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MATERIALS AND DEGRADATION MODES IN AN ALTERNATIVE LLW DISPOSAL FACILITY*

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ABSTRACT

The materials used in the construction of alternative low-level waste disposal facilities will be subject to interaction with both the internal and the external environments associated with the facilities and, unless precautions are taken, may degrade, leading to structural failure. This paper reviews the characteristics of both environments with respect to three alternative disposal concepts, then assesses how reaction with them might affect the properties of the materials, which include concrete, steel-reinforced concrete, structural steel, and various protective coatings and membranes. It identifies and evaluates the probability of reactions occurring which might lead to degradation of the materials and so compromise the structure. The probability of failure (interpreted relative to the ability of the structure to restrict ingress and egress of water) is assessed for each material and precautionary measures, intended to maximize the durability of the facility, are reviewed.

INTRODUCTION

Near-surface disposal (in depths up to 30 m from the earth's surface) of low-level radioactive waste (LLW) includes such technologies as conventional shallow land burial (SLB), engineered structures and barriers, and various other concepts. The viability of SLB over very extended time periods (300 to 500 years) is a matter of continual concern and consequently alternative methods of disposal, aimed at minimizing radionuclide transport from the disposal site into the surrounding biosphere, are being considered. Description and evaluation of the various alternatives to SLB can be found in several sources (1-4).

This paper is concerned with the materials and degradation modes of three alternative disposal technologies: below-ground vaults (BGV), earth-mounded concrete bunkers (EMCB), and augered holes or shafts (AH). It attempts to provide an assessment of the compatibility of the construction materials with the disposal environments (both internal and external) and of the possible degradation and failure modes arising from material/environment interactions.

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The probability of failure (interpreted relative to the ability of the structure to restrict ingress and egress of water) is assessed for each material and precautionary measures, intended to maximize the durability of the facility, are reviewed. As the materials of construction are likely to be very similar for all three alternatives the assessments of material/environment interaction effects are considered applicable to all three concepts.

The paper is based on the contents of a report (5) prepared for the U.S. Nuclear Regulatory Commission and those seeking more detailed information and a more comprehensive list of references should consult that report.

THE MATERIALS

The material which will most probably be used for major structural components is concrete (more specifically, steel-reinforced concrete). Both the BGV and the EMCB concepts will employ this material for walls, floors, partitions and roofs. Similarly, plain or reinforced concrete would likely be used to line the shaft in the AH concept.

Of equal importance in maintaining an effective barrier between the waste and the surrounding biosphere are components which do not contribute directly to the strength of the structure. These may be collected under the generic title of "moisture barriers," in that their chief function is to prevent water or other liquids from coming into contact with, or passing through, the main concrete structure. They include: waterstops (made of Type 316 stainless steel, polyvinyl chloride (PVC)); sheet membranes (polyethylene, polyurethane, neoprene, butyl rubber, plasticized PVC); and joint sealants (epoxy resins, polyurethane, acrylics, rubber compounds). Materials such as bentonite, shotcrete and numerous polymers, may also be used to help protect the concrete structure.

THE ENVIRONMENTS

Whatever alternative concept is chosen for the disposal of LLW, the structural materials must be capable of maintaining their integrity while simultaneously exposed to two different environments. The characteristics of the internal environment will be determined essentially by the properties of the waste being contained. Although these properties will depend on the sources of the waste, the general environment inside the structure is unlikely to vary significantly from site to site. Thus, in theory, it is possible to provide an approximate assessment, in both qualitative and quantitative terms, of a "typical" internal environment. By contrast, the characteristics of the external environment will be site-specific. The approach in this case is restricted to identification of those characteristics which may impact upon the durability of the structural materials. The main features of both environments are summarized below and provide a simplified description of the overall environment in which an alternative disposal structure will be required to function.

The Internal Environment

The sources of LLW can be separated into roughly three categories: commercial nuclear power plants; the industrial sector; and institutions and government. Based on past experience, about 60% of the waste is generated by the commercial reactors, 30-35% by industry, and 5-10% by institutions and government. However, new techniques for handling and disposing of wastes are continually evolving and these proportions can be expected to change in the future. Both the power plant wastes and the institutional wastes can be fairly well characterized but this is not so with the waste stream from the industrial sector (6).

Commercial nuclear power in the U.S. is produced by basically two types of reactor (pressurized water reactors and boiling water reactors). There are differences in the waste stream characteristics of the two types of plant, but each stream can be divided into wet and dry types of waste. The wet component typically comprises up to one third of the total waste volume and consists of resins, concentrates, and, for BWRs only, sludges. These wastes are subject to several possible treatments but the final disposal condition is often a solidified form, with cement the most common solidification agent. Dry waste is composed of both compactible (paper, plastics, cloth, etc.) and non-compactible (filters, tools, equipment, wood, etc.) items.

The waste from the industrial sector can be segregated into fuel cycle and non-fuel cycle contributions. Waste from both sources is largely dry, consisting of compactible and non-compactible solids, and solidified forms but there is also a small amount of wet waste.

The third waste stream, from institutional and government sources, can be divided into four types: biological, scintillation vials, solidified and absorbed liquid waste, and dry solid waste. Of these, scintillation vials and fluids, which amount to about a quarter of the waste from these sources, are now classed as mixed waste and are no longer disposed of in LLW sites.

Using the information summarized above, it is possible to construct a very approximate quantitative breakdown of the waste forms to be expected in a disposal structure (Table I). In reality, of course, the distribution may vary considerably from site to site, depending on the principal generators in each state or compact.

TABLE I

Waste Form Distribution.

Waste Form	Percentage of total waste volume			Total
	Power plants	Industry	Institutions	
Dry compactible	25	8	3	36
Dry non-compactible	16	17	0	33
Solidified	19	4	2	25
Not solidified	0	3	3	6

The dry compactible waste will be composed essentially of organic matter but may also contain small amounts of potentially reactive ions such as sulfate and chloride. Other potentially damaging substances (e.g., hydrogen, ammonia, hydrochloric acid gas) may be produced via radiolysis (7) but they will probably be small.

The dry non-compactible waste is unlikely to contain much that might be considered chemically aggressive, the most probable source being products of the biodegradation of wood.

Items such as resins, sludges and concentrates are usually disposed of following consolidation in a variety of solidification agents (cement, bitumen, vinyl ester styrene, etc.). In each case, the dilution factor (waste/binder ratio) is important in determining the amount of potentially damaging substances (sulfates chlorides and nitrates) which may be released into the environment. In addition, radiolysis can give rise to hydrogen, ammonia, and various acidic products. In cases where the waste is solidified in cement, the acids would probably be neutralized by the alkali and lime present in the cement. The amount of free water in solidified waste is limited (by 10 CFR Part 61) to less than 0.5% of its total volume.

The unsolidified waste includes hydroxide filter cake, incinerator ash, biological waste, and general trash. This waste may also contain some free water but the amount is limited (again, by 10 CFR Part 61) to less than 1.0% of the total volume of this type of waste.

It is apparent that only about 31% of the total waste volume is likely to contain any free water. Taking into consideration the limitations imposed on the solidified and the not-solidified waste forms it is estimated that the amount of free water available in the total waste will be limited to about 0.2% of the total waste volume. In reality, there will probably be isolated cases (for both types of waste) when the free water content limitation will be inadvertently exceeded, but these will represent only a small proportion of the total waste volume shipped for disposal.

The preceding paragraphs essentially describe the chemical composition of the internal environment. The radiation field present also has the potential albeit very small, for causing damage in the materials of the disposal structure. Although no precise figures exist, it is anticipated that the total radiation dose experienced by the structure will not exceed more than 100 Mrad.

Most, if not all, of the waste will be placed in containers for ease of handling and transportation, and also to provide some structural stability. In the past, some wastes have been packaged in wooden boxes but it is probable this practice will not continue. The most common container material is carbon steel, often lined with polyethylene. Other containers, especially the high integrity variety, may be made of corrosion-resistant alloys, concrete or some organic-based materials. The containers themselves impact only indirectly on the internal environment, in that, while they retain their integrity, direct contact between the wastes and the disposal structure is avoided.

The final component of the internal environment is the fill placed in the voids between and above the waste packages. This fill may be a free-draining soil of low moisture content, with precautions taken to prevent it becoming saturated during operation of the disposal facility. Obtaining such fill in desert locations will not be a problem but conceivably these soils could have high salt contents, in which case it will be imperative to assure that the fill remains dry. At more humid sites, it will be doubly important to assure that the chemical activity of the soil is low, and, if feasible, to dry the soil before using it as fill. Alternatively, specially engineered backfill or grouting with concrete may be used.

In summary, it is apparent that two thirds of the waste contain essentially no water and are unlikely to contribute toward water-mediated degradation of the disposal structure unless liquid physically enters the structure. Limitations imposed on the remaining waste will ensure that, unless there is ingress of water from other sources, the maximum amount of free water in the waste will be equivalent to less than 0.2% of the total waste volume. Both the solidified and the unsolidified wastes contain chemically reactive species which could be leached out by the available free water. Such action, in turn, could lead to breaching of the waste containers and transport of the corrosives and radionuclides into the fill material which occupies the space between the waste packages. The other source of potentially damaging effects resulting from the wastes is the radiation field which will give rise to gas production in the wastes and possible physical damage in the materials of construction. Also of importance are the properties of the fill material placed in the voids between and above the waste packages.

The External Environment

The site-specific nature of the external environment prevents the formulation of a general characterization of this environment in the manner adopted for the internal environment. Rather, it is more appropriate to consider all the parameters which determine the character of the external environment then identify those which are most important in determining the potential for materials degradation. The key basic parameters from this point of view are: water content of the soil; water chemistry; soil salt content; soil organic matter; bacteria content; and gaseous constituents.

The presence of water is essential if chemical action is to take place at the soil/material interface. If the water content of the soil is very low and replenishment infrequent, then the possibility of materials degradation due to chemical interaction will be minimal. When water is readily available in the soil, the properties of the soil water and the type and extent of chemical activity will be determined by the chemical composition. These are dependent on such factors as soil mineral and organic content, and water replenishment sources. The most commonly used indicators of potential chemical activity are the soil water pH and the ionic content. Soil water in the U.S.A. is most often slightly acidic (pH values 5 to 6) but specific locations may be strongly acidic (pH 3 or less) or strongly alkaline (pH 10 or more). The ionic content of a soil is reflected in its electrical resistivity, the two quantities being related in an inverse manner. A soil with low resistivity (less than 500 ohm-cm) will have a high ionic content and thus a potential will exist for extensive chemical activity.

Of more relevance than the values of properties such as electrical resistivity are the actual ions and gases dissolved in the soil water. The most important of these with respect to concrete degradation are the sulfate and chloride ions. Data collected from some 50 to 60 sites (8) indicated that water extracts from the majority of the soils had sulfate and chloride contents of less than 500 ppm and would generally be considered non-aggressive toward concrete. However there were a significant number of sites with much higher concentrations (greater than 2000 ppm) which could cause rapid degradation.

Other anions commonly found in soil water include carbonates (and bicarbonates), nitrates and sulfides. Of these, the sulfides, which can be easily converted to sulfates, might be considered the most detrimental to concrete. Fortunately, concentrations of sulfides tend to be very localized and such sites easily detected and avoided.

The cations most prevalent in soil water are sodium, calcium, and potassium but they are usually only important inasmuch as they are associated with potentially aggressive anions. With the exception of magnesium and calcium, little concern is expressed about the cation contents. The magnesium content is generally of the order of 100 ppm or less, but it can be found in higher concentrations. These higher levels are known to enhance the chemical activity of sulfate and chloride ions. The calcium content, if unusually low, could be an indication that the soil medium is aggressive towards concrete.

Some soils contain free mineral acids and weak organic acids, both of which can cause concrete degradation, sometimes very rapidly. Fortunately, locations with such conditions are rare, easily identifiable and thus unlikely to be selected as sites for LLW disposal. Soils are also capable of sustaining bacterial activity which may involve sulfate formation. The type and extent of activity depend on factors such as degree of aeration in the soil and it is probable that such action will probably be greatly reduced at the depths involved in LLW disposal.

Soil water often contains dissolved carbon dioxide, thereby becoming carbonic acid. Such solutions are capable of leaching the lime from concrete and causing eventual disintegration. However, carbonic acid exists primarily at low pH values (less than 5). Thus, the majority of the soils in the U.S.A. (pH greater than 5) will probably have a low dissolved carbon dioxide level (less than 30 ppm). At the same time, carbon dioxide in the gas phase can lead to degradation of concrete via the carbonation reaction. On the other hand, the presence of the gas in restricted quantities, a likely possibility in a burial environment, not only reduces carbonation but can lead to retardation of the much more aggressive sulfate reaction.

The presence of oxygen is important in starting and sustaining chemical reactions and highly aerated soils are usually among the most chemically aggressive. However, as with carbon dioxide, burial conditions will tend to minimize access to the gas.

Other soil parameters, such as the cation exchange capacity and the redox potential, can determine the chemical activity of a soil but their effects are not easily quantifiable. Moreover, they are probably only of minor importance from the aspect of material/soil interactions.

The preceding paragraphs emphasize the importance of site characterization during the site selection process. In addition, some account must be taken of the changes induced in those properties as a consequence of excavation and construction. Such changes may be minor and within the variability of the site as a whole, but should not be ignored.

In summary, although the potential exists for extensive interaction between the disposal structure and its external environment, the site selection process will probably result in the elimination of the most aggressive environments from consideration. The preferred sites, from the viewpoint of low chemical activity, would be those located in dry regions with well-drained soils. However, not all states and compacts have this option available so it must be assumed that water is usually available in the soil and that some chemical activity will exist. That being so, the presence of above-average sulfate and chloride levels can lead to degradation of structures made of plain or reinforced concrete. Acidic soils with carbon dioxide dissolved in the water also present a potential source of material degradation. There exist other parameters which are capable of affecting the chemical activity of the external environment but their effects probably will be minor.

Summation of Environments

It is apparent that disposal structures will be exposed to environments having many variables of differing importance. Table II represents an attempt to summarize these factors and thereby provide a very brief, qualitative description of the overall environment to which a disposal facility will be exposed.

TABLE II

Summary of Environment Parameters Relevant to Materials Degradation.

Parameter	Internal Environment		External Environment	
	Present?	Probable amount	Present?	Probable amount
Water	Yes	<0.2 v/o*	Yes	Site dependent
Sulfate	Yes	Small	Yes	<500 ppm?#
Sulfide	Unlikely	-	Possibly	Very small
Chloride	Yes	Small	Yes	<500 ppm?#
Nitrate	Yes	Very small	Yes	Very small
Calcium	Yes	-	Yes	<500 ppm?#
Magnesium	Probably	Very small	Yes	<100 ppm?#
Hydrochloric acid	Yes	Small	Unlikely	-
Ammonia	Yes	Very small	Possibly	Very small
Hydrogen	Yes	Small	No	-
Carbon dioxide	Yes	+	Yes	Very small
Radiation	Yes	<100 Mrad	Yes	Background

* - assuming internal fill material is dry.
 # - content in soil water.
 + - variable; depends largely on aerobic biodegradation; theoretically, could replace most of the oxygen present originally and any oxygen which diffuses into the disposal unit.

DEGRADATION OF DISPOSAL STRUCTURE MATERIALS

In the following discussion, the assumption has been made that the waste containers provide no barrier between the waste and the fill material placed around the packages. In reality, of course, the packages will serve to separate the waste from the fill for a certain length of time. Carbon steel containers may retain their integrity for a few decades (9, 10), while high integrity containers will probably last much longer. By assuming that the containers have a zero barrier effect at all times, evaluation of the effects of the internal environment on the disposal structure materials is not only simplified but also gains a degree of conservatism. It is also assumed that the container materials themselves are not potentially degrading to the main disposal structure materials. This assumption is not, strictly speaking, valid if consideration is given to the breakdown of organic materials such as polyethylene.

Concrete

There are many factors which affect the quality of concrete and its long-term stability, including those which the fabricator can control during the construction process. However, the focus in this paper is on the environmental factors only, it being assumed that the fabricator will employ appropriate construction practices to ensure a high-quality product.

The various environmental agents and processes which can cause degradation of a concrete structure include: freeze-thaw cycling; sulfate attack; chloride attack; acid attack; leaching of calcium hydroxide; abrasion/erosion; radiation; and biodegradation.

The basic mechanism in freeze-thaw cycling involves the expansion on freezing of the water in the capillary cavities and the attendant development of severe stresses in the concrete. These are relieved by cracking and fissuring, thereby increasing the permeability of the concrete (11). The process, which can also eventually lead to structural failure, thus constitutes failure in the present context. Damage from freeze-thaw cycling will be a factor only during the construction and operation phases, and then only if the structure is located in a cold climate. For most of the intended life of the disposal facility, the structure will be buried and not subject to significant temperature cycling due to local climatic variations. However, it will be desirable to use air-entrained concrete if there exists the possibility of frost damage occurring during the initial phases.

Sulfate attack is potentially the most serious concern as both the internal and the external environment will contain this ion. The mechanism of attack involves reaction with lime and with hydrated calcium aluminate in the cement paste. The reaction products, calcium sulfate and calcium aluminosulfate, are much greater in volume than the reactants and thus induce severe stresses and cracking as they form (11). The degree of attack will be dependent on the actual sulfate contents involved and the availability of moisture. The problem has long been known in the concrete industry and consequently standard formulations exist which can be used to make sulfate-resistant cements. Adherence to the guidelines which define which formulations are appropriate for the various environmental conditions should ensure that the concrete structures in an alternative disposal facility are resistant to sulfate attack.

Plain concrete can be attacked by strong chloride solutions but the environments at a disposal facility are unlikely to provide a sufficient concentration of chlorides to cause anything more than very minor damage. However, even low concentrations of chlorides can cause significant damage to steel-reinforced concrete. This damage occurs as a result of diffusion of chloride ions through the concrete pore structure and subsequent reaction with the steel reinforcing bars. As with sulfate attack, the corrosion reaction results in a volume increase. This, in turn, creates internal stresses in the overlying concrete which eventually cracks and becomes more permeable to water (12). The potential for degradation by this mode can be minimized by the use of concrete with very low permeability and by applying a protective coating of epoxy to the reinforcing steel. Again, considerable experience has been gained in protecting reinforced concrete from degradation in chloride-containing environments much more aggressive than those likely to be encountered in LLW disposal, and the probability of significant damage by this mode of attack must be considered very low if the necessary precautions are taken.

The principal degradation mode associated with acid attack involves reaction with lime (and possibly calcium silicate hydrates) in the cement paste and the formation of soluble calcium salts. The latter can then be leached out, destroying the binding ability of the paste and weakening the concrete (13). Cracks developed in the weakened concrete would lead to increased permeability of the structure to water. Whenever there is a likelihood of acids coming into contact with concrete, the normal action is to apply a protective coating. This may not be a serious concern in the case of disposal structures as the occurrence of acids in sufficient concentrations to cause significant damage is considered highly improbable.

Leaching of calcium hydroxide by water has essentially the same consequences as acid attack followed by leaching of the soluble salts thus formed. Obviously, a large amount of water will be required to dissolve an appreciable amount of lime, a situation which will not pertain inside a disposal structure. Externally, the required quantities of water would likely only become available if the disposal unit was located beneath the water table. In all probability, then, significant degradation due to leaching of lime by water should not be of concern.

Abrasion and erosion are both of only minor concern in the present case. Erosion, in particular, which requires a reasonably rapid flow of water containing entrained solids, can be virtually ignored. Abrasion, however, can occur during the construction and operation periods and, if unattended, could lead to the development of cracking. Use of high quality concrete will, in general, restrict the damage to a relatively thin surface layer which can be repaired prior to closure of the site. Thus, abrasion is not considered a likely source for degradation of the concrete structures over the long term.

Two other factors capable of causing damage are radiation and biodegradation. Direct radiation damage to concrete will not be significant because of the low maximum dose likely to be accumulated in a LLW disposal structure (14), although recent data indicate that loss of compressive strength may be experienced at doses in the range 10-100 Mrad at low dose rates (15). Similarly, concrete is not expected to suffer significant direct damage due to biodegradation, although secondary processes could have adverse effects over

long times. However, radiolysis and biodegradation of the organic materials in the internal environment will produce considerable amounts of gas, the predominant one being carbon dioxide. Internal pressurization of the structure is possible and, if large enough, could conceivably lead to cracking of the concrete. This latter scenario is considered unlikely due to the gas permeability properties of concrete. Degradation could also arise from reaction of the carbon dioxide with the lime in the concrete to form a soluble salt which can be leached from the cement paste. This is a variation on the acid attack process described above and much the same analysis applies. That is, the leaching process cannot occur unless a relatively large amount of water is available, a highly improbable situation.

Organic Materials

Organic polymers will be used to complement the structural function of the concrete. The components include sheet membranes, coatings and sealants, waterstops and joint sealants, and it is likely that the same polymer will be used in several different applications. In general, these organic materials, which have a high resistance to attack by aggressive aqueous media, will be little affected by the agents and processes that cause degradation in concrete. They are, however, susceptible to degradation via: ultraviolet (UV) photolysis; oxidation; radiation; alkaline hydrolysis; and biodegradation. Failure by mechanical means during the operation phase is also possible but it is assumed here that the damage will be repaired before closure. Thus this failure mode should not constitute a problem over the long term.

UV photolysis (16) will only occur during the construction and operation phases as there will be no exposure to light after closure. However, any deterioration that occurred during the early stages could lead to premature breaching of the moisture barrier. Resistance to chemical change can be enhanced by the incorporation of a UV stabilizer in the polymer. At the same time, it should be noted that exposure to UV light, while perhaps not causing significant direct degradation, can lead to enhanced biodegradation later in time, after site closure.

Direct atmospheric oxidation and reaction with oxygen gas may be only very minor effects, though conceivably reaction with ozone could cause more damage. However, oxidation induced by nuclear radiation and by microorganisms must also be considered. The former mode, in particular, can produce rapid deterioration at slightly elevated temperatures but the reaction is much slower at temperatures close to those expected in a belowground disposal facility. On the other hand, the type of bond breakage that occurs in the oxidation reactions observed with some polymers at low dose rates could lead to the formation of molecular fragments which would be susceptible to biodegradation. As with the UV photolysis process, the oxidation reactions can be retarded by additives (in this case, antioxidants) to the polymers.

All organic materials are susceptible to radiation damage although the properties of the high molecular weight polymers will likely be less adversely affected than those of most non-polymeric materials. Radiation damage can occur at doses as low as 1 Mrad, particularly at low dose rates (17), and significant loss of ductility can be observed after 100 Mrad, irrespective of dose rate. The damage incurred at low dose rates is usually attributed to oxidation effects and can be reduced by the presence of anti-oxidants in the

material. In addition, doses as high as 100 Mrad are unlikely to be seen at the locations where the organic materials would be used, except, possibly, at a very few local "hot" spots. Thus, radiation damage to the organic materials may be relatively small and not have a significant impact on the integrity of the moisture barriers.

Another process by which an organic material can be degraded is hydrolysis by alkaline (calcium and sodium) hydroxides in the pore structure of the concrete. This may be particularly pertinent if the concrete is impregnated with an ester, although no long term data exist to indicate if this will be a significant problem. It is also conceivable that hydrolysis might affect certain coatings by the destruction of the chemical bonding to the concrete.

It is likely that organic materials used for moisture barriers will be subject to biodegradation, but the degree of attack cannot be predicted. While microorganisms are incapable of metabolizing high molecular weight polymer molecules, actual polymeric material will also contain small amounts of residual monomer and low molecular weight organic molecules in the form of additives. In addition, biodegradation rates which would normally be quite low may be markedly enhanced by the presence of UV light and nuclear radiation.

From the above, it is apparent that many uncertainties exist in predicting the service life of components made of organic materials. Because of the interrelationships between the various degradative processes, it is unrealistic to expect these materials to function adequately for the several hundred years required of a disposal structure. More probably, the life expectancy for polyethylene and the more durable of the other materials will be of the order of many decades.

Steels

Steels will be used in several applications, including reinforcement for the concrete, waterstops, portal frames and crane rails. Most of these, except the waterstops, will involve plain carbon steels. The waterstops will likely be made out of Type 316 stainless steel, the choice of which arises because of the questionable durability of organic materials over the intended life of the disposal facility.

Of the environmental factors which might cause deterioration of steel, only those which are corrosion-related are of concern. For example, although steels can become severely embrittled by neutron radiation, such an environment will not exist in a LLW disposal facility. Steels and other metals are generally unaffected by gamma radiation. Also, steels are not subject to biodegradation in the sense that the term is applied to organic materials, although microorganisms in soil can create a corrosive environment and induce pitting attack.

Corrosion of the steel components will arise mostly from exposure to a soil environment. The waterstops could be exposed to both the external and the internal environment, while other items will see essentially only the internal fill material. The types of corrosive attack which should be considered include: general metal loss and pitting; crevice corrosion; and stress corrosion cracking.

Corrosive degradation of the steel reinforcing bars in the concrete has been briefly described in preceding paragraphs and will not be discussed further here. In addition, steel components other than the waterstops and reinforcing bars have no function after completion of the construction and operation cycles. The rate at which they deteriorate during closure and stabilization of the site, and during the post-closure periods is of little direct relevance to the overall structural integrity of the main engineered barrier. It remains only to ensure that the functioning of the barrier is not compromised where these components interface with it. Thus, their degradation will not be treated further here and attention will be directed to the performance of the steel of the waterstops.

Failure of the waterstops is of much concern as this could lead to unrestricted passage of water and other liquids through the engineered barrier, irrespective of the integrity of the concrete. Type 316 stainless steel is preferred over the carbon and low alloy steels because of its much superior corrosion resistance. Corrosion of stainless steels in soil is generally very low (8,18) and extrapolation of metal loss data indicates that, if the thickness loss is uniform, the waterstops will easily maintain their integrity over a period of 300 years. However, a considerable amount of the metal loss will likely be via localized corrosion processes such as pitting. It is conceivable that some pits could penetrate completely through the metal and allow the passage of liquid. The probability of this happening is thought to be low but the data available do not permit a rigorous quantitative evaluation of the rate of pitting attack. Thus, precautions should be taken to minimize the degree of attack, possibly by coating the waterstop with epoxy or similar material, as is recommended for the reinforcing steel in the concrete.

Crevice corrosion is often thought of as a special case of pitting corrosion brought about by component designs which include very narrow gaps between two materials. Such gaps severely restrict access to dissolved oxygen while simultaneously allowing concentration of anions, thus forming an increasingly acidic environment. The geometric configurations associated with the waterstops may favor this type of attack. However, if precautions such as coating the steel are taken, the rate crevice corrosion progresses can be significantly retarded and the possibility of premature failure considerably reduced.

Type 316 stainless steel is very susceptible to stress corrosion cracking. However, for it to occur, three factors usually need to be in place: high chloride content, oxygen and stress. Although some concentration of chlorides is possible, the access of oxygen will be severely restricted by the depth of burial. In addition, the stresses in the waterstops will probably be very low. Thus the possibility of the waterstops failing by stress corrosion cracking is considered quite remote.

Based on the above, it is expected that waterstops made of Type 316 stainless steel, suitably coated, should have a life expectancy as great as that of the disposal structure itself, and that the performance of the concrete will not be adversely affected.

bentonite

Bentonite, a naturally-occurring expansive clay, is a potential moisture barrier material. Its performance can be affected by agents and processes which are different again from those which affect concrete and the other materials used in the disposal structure. Bentonite barriers can be breached by physical damage sustained during construction and operation of the facility, by freeze/thaw cycling and, after closure, by expansion and contraction due to large fluctuations in the water supply. All these factors can be minimized by taking appropriate precautionary measures and thus should not be significant factors in determining the life of the barrier.

In addition, there exist several processes which tend to transform the bentonite to other mineral forms (illite, kaolinite, albite) and so diminish its water sorption ability. These processes include hydrothermal instability, selective dissolution and radiation (19). However, most of the reactions will be very sluggish under the environmental conditions associated with a disposal facility and are unlikely to cause any significant degradation, even over a period of a few hundred years.

SUMMARY AND CONCLUSIONS

The materials used in the construction of an alternative LLW disposal facility will be many and varied. The principal structural components will probably be made of reinforced concrete. These will be complemented by several components which can be grouped under the heading moisture barriers and which include stainless steel waterstops, organic polymer sheet membranes, joint sealants and bentonite. A third group of miscellaneous components whose use will be limited mostly to the construction and operation phases will probably be made of structural steel.

All the above materials will be subject to interaction with both the internal and the external environments associated with the facility. The compositions of these environments have been reviewed and it is concluded that both contain potentially harmful constituents, such as sulfate and chloride ions. However, the presence of moisture is essential if any significant chemical activity is to occur.

There are many reactions which might take place between the materials and the environments. These have been reviewed to identify those which might lead to degradation of the materials and so compromise the structure. The probability of failure (interpreted relative to the ability of a component to restrict the passage of water) has been assessed for each material and precautionary measures, intended to maximize the durability of the facility, have been indicated.

It is concluded that a disposal facility structure can be made which should exhibit satisfactory long-term performance under the environmental conditions likely to be associated with the facility, provided that certain recommendations are followed and that appropriate codes and standards are employed during construction and operation.

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