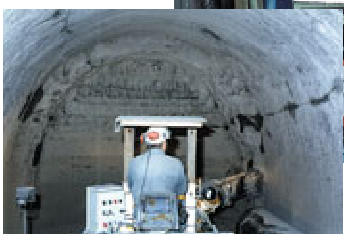
# RADIOACTIVE WASTE AND ITS IMPACT ON THE ENVIRONMENT

*What impact will radioactive waste have on the environment and mankind ultimately? If category B waste and all or some of category C waste is disposed of in a deep geological facility, after an interim storage period which presents its own risks, scientists can now predict that its worst-case impact will be minimal and localized. While they cannot strictly demonstrate the safety of disposal over the time scales in question, they can nevertheless vouch for sound, well-engineered design. They can furnish a whole host of convergent evidence to demonstrate that they really have thought of all the events that could affect radioactive packages disposed of in a given environment, separated from the biosphere by barriers with well-defined properties.*



C. Cieutat/IRSN

***Boring on the Tournemire site (Aveyron). The galleries sunk in the clay layer (photo inset) have revealed fractures linked to the tunneling work, but there is also evidence of much older fractures of tectonic origin. Most of them are clogged up with calcite tiff precipitation, but some water is seeping through. These fractures are difficult to predict. They might compromise somewhat the effectiveness of the geological barrier (Source: J. Cabrera, IRSN).***



One of the solutions proposed for category **B** waste and all or some of category **C**(1) waste after an interim period of storage, is that it goes into deep disposal. **Storage** and **disposal**, which are complementary rather than conflicting options, present different types of risks for the environment. The issue is controversial: here we are restricting our survey to its scientific and technical aspects.

## Interim storage first, fine but …

**Radioactive**-waste storage resembles many other types of industrial storage, and engineers are hardly fazed by the facilities' planned life span. In the nuclear industry, the practice of storing glass packages or spent **fuel** does not cause any major problems. The current feedback is that under normal circumstances a store has no radiological impact on the environment as it is designed to totally **contain** the waste it accommodates, with the exception of the very low **doses** received by professionals working in the installation. The fact that radioactive waste has not given rise to major accidents in the West does not mean that it does not harbor any risks for the environment. Storage facilities, designed to guarantee the future retrieval of waste **packages** are easily accessible. Their near- or **subsurface** location calls for special monitoring to avoid human intrusion and malicious acts. Furthermore they are not **passively** safe, in that existing facilities require intervention for maintenance, which makes them prey to events such as dereliction or neglecting maintenance. It follows that storage scenarios where things do not run according to plan could have an impact on man and the environment. Up until now these doomsday scenarios have been investigated on a case-by-case basis, peculiar to each installation. It must be said that there is low probability of them occurring, and secondly that the potential radiological consequences are serious. These consequences are dire because interim storage has no geological **barrier** for "rearguard action", that is to slow down and dilute **radionuclides** reaching the **biosphere**. This explains the inclination to limit storage time as much as possible: for who can guarantee that our societies will be stable throughout the time scales laid down for very-long-term storage?

## After the interim

Disposal will have to come after the storage phase, at least for some waste categories.

(1) We are limiting our focus to the environmental impact of long-lived waste, category B and C waste and so excluding other types of waste, category **A**, **VLLW** and mine tailings, which pose highly specific problems.

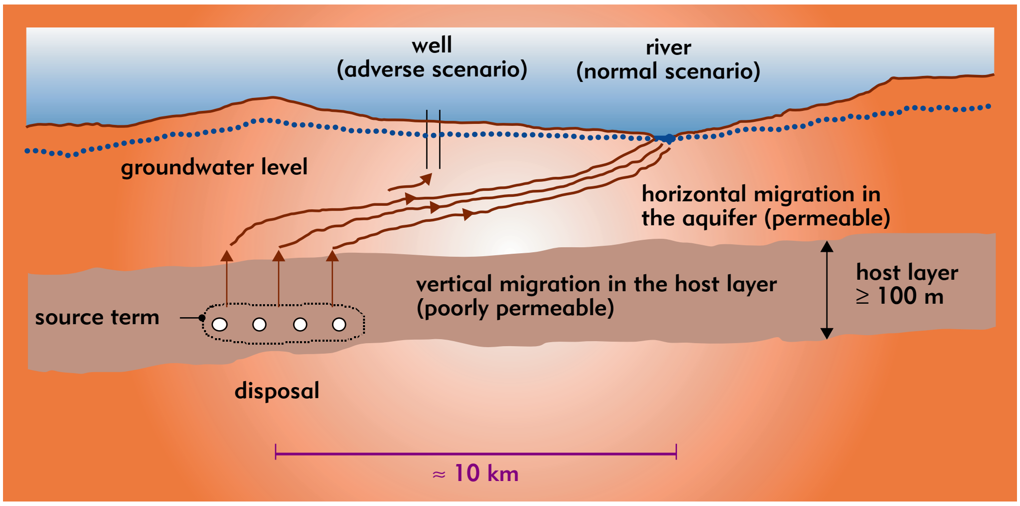



*Figure 1. Radionuclides on their way to the outlet.*

The role of disposal is simple – to contain the waste for long enough to allow **radioactive decay** to complete its work. The length of the mission assigned to a disposal facility sets it apart from all other man-made structures. It has to last at yeast 100,000 years and scientists have no practical feedback on this kind of facility! Disposal also differs in principle from storage in that in the normal course of events it will end up releasing some radioactivity, even if the amount involved is minute and the event projected far into the future. This release can only be *calculated* in view of the time scales we are talking about. There is no other option then, but to resort to predictive **modeling**.

## The first thousand years

The likely evolution of the waste consigned to disposal is described in the following "normal" scenario. High-level waste packages will heat up the surrounding rock, until it reaches a temperature of about a hundred degrees Celsius or so during the first thousand years, at the start of their time in disposal. The rock will then slowly cool down in step with the radioactivity decay rate. The clay barriers will become waterlogged at the same time. Rocks a few hundred meters below the surface will become saturated with water because they are generally below the water table(2). It is also during the first millennium that the underground structures will settle, possibly opening fissures in nearby rock. This settlement, compounded by the corrosion of secondary metal canisters will make it harder - but not impossible - to recover the packages at a later date.

## 10,000 years and beyond

Much later (at least 10,000 years and no doubt much later), glass packages and uranium oxide will have started to dissolve through the action of the underground water, (see *Glass packages guaranteed for millions of years*), causing the few released radionuclides to disperse. These will then slowly begin to migrate through the bedrock. The water will percolate through host-rock pores and fissures before reaching an aquifer(3) to migrate horizontally, finally ending up in a river(4) (figure 1). Very impermeable host rock will greatly slow down this migration while a "slow" aquifer and a distant **outlet** should lengthen the journey time even more. Scientists have shown that in low-permeability geological formations, millions of years could elapse before any water would flow back to the outlet.

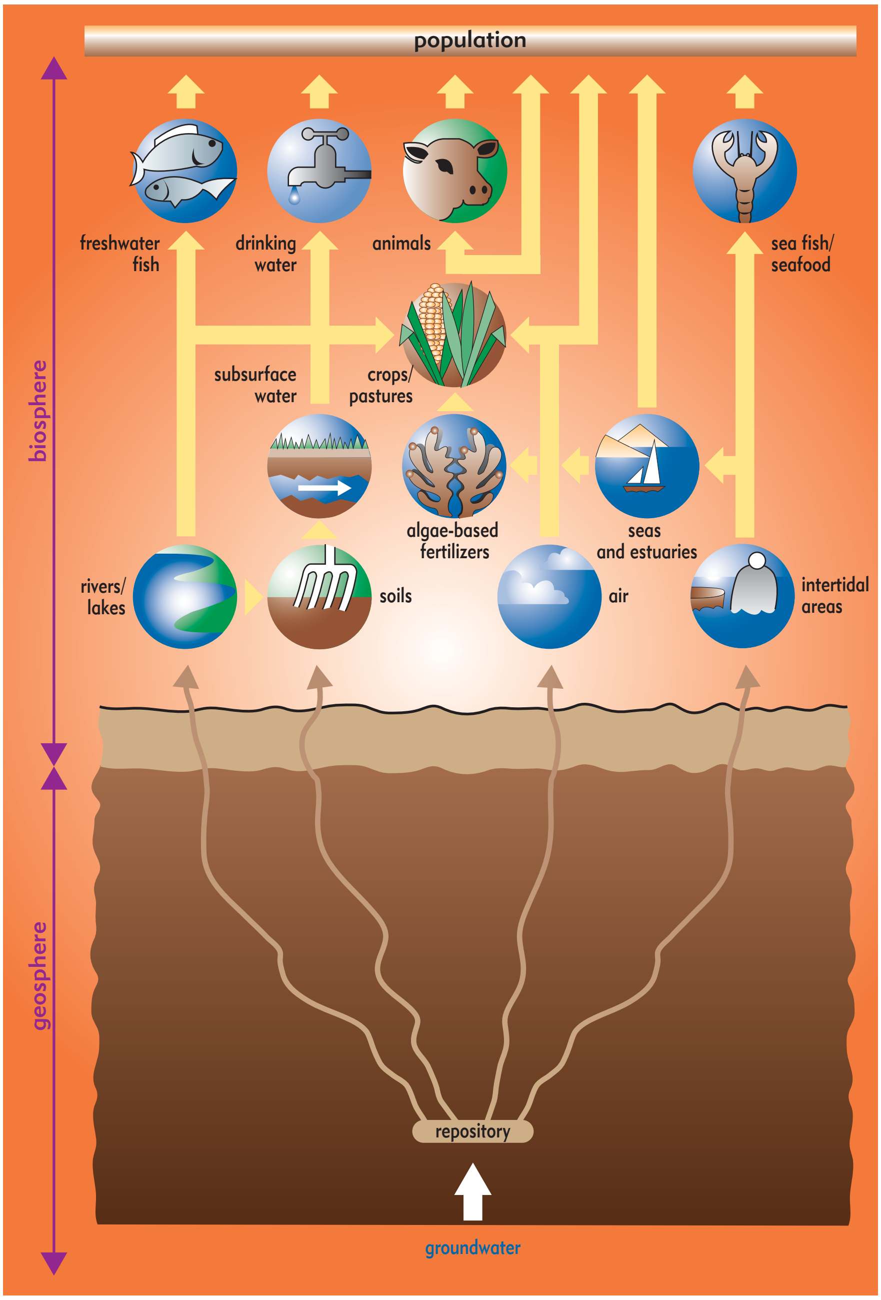
## Millions of years on: delay means decay!

A few unfortunate exhausted radionuclides will surface, their activity level diminished by radioactive decay.

At the end of its evolution, deep disposal will indeed have some radiological impact on the environment, as the quantity of radionuclides reaching the biosphere is not

(2) The only exception is the US Yucca Mountain site (cf. box H). It is located right in the desert and the disposal is above the current water table.
(3) Aquifers are porous and permeable layers of the bedrock, in which underground water infiltrates and circulates.
(4) The description of the "normal" scenario made here applies to disposal in a granite or clay formation (French research is concentrating on these environments). Geological disposal in saline formations, implemented at the US WIPP and envisaged in Germany, is a special case in that salt can hardly be described as a waterlogged porous environment. Moreover the migration mechanisms of radionuclides are quite different in that case from those at work in granite or clay.

*Figure 2. Compartment model simplified to show pathways to the biosphere.*




nil. But research carried out so far suggests that compared with natural **radioactivity** flows, a properly designed engineered barrier, combined with a well-chosen geological barrier, will delay the return of the radionuclides to the biosphere to such an extent that the releases will be minute.

## Planning for the worst to guarantee long-term safety

Could these reassuring predictions be overturned by a volcanic eruption, a major earthquake, unforeseen erosion or major climatic change? Geologists believe they are in a position to answer. These catastrophes do not just happen out of the blue, nor just anywhere. Apart from well-known zones, it is certain that no new volcano will emerge within the next 100,000 years. However, strong earthquakes are expected during the lifetime of the disposal. But their consequences should be fairly limited, if only because seismic movement is weaker down in the depths than it is on the surface. If the precaution is taken to avoid well-known earthquake-prone areas and the disposal is located far enough away from active faults, it is extremely unlikely that any new fault will traverse the facility during its lifetime. Major earthquakes certainly do upset relief contours, but plains are not converted into mountains in the space of as little as 100,000 years(5)! It appears possible to predict erosion, potentially capable of exposing the disposal before radioactivity decay has completed its work, and so minimize the ensuing risks by choosing sites on plains. Finally, glaciations will no doubt occur(6). While the ice cap should not descend directly over the storage site, glaciations could affect underground water circulation in ways that are hard to predict and so should be taken into account.

The biosphere also needs to be mathematically modeled if we are to forecast the disposal's long-term impact. The standard practice is to use models to divide it into compartments the pollutants will flow through according to simple, usually linear laws, with empirically set transfer coefficients. However the real biosphere will certainly evolve rapidly in terms of geological time scales and this evolution will not be so easy to forecast. So a degree of circumspection is required about the dose impact calculated through this modeling and this should be seen for what it is, namely just one conventional criterion among others used to assess the impact of a disposal site (figure 2).

## Piecemeal validation

As the time scales implied by disposal are inaccessible to direct experimentation, there can be no overall validation experiment for all these predictive calculations. Scientists are thus forced to resort to validating the models piecemeal with the prime aim of checking that we have understood the main phenomena at play in how the various disposal elements operate and that reliable predictions can be made on the long-term behavior of the system. There are other reasons for not being over-ambitious. As the natural environment is highly complex, variable and many-faceted, it would be a tall order to supply the computing software with relevant entry data.

Some ten underground laboratories are currently in operation dedicated to research into deep disposal across the globe (see box H, *What are the other countries doing?*). The aim of their work is to validate the modelers' predictions of the impact of disposal facilities' on the environment. This research carried out in underground laboratories or on

(5) The most recently formed mountains in Europe, the Pyrenees, are 40 million years old.
(6) The next glaciation is due in about 10,000 years.

Hosatte /CEA

*The Oklo natural nuclear-reactor site in Gabon. Research into the reactors helps scientists assess the future of very-long-lived radionuclides in an environment that bears similarities to man-made geological disposal sites.*

natural analogues, will clarify the picture of a deep disposal facility as time goes by.

## Landmark results

Landmark results have already been obtained. Research has shown that saline, clay and granite formations are all suitable host rocks for deep disposal. The essential chemical reactions between these rocks, water and any water-borne pollutants make an appreciable contribution to slowing down the migration of many radionuclides. The main outlines of water's path across these low-permeability rocky formations are also understood, as we have been able to reconstruct the history of this passage through past geological eras by studying natural tracers. The findings are that migration in a well-chosen host rock can be very slow (figure 3).

Some questions raised by underground laboratory research remain unresolved. To mention just one example, research into the influence of any fractures in the clay environment on the effectiveness of the geological barrier is still outstanding. However, while these questions do not undermine the specialists' confidence in the ruggedness of deep disposal, they do justify further research in underground laboratories or on natural disposal analogues, such as the Oklo site in Gabon.

## A thousand times less than natural radioactivity

Several international exercises have assessed the radiological impact of a typical deep disposal facility, the two most recent being Everest for category B and C waste and the Spa Spent-fuel disposal Performance Assessment program. What are their findings? Regardless of the geological environment investigated (salt, granite or clay), provided the disposal facility evolves in line with the "normal" scenario described above, its impact is zero during the first 10,000 years and then is calculated in millionths of a sievert per annum for the most exposed populations, i.e. about a thousand times less than exposure to natural radioactivity. Adverse scenarios, such as the sinking of a well close to the disposal facility can spring to mind. Their impact will be stronger and more immediate, but it will be very localized.

Those radionuclides that play a part in the radiological impact of a deep disposal facility must meet two criteria: firstly, they must be present in large amounts in the stored

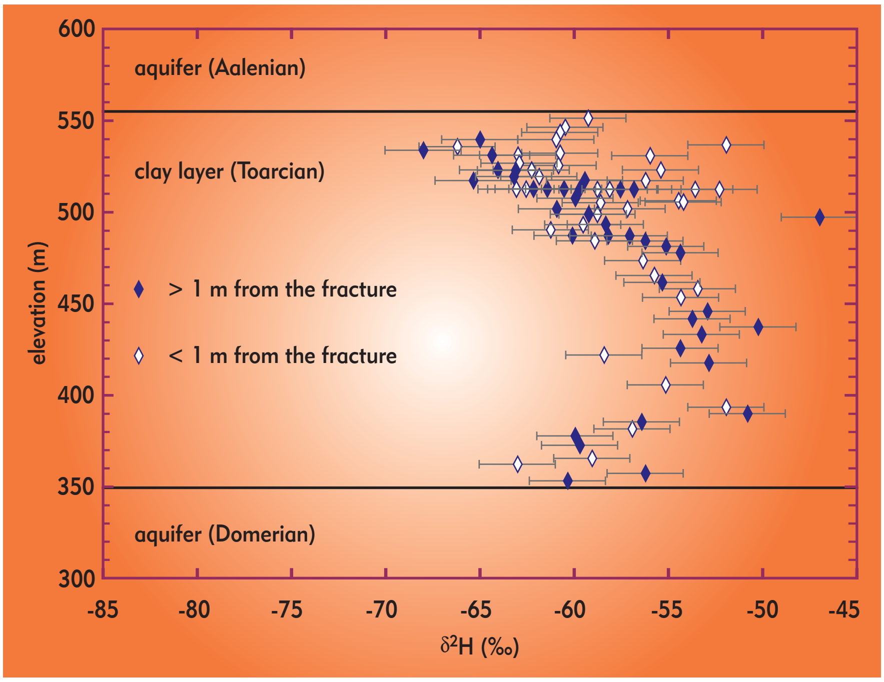
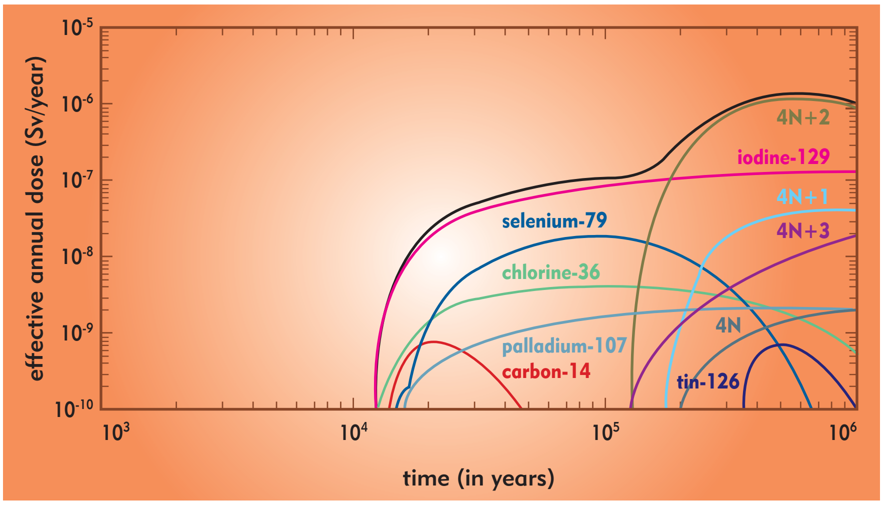



*Figure 3. Study of a natural tracer at the Tournemire (Aveyron) experimental station. Water is shown to migrate through the clay layer very slowly by analyzing the deuterium content of the site pore water, measured along a vertical boring, as the initial composition of the water is partially preserved in the core of the layer despite the very distant date of its formation (180 million years). Away from the fractures (colored dots) the profile is regular, while it is more irregular close to the fractures. This suggests that the fractures play a part in the circulation of the tracer. This kind of research helps arrive at a better grasp of the long-term effectiveness of the geological barrier (Source: Y. Moreau Le Golvan, IRSN).*

*Figure 4. The dose impact of deep spent-fuel disposal in a granite environment revealed by the Spa international exercise. In this particular instance, the impact is zero in the first 10,000 years following sealing of the facility. Then highly mobile iodine-129 is the first isotope to reach the outlet and contributes most to the dose. After several hundreds of thousands of years, the heavy atoms ($^{226}Ra$, $^{230}Th$) from decay chains 4N ($^{232}Th$ chain), 4N+1 ($^{241}Am$ and $^{237}Np$ chain), 4N+2 ($^{238}U$ chain) and 4N+3 ($^{235}U$ chain) take over the running. (Source: P. Beaudoin, IRSN).*




waste inventory and have a large **radiotoxicity**. Secondly, their **half-life** must be long enough to enable them to complete their voyage towards the biosphere, taking into account the chemical-retention phenomena in the undergound medium.

The first criterion can be quantified in terms of **radiotoxic inventory**. On this criterion alone, **actinides** would easily make it to the top of the list of radionuclides giving cause for concern. As for at the second criterion, **long-lived fission products** come to the fore. They are the first to reach the outlets and food chains, as they are the most mobile in the geological environment.

Now the impact of deep disposal on man and the environment cannot be judged by the sole yardstick of the radiotoxic inventory of the waste in isolation! The effectiveness and duplication of the barriers that make up the facility should ensure that impact of deep disposal evolving normally remains minimal, local and postponed. Adverse scenarios, whose impacts may be stronger and which are by nature unpredictable (especially when human intrusion is involved) are nevertheless likely to undermine any safety margins built in.

For all these reasons, disposal safety assessments should aim at a key objective: they should build confidence by providing a host of convergent evidence to demonstrate that all the mishaps likely to affect the disposal facility have been properly taken into account and that the design of the facility is rugged and well-engineered.

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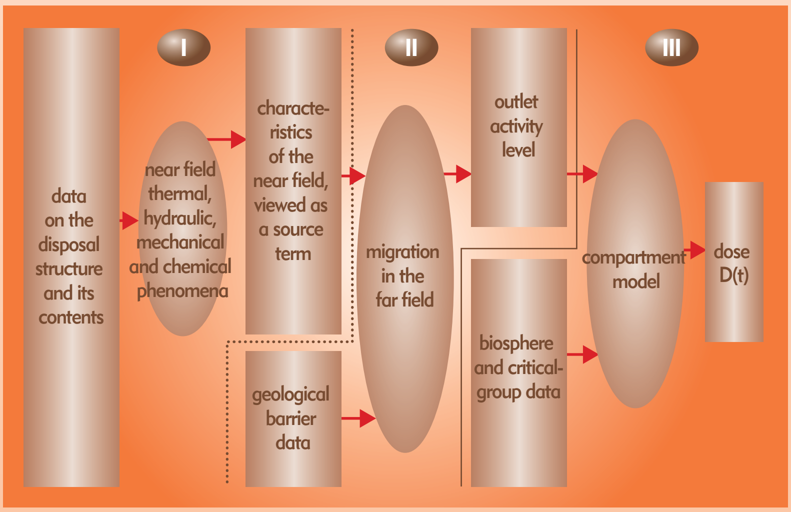
## How to assess the impact of deep disposal

In order to predict the impact of deep disposal, the **models** must be built on data describing the state and evolution of its various components. In **near field** (near the disposal), the thermal, hydraulic, mechanical and chemical phenomena are tightly intermeshed and coupled with each other. Intricate modeling should result in describing the near field as a source term with known characteristics (geometrical shape, type of **radionuclide** concentration at the boundaries of this source term, length of activity, etc.) (phase I of the diagram). A second phase could be to describe the migration of radionuclides in the far field through the geological **barrier**. The main difficulty lies in knowledge of the underground environment and its heterogenous structure. At the end of this phase, it should be possible to assess the **outlet** activity level for each radionuclide against time. Comparing this with the natural dose rate should demonstrate how low the impact of the disposal facility is (phase II). The last modeling phase, describing the transfer of radionuclides through the various compartments of the biosphere should result in calculations of the dose impact (phase III).

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