The Swedish final repository and the possible risk of interactions by microbial activities

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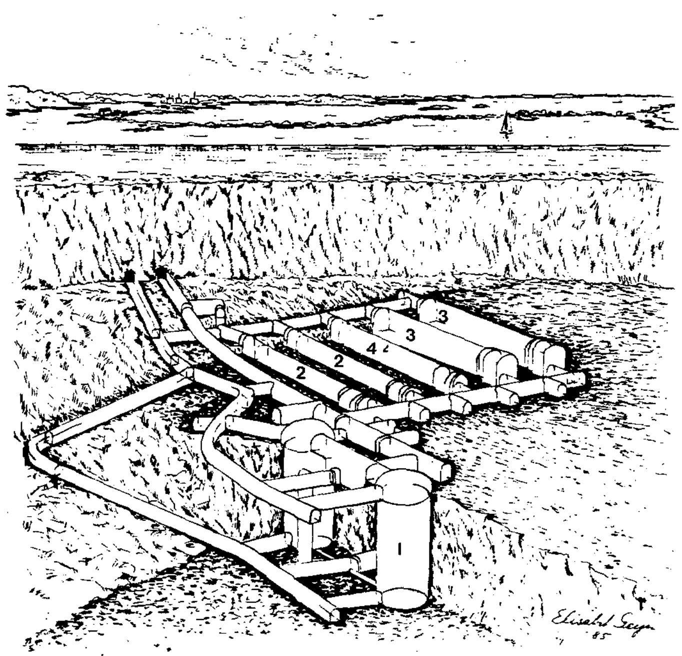
Summary. The final Swedish repository for low- and intermediate-level nuclear waste is described, and some of the possible problems caused by microbial activity during storage are discussed. Microbial degradation of bitumen constitutes one of the greatest risks in the silo part of a repository. The production of carbon dioxide due to both aerobic and anaerobic processes might lead to a decrease in the pH of the water, inducing corrosion of the metal construction and storage containers, with large amounts of hydrogen gas being produced. A risk assessment for the repository must thus take into account the various activities of microbes.
Key words. Bitumen; biodegradation; gas production; radioactive waste.

At present in Sweden low- and intermediate-level nuclear waste is being stored temporarily at nuclear power plants until completion of the final repository site. This will consist of a number of mined rock caverns situated off the coast of Uppland around 50 m below the Baltic sea bed (fig.). The repository will be surrounded by a concrete barrier, and outside this there will be a clay (bentonite) barrier to minimize water flow through the system.

The repository is designed to house a total of 90,000 m^3 of low- and intermediate-level radioactive waste generated during 30 years of operation of the Swedish nuclear power plants. It consists of two vertical circular rooms (silos) with a height of 50 m and a diameter of 27 m, holding 35,000 m^3 of waste. Each silo is surrounded by a 1.25-m-thick bentonite barrier. The silos are divided into compartments by concrete walls. In addition, in five horizontal caverns, waste in concrete tanks, steel drums and concrete blocks will be stored. Table 1 summarizes the various types of waste that are to be stored in the different parts of the system. After the repository is sealed it will slowly fill with water over a period of 30–300 years. The hydrostatic pressure will increase to 5 bar. During the operational period, local temperatures can be expected to rise from + 10°C to approximately + 60°C, due to the formation of hydrates of the concrete used as backfill inside the silos.

The main function of the barriers around the silo is to minimize the water flow into the waste and to retain the leached radionuclides to such an extent that no significant concentrations will reach the biosphere, so that there will be no risk to public health or safety. Therefore, the barriers provided by waste packing and the engineered and natural barriers of the repository must provide the required long-term isolation of radionuclides. Furthermore, it is necessary to forecast, with reasonable safety margins, the behavior of the disposed waste during the expected storage time in the environment existing in the repository.

Several studies have shown that microbial activity exists in deep geological formations and rock caverns even under extreme conditions[8,12] and a number of studies have attempted to evaluate the risks that might result from microbial activity in nuclear waste disposal[1,2,4,6,7,9,14–16,18]. It has been estimated that microbial activity will be possible in the repository under the prevailing environmental conditions[11]. The composition of the waste, as well as the environmental conditions, will determine the extent of microbial activity. One important factor is the amount of degradable material. In the repository a number of materials such as cellulose, organic compounds in ion exchangers, textile materials etc. are degraded by microorganisms. Some of the waste will be encapsulated in bitumen. It is in the silo part, where bitumen dominates as an organic substrate, that microbial activity could cause the greatest problems.



Design of final repository SFR for LLW and ILW radioactive waste. 1, Silos; 2, BTF (concrete tank storage); 3, BMA (rock cavern MLW); 4, BLA (rock cavern LLW).

Approximately 3 × 10^4 moles of oxygen will be present when the repository is sealed, and will be available for the aerobic degradation of bitumen and other organics, but in time an anaerobic situation will develop. Experiments

Table 1. Estimated amounts of reactor waste from Swedish reactors accumulated during a period of 30 years which are to be placed in the final repository for LLW and ILW.

Type of packing and storage	No. of packages	Volume (m^3)
Silo		
Concrete/steel cube (cement)	13700	23600
Steel drum (cement)	3300	1000
Steel drum (bitumen)	7700	2500
BMA		
Concrete/steel cube (cement)	4300	7500
Steel cube (bitumen)	1500	2500
Steel drum (cement)	1100	400
Steel drum (bitumen)	4700	1500
BTF		
Concrete tank	1010	10100
BLA		
Container 20'	716	27200
Steel drum (cement)	6000	1900

Table 2. Chemical and microbial analysis of groundwater from HKl, Singölinjen, Forsmark.

Compound	Concentration	Compound	Concentration
CO_3^{2-}	59 mg/l	Mn	0.59 mg/l
NH_{4+}	0.19 mg/l	Fe(II) tot	0.50 mg/l
NO_{3-}	0.01 mg/l	Cl	4300 mg/l
NO_{2-}	0.004 mg/l	F	0.79 mg/l
PO_4^{3-}	0.01 mg/l	pH	7.5 mg/l
SO_4^{2-}	220 mg/l	Conductivity	1290 mS/m
H_2S	< 0.01 mg/l	Fungi	< 1/ml
Na	1500 mg/l	Aerobic bacteria	8.0×10^2/ml
K	8.8 mg/l	Anaerobic bacteria	< 1/ml
Ca	1200 mg/l	Sulfate-reducing bacteria	< 1/ml
Mg	170 mg/l	Oil-degrading bacteria	2.1×10^2/ml

on aerobic and anaerobic degradation of bitumen are presented elsewhere in this review [13].

An analysis of the groundwater surrounding the storage site shows the presence of microorganisms including hydrocarbon degrading bacteria. The number of anaerobic microorganisms, however, is low (table 2). The groundwater composition changes after passage through the engineered barrier around the waste [3]; for example, both carbonate concentration and pH increase (pH up to pH 12).

For several reasons bitumen has been chosen as a suitable material to encapsulate radioactive waste. The properties of an encapsulating material which are judged to be important for the safe storage of waste have been reviewed [3] and are, in summary:

- resistance against leaching media;
- radiation stability, and effects of radiation;
- thermal stability, and effects of temperature changes;
- sedimentation of incorporated solids;
- combustibility and explosiveness;
- mechanical stability;
- swelling caused by radiolysis gases and by uptake of water.

The stability of bitumen may be reduced in an environment capable of sustaining microbial life. Bitumenized waste may alter during storage by phenomena internal or external to the product, which influence either the retention or liberation of encapsulated radionuclides. These phenomena can be of chemical, physical or microbial nature and will depend on the properties of the waste encapsulated in the bitumen, as well as on the characteristics of the repository and its environment. Colonization of bituminized waste by microbes, and products from degradative processes, could accelerate radionuclide release, and the microbial activity may also contribute directly or indirectly to corrosion of other barrier materials and give rise to gas evolution with the risk of increased internal pressure developing in the repository.

Table 3. Calculated values for gas production in the silo part of the repository up to the year 2200.

Process	m³/year				
year	2010	2020	2050	2120	2200
Radiolyse	30	15	6	–	–
Biological activity	–	10	10	10	10
Corrosion	–	~2500	~2500	~2500	~2500
Total	30	~2500	~2500	~2500	~2500

Gas may be produced from the waste as a result of several processes, for example degradation of bitumen under the prevailing conditions can contribute to gas production [17]. The amounts of gas expected to be produced are given in table 3 [5]. However, the largest amounts of gas to be produced are due to hydrogen-evolving corrosive processes. It has been shown that when steel is in contact with concrete at pH 12, corrosion with the release of hydrogen gas does not occur. However, if carbon dioxide is produced by microorganisms in sufficient quantities to cause a decrease in pH to 4–5 under anaerobic conditions, hydrogen-evolving corrosion increases significantly. The corrosion rate is correlated to the partial pressure of carbon dioxide and the temperature. Carbon dioxide may be absorbed by concrete, and water in contact with concrete has a low buffering capacity [10,17].

Conclusions

It must definitely be assumed that there will be microbial activity in the repository. The amount of microbial activity, and its effects on stored waste are difficult to forcast, due to the 50-500-year-long time span under consideration for storage. It is of great importance to examine the rates of microbial degradation of bitumen under both aerobic and anaerobic conditions in this environment, where bitumen is the main carbon source that can be used by microorganisms. Such degradation rates as well as gas production have been determined in Sweden [13] as well as in other countries.

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Characteristics of nuclear and fossil energy wastes

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Summary. The radionuclides and toxic metals in transuranic, low-level radioactive coal combustion, and coal conversion wastes are summarized. These wastes also contain a variety of organic compounds, some of which can support indigenous microbial activity resulting in solubilization or stabilization of toxic metals and radionuclides.
Key words. Toxic metals; radionuclides; organics; low-level radioactive wastes; transuranic wastes; coal wastes.

Introduction

The wastes generated from the use of fossil and nuclear fuels contain a variety of organic and inorganic compounds, including radionuclides. Subsurface disposal of the large quantities of solid wastes seems to be the viable alternative and may occur as back-to-pit operations or in specifically constructed landfills. Disposal of these complex chemical substances in the subsurface environment can result in the contamination of ground and surface water by waste leachate containing radionuclides, toxic metals, and organic compounds, which renders regional groundwater unsuitable for domestic use or irrigation and presents a significant environmental health and ecological hazard.

The characteristics of the waste vary widely with the source and the process used. In general, the kinds of organic compounds, radionuclides and toxic metals in nuclear and fossil energy wastes are known[1–11]. However, the form in which the radionuclides and toxic metals are present in the wastes, e.g., elemental, oxide, coprecipitate, ionic, organic or inorganic complexes, is least understood, but is important from the standpoint of stability and mobility in the environment. The general characteristics of the type of wastes generated from nuclear and fossil energy are summarized in this paper.

Radioactive wastes

Radioactive wastes are generated from mining, milling, preparation of fuel for reactors, and weapon-production. The wastes containing the radioisotopes may be in the form of gases, liquids, or solids, may be soluble or insoluble, and may give off various types of radiation at many energy levels. Radioactive wastes are classified as high-level wastes, transuranic wastes, and low-level wastes[10].

High-level wastes

High-level wastes (HLW) are either intact fuel assemblies that are discarded after serving their useful life in a nucle-