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Microorganisms in nuclear waste disposal. Conclusions

R. Bachofen

Institute of Plant Biology, University of Zürich, Zollikerstr. 107, CH-8008 Zürich (Switzerland)

What is the importance of microorganisms in nuclear waste disposal?

From the various subsoil microbiology programs we know that microorganisms with widely varying activities are present in all kinds of soils and rocks, down to depths of over 500 m; thus it must be concluded that whether autochthonous or brought in during building and filling, microorganisms will be present in any repository.

In contrast to the situation in higher plants and animals where species are thought to be 'habitat bound', archetypal microbial populations for specific environments probably do not exist. While different habitats may have different and location-specific microbial activities, many microorganisms have a world-wide distribution and can be isolated from many different sources. In most situations they may be dormant and show no physiological activity, although they may become active after being brought into the nutrient-rich laboratory test systems. It is therefore not surprising that in laboratory experiments conducted with waste, backfill or rock material, there is no difference in physiological activities whether the system has been inoculated or not. This has been observed e.g. for bitumen degradation, for nuclide adsorption or in black box experiments containing the real components of a repository. It has been known for microorganisms which survive the most hostile environments and stay at conditions which allow absolutely no growth for thousands of years, to suddenly become active when transferred to the conditions to which they were originally adapted; for example it has been demonstrated that thermophiles are present in lake sediments where the temperature has remained at 4 °C for the last 10 000 years.

Microbial ecologists agree that probably all natural ecosystems are more or less heterogeneous, macroscopically as well as microscopically. Environmental conditions change in the m to km range as well as in the µm to mm range. At this level of heterogeneity a great number and a broad diversity of niches is created which allows the growth and activity of a wide variety of microorganisms. Often microorganisms form biofilms by attachment on abiotic or biotic surfaces; experimentally, biofilms have been observed even on surfaces of bitumen and concrete. Biofilms are heterogeneous layers of cells mostly of a variety of species and exopolymers, they act as barriers or filters which result in steep chemical gradients across the film, for example pH-gradients across biofilms on concrete.

How do microorganisms change the known processes going on in a repository?

The immediate goal of the various agencies in each country in charge of the safe disposal of waste is to determine whether the presence of microorganisms affects the different physical and chemical processes going on in a repository, either in a positive or in a negative sense, e.g. corrosion of metals or concrete, gas formation from organic material disposed or mobility of elements in ground water and rocks. Although microorganisms cannot change overall thermodynamics, their metabolism may lead to different intermediates promoting indirect effects, e.g. reaction rates may be greatly accelerated, new degradation products may accumulate or the physical environment may be altered. The question is therefore to determine the cases in which microorganisms may be critical to safety analysis. So far such determinations are often based only on geological, physical and chemical factors.

Do we know all the possible effects microorganisms can have in a repository?

Adsorption of inorganic and organic compounds, gas formation, excretion of complexing agents, biodegradation of complexing agents or filling materials, reduced porosity in soil and rocks by excreted polymers are processes known to be the result of the presence of microorganisms. How much will the presence of microorganisms alter diffusion and transport of nuclides in the pore water?

Modelling of microbial processes is just beginning for complex cases such as natural ecosystems. So far not enough quantitative data are available on most ecosystems and therefore extrapolation for a future prognosis seems to be problematic. Good models are known for homogeneous systems such as fermentors, however, assuming homogeneity in ecology will lead to highly erroneous results. While the qualitative behavior of a system with arbitrary numbers for the x- and y-axis may illustrate possible successions and activities, both the time axis (x) and the effect axis (y), e.g. cell number, gas produced or substrate used, may vary greatly in space due to the large inhomogeneity of the system studied.

Chemical researchers have developed models to predict changes within the repository based on chemical processes. In many cases microorganisms accelerate the chemical reactions going on. Frequently, in spite of the formation of the same products, new intermediates with different properties may arise. It must be questioned whether the worst-case scenario of a chemical model also takes the microbial effects into account, or whether more detailed and specific microbial models must be developed. Chemical models assume a homogeneous system, but a repository is an extremely heterogeneous ecosystem. Mixed microbial associations interacting metabolically are able to grow on mixed substrates. Gradients of organic and inorganic substances are formed. Particles of inorganic materials are present allowing the formation of immobilized bacterial communities as biofilms. Cells may be in competition with mineral particles and humic substances for the availability of soluble compounds. A realistic model which includes microbial activities must therefore be more than existing homogeneous models which may depict a steady state in a chemostat. Phenomena such as metabolic interactions and metabolic communication between populations in complicated degradation pathways, competitive displacement of populations, separated and overlapping niches, selection and evolution of species under selection pressure or biochemical cycling have to be included in such models.

In summary, we have amassed quite a considerable amount of qualitative information from general microbial ecology and from repository-directed experiments. For a good safety analysis however, and in order to be able to model the future behavior of a repository with the inclusion of microbial effects, we clearly need more quantitative data. More basic research is needed on biofilms and their activities, on activities of microorganisms in such environments in situ, on the persistence of adsorbed and bound organic and inorganic materials and on the biological heterogeneity or spatial variability of natural ecosystems as well as of a repository. In modelling it is of primary importance that this heterogeneity be included. Spatial heterogeneity is probably the reason why experiments with microorganisms do not result in straightforward numbers as with chemical experiments in solution, but rather in broad ranges of values. Extrapolation for thousands of years thus becomes difficult, and agencies concerned with safety analysis lose confidence in such data.

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