SOME CONSIDERATIONS IN THE EVALUATION OF CONCRETE AS

A STRUCTURAL MATERIAL FOR ALTERNATIVE LLW DISPOSAL TECHNOLOGIES*

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ABSTRACT

The objective of this study was to develop information needed to evaluate the long-term performance of concrete and reinforced concrete as a structural material for alternative LLW disposal methods. The capability to carry out such an evaluation is required for licensing a site which employs one of these alternative methods. The basis for achieving the study objective was the review and analysis of the literature on concrete and its properties, particularly its durability. In carrying out this program characteristics of concrete useful in evaluating its performance and factors that can affect its performance were identified. The factors are both intrinsic, i.e., associated with composition of the concrete (and thus controllable), and extrinsic, i.e., due to external environmental forces such as climatic conditions and aggressive chemicals in the soil. The testing of concrete, using both accelerated tests and long-term non-accelerated tests, is discussed with special reference to its application to modeling of long-term performance prediction. On the basis of the study's results, conditions for acceptance are recommended as an aid in the licensing of disposal sites which make use of alternative methods.

INTRODUCTION

Recently, several states and state compacts have expressed interest in pursuing alternatives to shallow land burial (SLB) for disposing of low-level radioactive waste (LLW). These alternative methods would be compatible with the requirements of 10 CFR Part 61, and would involve engineered structures for waste containment rather than the trenches considered in traditional shallow land burial (SLB). The different alternative methods which have been used or examined for potential use here and in other countries are described in a series of reports by the U.S. Army Corps of Engineers.(1) They include aboveground vaults, belowground vaults, earth-mounded concrete bunkers, and augered shafts. Recently the Electric Power Research Institute (EPRI) has developed a system for classification of the different possible concepts based on four generic "functional features" affecting facility performance, namely grade, cover, structure, and fill. This classification system is described and examples of its application given in a paper presented at Waste Management '86.(2)

The principal material of construction expected to be used in alternative disposal sites is concrete. Despite the widespread use of Portland cement concretes throughout the world in the last century, there is little record of long-term experience for such a period. Yet in order to satisfy the requirements of 10 CFR Part 61, it may be necessary to demonstrate concrete durability for even longer periods, e.g., 300 to 500 years. The basis of the study for this paper was the review and analysis of the literature regarding the properties and degradation mechanisms of concrete and steel-reinforced concrete. The main objective was to develop information needed to evaluate the long-term performance of concrete as a structural material for alternative LLW disposal methods. As part of the analysis, criteria for evaluating performance of concrete and factors that can affect its performance were identified. Based on the results of this study, minimum acceptance criteria were recommended to aid NRC in the licensing of LLW disposal sites in which alternative methods are to be used.

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Further, methods were suggested to help provide reasonable assurance that a concrete structure could meet the performance objectives and relevant technical requirements of 10 CFR Part 61. Results of the study, including considerations of coatings and impregnating materials, are given in more detail in the report NUREG/CR-4714.(3)

CONCRETE DURABILITY

It is useful at the outset to consider what is known about the life expectancy of concretes. Examples of ancient concretes which have lasted (in the sense that they are still strong and capable of performing adequately in their original roles) for 2000 years or more are a matter of record. Recently, samples of such concretes have been thoroughly examined chemically and petrographically. Probably the most thoroughly studied of the ancient concretes are the Roman samples investigated by Roy and Langton(4,5) and by Nichedlov-Petrossian et al.(6) Roy and Langton found no evidence of crystalline C-S-H compounds (calcium silicate hydrates),* so apparently very little C-S-H gel remained and most of the original C-S-H and the $Ca(OH)_2$ had been converted to $CaCO_3$ and SiO_2. This product of total carbonation appeared to be a durable material with good mechanical strength. Nichedlov-Petrossian et al. reported that in the concrete samples they examined crystalline C-S-H phases had been formed. Atkinson and Hearne(7) state that these C-S-H minerals can normally only be synthesized in the laboratory under hydrothermal conditions, which is not in accord with the report of Nichedlov-Petrossian et al. However, Atkinson and Hearne point out that there is a possibility the minerals could form under ambient conditions over very long times (millenia) in the absence of carbonation. They stress the importance of resolving this matter.

Although modern concretes (i.e., those using true Portland cements) have not been in use for much more than a century, there are many examples of excellent performance for periods of several decades, and a few for periods of the order of 100 years. Of the latter, one of the most notable is a reinforced concrete bridge built in 1889. Recent tests(8) on a sample of this material showed that it was probably made from ordinary Portland cement (OPC), sand, and gravel, and that its compressive strength is now about 9000 psi. The cement is fully hydrated, and there is little or no rust on the rebars. While this and other century-old concretes provide valuable evidence for the potential long-term durability of "modern" concretes, they were exposed only to rainwater leaching, atmospheric carbonation, and freeze-thaw cycling, but not to attack by aggressive chemicals in the soil. As it is, they have been able to provide excellent protection from the three former processes.

Although there are few documented examples of century-old concrete in excellent condition, many examples exist of concrete structures in their second half-century of use and many of these have been exposed to destructive environmental conditions. Probably the most destructive process for concrete structures in the context of LLW disposal will be attack by sulfates in soil and/or in the waste. Several structures have remained in good condition under severe sulfate exposure for periods up to 50 years. One such structure(9) is the Fort Peck Dam, which was built in 1935 with cement similar to that used in present-day OPC. The concrete showed almost no damage from contact with groundwater containing up to 0.2 M Na_2SO_4 (28,000ppm), and cores taken at 40 years gave compressive strengths from 6,000 to 9,000 psi, which is higher than the strength at 28 days. Another notable case is that of the 40-km concrete water pipeline at Cartagena, Colombia,(10) in service since 1938. The exterior surface of this pipeline was in excellent condition over its entire length except for two isolated 5-m sections which failed after 30 years. Although much of the pipeline is in soil with high sulfate content (up to 31,000 ppm), no sections in the high-sulfate soil showed significant damage after 34 years. The two failed sections were in soil of relatively low sulfate content, and the failure was judged to be most likely the result of manufacturing defects or damage during installation.

In assessing the potential durability of a particular concrete, one must consider both the functions it will have to perform and the environmental conditions to which it will be exposed. A concrete structure must provide support and stability to a LLW disposal unit, but it would also be desirable if it restricted release of radioactivity, particularly by limiting water movement into and out of the unit. In practice, most concretes will probably lose their strength as they become more permeable to water, so that strength is likely to be a useful criterion in assessing durability, in terms both of structural stability and of preventing passage of water. Conditions at licensed LLW disposal sites will be appreciably less severe than those to which many of the structures referred to have been exposed, if only because contact with aggressive groundwaters should generally not be a factor (10 CFR Part 61 siting requirements).

The good long-term performance of the particular ancient and modern concretes discussed above does not guarantee that a disposal facility can be constructed to function adequately for 500 years. This is because the ancient concretes are chemically and physically different from those that would be used today, and because the modern concretes have shown their excellent properties for only 100 years. However, the good condition of the ancient concretes after extended time periods under harsh conditions, and the relatively benign conditions expected at licensed LLW sites, are indications that such a durability for several hundred years is achievable.

CONCRETE CHARACTERISTICS USEFUL IN EVALUATING PERFORMANCE

Technical requirements for choosing a LLW disposal site are given in Section 61.50 of 10 CFR Part 61, and in NUREG-0902, the Branch Technical Position on site suitability, selection, and characterization.(11) They include the hydrogeology and meteorology of the site, and such factors as ecologic and socioeconomic considerations. Section 61.51 describes the design features which must be taken into account for construction of a near-surface LLW disposal

*An explanation of the shorthand notation for chemical constituents of cement is given in Lea's, "The Chemistry of Cement and Concrete," Chemical Publishing Co., Inc., New York, 1970, and other texts on cement and concrete.

site. These features must be directed toward long-term isolation with avoidance of the need for continuing active maintenance after site closure.

The main property used to evaluaten a concrete's overall quality, including its durability, is its mechanical strength. High strength is necessary for good durability. Both will be dependent to a large degree on the physical and chemical nature of the components which are used to make the concrete.(12) Another important property of concrete to be used as a structural material in LLW disposal sites is low permeability to water, since it is desired to keep water from contacting the waste. Low permeability to water is an expected property of high strength concretes, but two concretes with the same high strength can have different permeabilities, so that permeability should be considered on its own, apart from strength.

Other properties which can be used for evaluation have to do with physical and chemical stresses. The physical process of most concern is that of freezing and thawing of the pore water in concrete, which can cause severe damage. Resistance to damage from freezing will, of course, not concern sites located in frostfree areas. It will concern sites in geographical areas subject to freezing weather only during their operational phase when below-ground structures are employed. However, in such locations, if above-ground structures are used, the criterion will be of long-term concern.

With regard to chemical stress in plain concrete, the applicable characteristics are resistance to external chemical attack, and absence of chemical reaction within the concrete leading to reactive expansion.(12) In reinforced concrete, resistance to corrosion of the reinforcing metal is an additional consideration. Chloride attack is responsible for most reinforcement corrosion problems, and can also damage plain concrete. Other external chemical effects which can lead to damage are sulfate attack and acid attack. Both of these could also potentially occur as a result of reactions occurring in the waste inside a disposal unit.

To sum up, properties required for durability and good long-term performance of concrete can be given as follows:

- high strength
- low permeability
- resistance to freeze-thaw damage
- resistance to sulfate attack
- resistance to chloride attack
- resistance to acid attack
- absence of chemical reaction (in the concrete) causing expansion
- resistance to corrosion of steel in reinforced concrete.

FACTORS AFFECTING CONCRETE PERFORMANCE

A key requirement for providing satisfactory engineered concrete structures for disposal of LLW lies in using concrete with adequate durability, i.e., with sufficiently long service life. Service life of concrete for LLW site structures must take into account not only the time for which it must provide protection against inadvertent intrusion (500 years) and structure for isolating the waste (probably at least 300 years), but also the time during which it must limit penetration of water (a similar period). There are a number of factors which will affect the service life, either by determining the intrinsic quality of the fabricated concrete, or by causing its subsequent degradation. The former are those which are under the control of the fabricator, and have to do largely with the concrete itself and its individual components. The latter are associated with forces external to concrete, which act on it after it has been made into a structure. The two broad categories are discussed below under separate headings, and the individual factors are listed in Table 1.

Factors Under Control of Builder

- Cement Composition

The performance of concrete is intimately connected with the composition of the cement paste used in its production. Assuming use of proper aggregates, appropriate water:cement ratios, and correct construction procedures, the proportions of the cement constituents required to give superior concretes of high strength and durability have been known for a long time. As an example, the C_3A ($3CaO{\cdot}Al_2O_3$) content must be kept low to provide the finished concrete with sulfate resistance. Likewise, deleterious reactions of reactive aggregates can be at least

TABLE I

Factors Affecting Concrete Performance

Factors Under Control of Builder	Environmental Factors
• cement composition • aggregate properties • concrete composition, particularly water:cement ratio • admixtures • air entrainment • reinforcing steel • construction practices batching, mixing, placement and cosolidation • curing	• freeze-thaw cycles • sulfate attack • chloride attack • acid attack • leaching of $Ca(OH)_2$ • abrasion/erosion Important for Sealants and Coatings • radiation damage • biodegradation

partially offset by use of cement with low alkali content.

- Aggregate Properties

Standard specifications for coarse and fine concrete aggregates given in ASTM C 33-81 are considered to ensure satisfactory materials for most concrete. Tests are listed which the aggregates must pass in order to meet the specifications. The specifications concern both composition and particle size grading. Composition of the aggregate can have a large effect on concrete performance due to damaging chemical reactions such as the alkali-aggregate reaction mentioned in the preceding paragraph, and oxidation of unstable mineral oxides and sulfides. Damage from these reactions can be so severe that replacement of the concrete is necessary.

- Concrete Composition

The compostion of concrete is crucial to its performance since, given correct production procedures and subsequent curing, the proportions of cement, aggregate and water effectively determine its quality and strength. The critical composition variable is the water:cement ratio, since this determines the strength of the cement paste. The strength increases with decreasing water:cement ratio. There is obviously a limit beyond which the ratio cannot be decreased if proper mixing and compaction are to be achieved, and in practice ratios much below 0.3 will not often be used. The proportions of fine and coarse aggregate are also important. The fine aggregate and cement together may be regarded as a mortar in which the coarse aggregate is set. The amount of this mortar must be sufficient to wet all surfaces of the coarse aggregate and properly bond all the particles.

- Admixtures

Admixtures are materials that are added during mixing of concrete in order to modify the properties of the product either in the fresh or hardened state. These additives are used for various reasons: to improve workability, increase air entrainment, cause accelerated set and increased early strength, retard set, or reduce water requirements. A wide variety of materials, either organic compounds or salts of organic compounds, are used in small proportions, as aids in air entrainment. Various pozzolans such as fly ash and silica fume are added to provide much reduced permeability, and hence increased durability due to reduction in rate of penetration of aggressive chemicals such as chloride and sulfate.

- Air Entrainment

The degree and type of air entrainment during mixing of concrete is critical to the production of the desired size of voids and their spatial and size distribution. There is an optimum amount of entrained air for good durability. Deliberate entrainment of air is capable of producing a paste that will resist freeze-thaw cycling damage, and the use of admixtures has been found to be effective in bringing about the void size and spacing required for such resistance. Permeability will increase and strength will decrease somewhat as air content increases, due to the greater total void space in the concrete solid. The relatively small strength decrease is the price paid to achieve resistance to frost damage.

- Reinforcing Steel

No problems should arise due to quality of the steel if ASTM specifications are followed. The specifications for chemical composition, method of manufacture, and minimum tensile strength are contained in ASTM standards such as A 615, A 616, and A 617, which specify the requirements for the deformations on reinforcing bars. Regardless of the quality of the steel, it will corrode under adverse conditions, as discussed later under "Chloride Attack."

- Construction Practices

Improper preparation methods can lead to unsatisfactory structures, regardless of the high quality of the components and the careful choice of proportions. The important factors concerned with construction methods are: batching accuracy (the extent to which mix proportions and quality of ingredients are kept constant in all batches), thoroughness of mixing (achievement of maximum degree of homogeneity), proper placement (prevention of segregation) and proper consolidation or compaction (prevention of unintentional voids).

- Curing

Curing of concrete refers to hydration of the cement paste. The porosity of the concrete decreases as hydration proceeds, and concrete quality (as measured by increase in mechanical strength) improves. There is sufficient water in most freshly mixed concrete for complete hydration of the cement. However, the water is readily lost by evaporation, so, in practice, curing is generally accomplished by intermittent and systematic wetting, or by water immersion. Increase in strength is usually rapid for 25-30 days, and then slows so that ultimate strength is reached only after years.

Environmental Factors

- Freeze-Thaw Cycling

Long-term resistance to frost damage will be a significant concern only for above-ground structures. Covered or subsurface structures in a cold climate will require resistance to frost damage during the operating period of a disposal unit. As noted earlier, such resistance is provided by use of appropriate admixtures to bring about the required degree of air entrainment.

- Sulfate Attack

Reactive sulfates occur naturally in soils, particularly the alkali soils found in the western U.S. An additional source of sulfate could be from certain solidified LLW, particularly BWR (boiling water reactor) evaporator bottoms. Sulfate attack occurs only when water is present to carry the sulfate to the interior of the concrete. Damage is a result of expansive reactions with lime and with hydrated tricalcium aluminate (C_3A) which cause formation of cracks in the concrete. One method of limiting sulfate attack is to use cement powder of low C_3A

content, such as Portland Type II (<6%C_3A) and Type V (<4%C_3A). Use of appropriate pozzolan admixtures, and low water:cement ratio (leading to a low permeability product), can also provide or enhance sulfate resistance. One of the most extensive studies of sulfate attack on concrete has been carried out by the U. S. Bureau of Reclamation. This work has inlcuded investigation of the mechanism of sulfate attack,(13,14) and development of concretes resistant to such attack.(13-15) Work along similar lines has been carried out by the U. S. Army Corps of Engineers(16) and by the UK Building Research Establishment.(7)

- Chloride Attack

Chloride attack is of most concern for concrete *structures* exposed to seawater, and for roads and airport runways where chloride salts are used as deicers. It will presumably be of little concern at most LLW disposal sites. Plain concrete can be attacked by strong chloride solutions. However reinforced concrete is subject to damage by dilute solutions since, if corrosion of the reinforcing steel occurs, the consequent expansion at the steel surface cracks the overlying concrete and opens the way to further attack. A thorough treatment of the factors that cause and control corrosion and measures for protecting embedded steel is given in a recent American Concrete Institute report.(17)

- Acid Attack

Acid attack of concrete is characterized by chemical reaction between the acid and calcium hydroxide in the hydrated cement paste. This results in the formation of water-soluble calcium compounds, which are leached away. The overall mechanism destroys the binding ability of the cement paste, thereby weakening the concrete. The attack of naturally occurring acidic water which results from the presence of organic acids or carbon dioxide is normally limited to the surface of the concrete and causes limited damage. Use of a dense concrete with a low water:cement ratio (i.e., one with low water permeability) gives reasonable protection against these weakly acidic conditions. Acid attack of good quality concrete will not generally occur if the pH is 5 or greater.

- Leaching of $Ca(OH)_2$

The deleterious reaction of acid with $Ca(OH)_2$ has already been discussed. Since the aqueous solubility of $Ca(OH)_2$ is appreciable, it can also be removed by water leaching. This should not be a problem in LLW sites above the water table which satisfy the requirements of 10CFR Part 61, since water contact in such sites should not be sufficient to permit extensive leaching. Sites below the water table which satisfy 10CFR Part 61 requirements would probably also not permit extensive leaching, but detailed calculations of diffusion rates would be needed to support such claims for specific sites.

- Other Factors

Two other factors potentially capable of causing damage to concrete structures are radiation and biodegradation. The data available on radiation damage of concrete indicate that a dose of $>10^{10}$ rad is required to cause significant damage,(7) and the dose which might be accumulated in LLW structures would be at least 2-3 orders of magnitude lower. Biodegradation is also not expected to be a significant problem, but data for assessing long-term primary and secondary effects are not available. Secondary effects (i.e., attack of concrete by metabolic products, particularly from the waste) might be observable in the long term. While concrete itself may not be damaged by either radiation or biodegradation effects, organic materials used to impregnate the concrete or as coatings could be adversely affected.

METHODS FOR PREDICTING PERFORMANCE

The major complication regarding the use of concrete for LLW disposal structures involves demonstrating 300-year or longer performance with reasonable assurance. Many of the available building codes and specifications provide guidance on parameters such as cement composition and construction practices for specific applications, but do not give quantitative estimates of time to failure.(18) This problem has been recognized, and methods are being developed to predict service life for materials.(18-20) These methods fall into the following three categories: accelerated testing, long-term (nonaccelerated) testing, and modeling. They are complementary in that no single method is accepted on its own as providing a completely reliable estimate of time to failure. Accelerated tests may be conducted to identify degradation mechanisms rapidly. The accelerated tests, in conjunction with nonaccelerated long-term tests, can be used to measure actual rates of degradation. Data from these tests may then be used to model (and thus predict) long-term performance. ASTM E 632 "Standard Recommended Practice for Developing Short-Term Accelerated Tests for Prediction of the Service Life of Building Components and Materials," provides a framework which can be adapted to the problem of predicting service life of structures for alternative LLW disposal technologies.

Testing

Before testing is undertaken, one must define the specific problem and determine the data required for its solution. For attempts at estimating service life of concrete LLW disposal structures, the data requirements involve identifying the rates of change in the concrete properties, e.g., compressive strength, scaling depth, and corrosion of steel reinforcement, if present. The rates should be determined under conditions which reflect the expected environment, both external and internal, to which the structure will be exposed. The expected environment may be design-specific (aboveground or belowground), site-specific (climate, soil chemistry, and soil permeability), as well as waste-specific (waste forms, high-integrity containers, radiation levels, gas generation, etc.). Finally, data requirements with regard to water transport properties must be established. As a minimum, this would involve permeability values for the concrete. Additional data would be needed regarding factors which cause increases in concrete permeability, and the rates at which such increases can occur.

Once data requirements have been established, tests which provide these data may be identified, or if such tests are not available, they may be designed as needed. The important point regarding testing is that for reliable predictions of service life to be made, the degradation mechanisms involved must be well known. Accelerated tests are most useful for identifying the factors which can have the most deleterious effects on a material.(18) However, predictions of service life should be based on extrapolations using non-accelerated tests. Hence, the material properties to be measured under the test should be sufficiently sensitive that changes can be monitored within a short time period.

There are test methods available for determining resistance to freeze-thaw cycle damage, sulfate, acid and other chemical attack.(12) As an example of accelerated testing, the Bureau of Reclamation has developed a wet-dry cycling test to measure degradation rates due to sulfate attack.(13,14) The wet portion of the cycle consists of immersion in strong sulfate solution. Change in compressive strength and modulus of elasticity of samples can be followed with time (i.e., number of cycles) but are destructive. Thus, the non-destructive test of measuring expansion is generally used, and a sample is considered to have failed at 0.5% expansion. The test is excellent for comparing different concretes, but the exact relationship of results from this test to failure times for concretes under the rather mild conditions for a LLW facility may be difficult to establish.

Modeling

Ideally, the prediction of service life should be based on past experience. Due to the shortage of long-term experience with modern concrete compositions, the alternatives for predicting service life must necessarily include modeling.

Development of a model for predicting durability or service life is intimately linked to a knowledge of the degradative mechanisms affecting the concrete. As long as the degradative mechanisms occurring with either in-service or accelerated tests are known, they can be modeled. The accuracy of predictions based on the model will depend on the degree to which the known mechanisms represent the actual damage production, as well as on the quality of the input data. The successful formulation of a model depends on the proper use of such inputs as rate laws for degradation, constitutive or property relations, life distribution functions, and conservation equations for mass, heat, and momentum transfer.

Mathematical models may be distinguished based on their classification as either deterministic or probabilistic.(20) Considering strength of concrete as an example, deterministic models based on fracture mechanics would predict a single ultimate strength. Probabilistic models based on reliability theory would predict a range of ultimate strengths in terms of a life distribution function chosen considering the interaction of the concrete with its service environment. The relevance of present models to concrete performance in a LLW disposal site is open to question, and it is apparent that further model development may be necessary if reliable predictions of service life are desired. Of particular interest in this regard is modeling work in progress by Rogers and Associates being carried out for EPRI.* The model will rely heavily on known concrete properties and on measured rates of degradation, and will attempt to estimate the performance of concrete structures under LLW disposal site conditions.

It appears, then, that modeling studies, if properly developed and conducted, have the capability of reducing the limitations of conventional and accelerated tests. Modeling, although a valuable technique, is not a panacea. It suffers from its own set of limitations, some of which are common to those found in testing.

EVALUATION OF ACCEPTABILITY

Necessary Information

Since 10 CFR Part 61 requires reasonable assurance that a site (including facility structures) will perform adequately for several hundred years, the principal basis for acceptance of a structure for licensing will be its adequate durability--i.e., reasonable assurance must be given of such durability. To provide this assurance, accurate information is needed on the quality of the concrete, and following that, on the quality of and care taken in the construction work. Specific items in these categories are:

- type of cement
- quality of water, especially chloride content
- type and quality of aggregate
- grading procedure for aggregate
- concrete composition, especially water:cement ratio
- QA/QC procedures in formulation and production of concrete
- results of 28-day compressive strength tests on concrete samples
- reinforcing steel specifications, including type of deformation
- depth of concrete cover over reinforcing steel
- construction methods, particularly placement and consolidation
- curing procedures
- building codes followed, and QA/QC procedures for the construction.

It is emphasized that there is at present no way to guarantee a specific service life for concrete--either the material itself or the structure made from it. The information suggested above will, however, enable a reliable judgment to be made as to the initial quality of the concrete and the structure. For an estimate of service life, modeling will presumably be useful.

Specific Requirements

In addition to providing the above information on the quality of the concrete and construction methods, it is recommended that LLW disposal facilities using engineered structures to augment SLB should satisfy the following specific criteria:

*Based on discussion at the EPRI Workshop on LLW Disposal Materials, held July 15-16, 1986, in Washington, DC.

• Inspection

Inspection should be carried out during construction, not just after structures are in place. Inspections might be carried out by representatives of the appropriate state agencies, but in any case detailed documentation of the inspection data should be available for review.

• Sulfate Resistant Cement

The proper type of cement as specified in building codes and manuals should be used when the structure will be exposed to high-sulfate conditions. Although sulfate-resistant cement need not be used at all sites regardless of soil conditions, soil sulfate content should be determined and the data used to support the choice of cement.

• Incorporation of Reinforcing Steel

The minimum cover for reinforcing steel should be increased above that required for use in soils with negligible chloride. Furthermore, if a set accelerator is needed, those containing inorganic chloride, e.g., $CaCl_2$, should be prohibited from use in steel-reinforced concrete.

Testing and Modeling Support

Testing, analysis, and modeling should be used as support for the information requirements outlined above. The following are considered of particular relevance.

• Soil Testing and Analysis

The soil adjacent to facility structures will have to be analyzed to determine the sulfate and chloride content and the acidity. This may be done for site characterization purposes, but if not it must be done to support the choice of the concrete composition to be used.

• Testing of Concrete

Testing of concrete samples, preferably cored from the structure, will be useful for supporting information on the concrete quality to help ensure that this will not be the limiting factor in long term performance of the structure. As well as standard compressive strength tests, permeability measurements should be made, since permeability not only affects the extent of water infiltration into the disposal unit, but also determines the rate at which and the extent to which all modes of concrete attack occur. Testing for sulfate resistance should be carried out when soil sulfate concentrations are known to be in the range potentially damaging to concrete.

• Modeling of Long-Term Performance

At the present stage of development, use of models will not be able to guarantee a specific service life. However, modeling to estimate the long-term performance of a structure on the basis of the concrete properties and probable construction defects could give added confidence in the structure's ability to perform well enough to meet its 10 CFR Part 61 requirements--i.e., providing site stability, protecting inadvertent intruders, and minimizing water infiltration--for the required period of time.

A different reason for modeling of this kind would be to examine the effects of a proposed facility structure on the site performance. One of the conditions of acceptability of a structure must be that it does not adversely affect site stability.

CONCLUSIONS

Review of the literature on concrete has led to the conclusion that it should be possible to formulate Portland cement concrete which will be durable enough to perform satisfactorily as a structural material in alternative LLW disposal methods. There are a number of examples of ancient concrete which have lasted thousands of years and are still in good condition. Excellent durability of modern concretes for periods up to 100 years is well documented. Good performance under severe conditions results from use of a concrete mix properly formulated and prepared for the particular conditions encountered, as well as from sound construction practices. Either improperly formulated concrete or poor construction practices, or both, appear to be responsible for most cases of early failure. Environmental conditions at LLW sites will generally be much less severe than those to which many of the durable concretes described in the literature were exposed. Therefore, it may be concluded that it should be possible to build concrete structures with sufficient durability to function properly for a few hundred years.

There is no way, however, to guarantee a specific service life (e.g., 500 years) for a specific concrete--either the material or the structure made from it. All that can be done is to provide reasonable assurance that a given structure, under the conditions to which it will be exposed, will perform its required function for the required time. In order to provide this assurance, there are several conditions which a license applicant should fulfill. These include providing full and accurate information on the formulation of the concrete and construction methods used, carrying out inspection during construction, and documenting inspection results and all other information including QA/QC methods used. Testing of the finished concrete is advisable, and modeling should be carried out to help support the applicant's position that the facility structure will meet the performance objectives and technical requirements of 10 CFR Part 61.

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