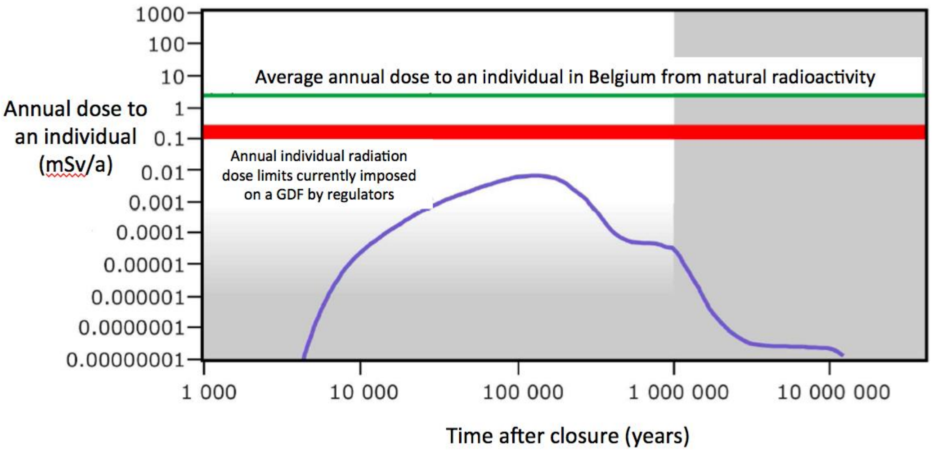
For example, a person living near the GDF who takes drinking and irrigation water from a deep well located just above the Boom Clay, where calculations indicate that the highest concentrations of radioactivity would be found, would be exposed to the largest radiation doses if they were living there more than 100,000 years in the future.

[4] Technical overview of the SAFIR 2 report. Safety Assessment and Feasibility Interim Report 2. ONDRAF/NIRAS Belgian Agency for Radioactive Waste and Enriched Fissile Materials. Report No. NIROND 2001–05 E, 2001.

[5] ONDRAF/NIRAS, Plan Déchets pour la gestion à long terme des déchets radioactifs conditionnés de haute activité et/ou de longue durée de vie et aperçu de questions connexes. Report NIROND 2011-02 F, 2011

This is shown in the figure below. Note that both the time and the radiation dose scales are logarithmic, meaning that each division shown is ten times larger or smaller than the previous one.

It can be seen that even the maximum exposure calculated for such a person (if they were living there in about 200,000 years time) would be 10 to 30 times lower than typical internationally accepted radiation dose limits for GDFs of 0.1 to 0.3 mSv per year. This calculated maximum radiation dose is extremely low: more than 250 times lower than the radiation dose received annually by a person living in Belgium from the natural radiation background at Earth's surface (about 2.5 mSv per year). The earliest calculated exposures shown on the diagram (after a few thousand years) are hundreds of millions of times lower than this natural background radiation exposure.



Another form of safety indicator is to compare the flux of radioactivity from a GDF to the biosphere with the radioactivity arising from everyday processes in which people are engaged. This is useful, given the inevitable uncertainty about future lifestyles. The figure below shows the calculated rate of release of radioactivity from spent fuel in a GDF in the Boom Clay as a function of time, again using a logarithmic scale. Here, radioactivity is expressed as 'radiotoxicity', the highly hypothetical radiation dose that would result if a person were to ingest all of a particular radioactive substance released from the GDF in a particular time period. The upper curve shows the total radiotoxicity from all the radioactive substances released into the environment from a GDF for spent fuel in the Boom Clay. The contribution to the total made by individual radioactive isotopes (of technetium, chlorine, iodine etc) is also shown.

The 'Reference Value' line shows, for comparison, the radiotoxicity of agricultural fertilizers (which are naturally radioactive) that are applied on farmland in the Flanders region: about 10 Sv/km^2 per year. A square kilometre is about the size of the GDF, so it can be seen that this is more than ten times higher than the total releases from the GDF.