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Secretary, U.S. Nuclear
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Washington, D.C. 20555

Attention: Docketing and Service Branch

RE: Docket No. PRM-61-1 Amendment 1

To whom it may concern:

The attached document represents Chem-Nuclear Systems, Inc. comments concerning the above referenced document.

The following points summarize Chem-Nuclear's position on this subject:

1. Polymer and fiber reinforced concrete products have merit and should be studied further for application in nuclear waste disposal technology.

2. Current schedules favor use of conventional concrete which has already been qualified, is licensable and is capable of meeting facility safety objectives.

3. Conventional concrete overpacks in conjunction with polyethylene liners would be comparable to polymer and fiber reinforced concrete products in impermeability, erosion resistance and high strength properties. High density polyethylene has been qualified and has an established performance record.

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PRM-61-1 AMENDMENT 1 COMMENTS

ALTERNATIVE CONCRETE MATERIALS EVALUATION

1.0 INTRODUCTION

The triple-safe design utilizes concrete for the construction of the overpacks and the waste vaults. The concrete performs several functions; namely, it serves as a barrier to prevent direct contact of water with any waste; it provides long-term structural stability to both the overpack and the vault; it acts as an intrusive barrier; and it provides radiation shielding to both the facility operators and ultimately the general population. The thickness of the overpack concrete and the concrete formulation provide structural strength, radiation shielding, and erosion barrier protection in the unlikely event that the overpack is ever exposed to significant amounts of water.

The Chem-Nuclear Systems, Inc. concrete specifications are aimed at ensuring that a high quality, consistently manufactured concrete is developed that meets the functional objectives. The formulation would be well tested and based on the French experience and qualifications used at their LaManche and L'Aube disposal facilities. These types of concrete formulations contain Portland cement, fly ash and have low water-to-cement ratio mixtures. They would normally be described as "conventional concrete", since the primary cementitious material is Portland cement.

We believe that the use of conventional, Portland cement based concretes in our design would meet all the performance objectives for the North Carolina Low-Level Radioactive Waste (LLW) disposal facility. We also recognize that considerable improvements have been made in concrete technology in recent years. These improvements relate to modified concrete formulations, including the addition of a number of synthetic materials. These advanced concretes have improved material properties which could enhance the LLW facility design. Conversely, these concrete types have far less in-service experience, and are developmental in nature.

The Sierra Club has proposed to the Nuclear Regulatory Commission an alternative concrete selection (Reference 1). The Sierra Club proposal does not meet the North Carolina statutory requirement that the bottom of the disposal facility be located at least seven feet above the seasonal high water table level. Therefore, in its entirety, the proposal cannot be considered for this project. However, the alternative concrete suggested may have some merit for consideration in the design proposed for this project. These concretes would add or substitute new materials to the proposed concrete formulation. Their objective is to improve the concrete water resistance capability, permeability and strength. The first alternative concrete proposed considers the addition of a polymer to the concrete to provide greater compressive strength, erosion resistance, and lower permeability. These types of concretes are designated by the American Concrete Institute (ACI) as polymer impregnated concretes or polymer concretes[1]. Another proposed alternative is the addition of reinforcing fibers to increase the material tensile strength and its fracture toughness. The ACI refers to this as fiber reinforced concrete.

Chem-Nuclear has researched the use of advanced concrete formulations, including both polymer concrete and fiber reinforced concrete. This research has been through the study of published ACI documents and conversations with concrete experts. Our assessment of the possible advantages and disadvantages of these specific materials are discussed in the following paragraphs relative to application for LLW disposal. We have focused our study on the current Chem-Nuclear LLW

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[1]Concrete is simply defined as a aggregate bound with a binder. The ACI uses the generic term, polymer concrete, to refer to a variety of formulations. The binder is not always Portland cement. Some polymer concretes consist of a polymer binder and aggregate. Others consist of a cured Portland cement concrete, which is injected with a monomer, and then polymerized by heat or irradiation (polymer impregnated concrete).

disposal facility design. We have concluded that alternative concrete may lead to significant improvements to the overpacks, but that these materials are comparatively new and will require extended development before they can be qualified for use. Only after these materials have been fully qualified, could they be applied for future LLW disposal operations. Due to the schedule, Chem-Nuclear plans to continue facility development based on the proven use of conventional concrete, with the option to switch to qualified alternatives in the future.

2.0 TECHNICAL DISCUSSION

2.1 General

The most beneficial application of advanced concretes would be in the fabrication of the concrete overpacks. The triple-safe system employs the overpack as the initial component for preventing radioactive material release. Hence, any material which minimizes the possibility of overpack failure would be worthy of study. In our design, the waste container is placed directly into a heavy walled, reinforced (conventional) concrete vessel (the overpack). The waste is then encapsulated within the overpack using a cement grout. Reinforcement bar (rebar) within the overpack wall provides structural strength. The steel rebar can be epoxy coated to prevent metal corrosion which could occur if the rebar is exposed to air (due to either a crack in the concrete or long-term erosion of the concrete layer covering the rebar). Note that the rebar will not corrode if it is fully encapsulated within the concrete (Reference 2).

Conventional concrete, in the process of curing, forms small pores or capillaries, which results in void spaces. The presence and extent of these voids are the most important factors in determining concrete performance. The void volume can be minimized by the use of low water content concrete or the additions of pozzolanic cementitious materials such as fly ash, blast furnace slag and silica fume. These increase compressive strength and also reduce permeability. However, even with the best of results, the resultant concrete is not impermeable.[2]

The addition of a plastic substance (or polymer) to the concrete matrix, if properly mixed, and if specially cured can reduce the concrete permeability. Basically, the use of polymers can lead to an essentially "void-

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[2]Conventional concretes have permeabilities in the range of 10^{-5}-10^{-7} cm/sec. Polymer concretes, with measured permeabilities in the 10^{-10}-10^{-11} cm/sec. range have been developed. Impermeability in this context is considered to be at 10^{-11} cm/sec.

free" concrete matrix. As a result, polymer concretes have been shown to have very high compressive strengths and to be virtually impermeable to liquids. The polymer material also functions as a water resistant surface coating.

The use of polymer concretes could be very advantageous for use in LLW disposal. Specifically:

1. A polymer concrete that is impermeable to water and water resistant, should not erode in the presence of a slow moving water stream. The portion of the concrete wall which is required for erosion protection is not needed. Hence, the potential concrete failure mechanism related to water erosion is also eliminated. Polymer concretes should also eliminate concrete failures due to harsh chemical reactions with the concrete. These occur when conventional concrete is exposed to chlorides, sulfates and acid soils. As proof of this, prior testing of polymer concrete has shown its successful use as a process vessel material when exposed to hot, concentrated saline water solutions (Reference 3). Material degradation was limited even in this severe environment.

2. Concrete of this type would not be affected by ambient temperature effects, such as freeze-thaw cycling, since water will not penetrate the capillaries within the concrete matrix. Such concrete failures are due to the expansion of freezing water within the concrete.

3. These concretes have high compressive strengths, in excess of 20-30,000 psi (Reference 4). These strengths are several times higher than conventional concretes. Their use may lead to overpack designs with thinner walls, and the possible elimination of rebar. Modified overpack designs should improve the waste packaging efficiency in the vaults, and also the fabricated cost.

As noted in Reference 5, there may also be technical advantages associated with the use of polymer concrete for improved sealing of the vault structure, including possible simplifications in vault fabrication. Research into the benefits of advanced concretes may be applicable to the vaults as well as the overpacks.

2.2 Polymer Concrete Advantages and Disadvantages

A review of applicable literature was performed. Various American Concrete Institute (ACI) reports were found with a large listing of associated references. The references verified that considerable R&D had been performed on polymer concretes over the last twenty years.

Reference 4 notes that specialized processes and procedures must be employed to ensure that a high quality polymer concrete is consistently produced. Also, our discussions with experts, indicated the need for specialized knowledge (Reference 7) to reach the material's full potential. It is clear that there are many varieties of "polymer concrete". The development effort to find and qualify the formulation most suitable for LLW disposal application would be costly and time consuming.

Reference 6 presented a comprehensive summary of the effect of polymer concrete on mechanical, thermal and physical properties. The advantages are as follows:

- Tensile and comprehensive strengths are high compared to conventional concrete.
- Flexural strength of polymer concrete is much higher than for conventional concrete.

- Shear capacity of flexural members is higher than conventional concrete because of the higher tensile strength capacity of polymer concrete.

- Bond strength between polymer concrete and reinforcing bars is higher than conventional concrete.

- The deflection of some polymer concrete elements is less than that of a conventional concrete because the modulus of elasticity is greater. Epoxy polymer concretes, however, have a lower modulus of elasticity and greater deflection.

- Long-term loading of a polymer concrete member is significant due to the viscoelastic nature of the material which is different than the Portland cement concrete creep mechanism.

- Thermosetting polymers such as epoxy and polyester produce shrinkage during polymerization, but shrinkage during hardening and temperature expansion can be controlled by the addition of aggregate filler.

- Polymer concrete is lighter in weight than Portland cement concrete.

- Resistance to acids, salt and other chemicals is relatively higher than with Portland cement.

- Freeze-thaw cycles have little effect on the polymer concrete since little or no water is absorbed into the mix.

There are possible disadvantages in the proposed use of polymer concrete:

- The cost of the concrete is high due to the cost of polymer additive and the special processing equipment required for curing. This cost may be compensated for if rebar quantities are reduced or external coatings on the concrete surface are not required.

- Radiation shielding capability is a function of concrete wall thickness. Reduction in the overpack wall thickness due to higher strength concrete may not be practical if radiation dose requirements are not met. (Note that polymer concretes use fine aggregate to develop high strengths - hence, high density concretes, with improved shielding capability cannot be used - since they use coarse aggregate.)

- Organic materials (such as polymers), are far more susceptible to radiation damage than inorganic substances (such as cement, stone aggregates, etc.). For this application, the integrated material radiation exposure is low (10^6 - 10^7 rad or less) due to the low waste activities. These exposure levels should not be problematic for polymer concrete. Nevertheless, the materials will require special testing and qualification in a radiation environment. (Note: Gamma irradiation was originally used by Brookhaven Laboratory to polymerize methyl methacrylate with a Portland cement matrix).

- The strength of polymer concrete can be catastrophically lowered when exposed to high temperatures. Reference 6 states that polymer concrete joints must be insulated if there is any possibility of exposure to fire. (This is not expected to be a problem.)

- Temperature and humidity of the environment affect the creep of the polymer concrete.

- Abrupt changes can occur in the mechanical properties of the polymers when the temperature exceeds the glass transition temperature.

2.3 Fiber Reinforced Concrete Advantages and Disadvantages

Conventional concrete is a material with considerable capacity for accommodating compressive loads. Conversely, its tensile and shear load strengths are normally much less (typically 7-10% of the compressive values). Concrete is also a very brittle material and material failures readily occur in the presence of impact loads. This is especially true if there are any preexisting cracks in the concrete.

These generic concrete limitations are normally compensated for by the addition of long steel rods as a reinforcement to the concrete structure (reinforcement bar or rebar). Rebar is costly, presents manufacturing difficulties, and is prone to long-term corrosion if the steel is exposed to air. An alternative means of concrete reinforcement is the replacement of rebar with high strength fibers. Fiber reinforcement of concrete employs the same principle as rebar but substitutes short, thin strands of a fibrous material for the metal rods. Fibers may be steel, glass, or plastic (polypropylene is most common).

The fibers are directly added to the concrete mix. As with rebar, the effectiveness of the fibers is dependent on the relative volume of the reinforcement material, the fiber tensile strength and the orientation of the fibers within the finished concrete structure.

Significant development in fiber reinforced concrete has been underway for about 20 years. A large number of ACI references were found and were reviewed on this subject.

The consensus is that effective concrete tensile strengths of from 800-1200 psi are achievable, solely with addition of reinforcement fibers. This is two-three times higher than conventional concrete. Most of the published data relates to the use of steel fibers. However, glass and polypropylene could be effective since corrosion resistant properties are desired (these materials are chemically inert). The material has excellent fatigue properties, and the fibers act as crack arrestors. Hence, this is also a "tougher" material than common reinforced concrete.

There are several possible advantages for LLW disposal application:

1. Adequate structural strength can be achieved while eliminating the need for rebar. This is particularly important when calculating the predicted lifetime of the concrete overpacks, since the only credible mechanism for overpack failure, is the exposure and resulting corrosion of rebar.

2. May be more economical than epoxy coated rebar.

3. Fibers can be added to polymer concretes. This synergistically improves a number of material properties.

As with polymer concrete, fiber reinforcement is a comparative new technology. Costs associated with material qualification and the resulting testing time are expected to be higher than for conventional concretes.

There are several areas of concern regarding material quality. Reference 8 presented an overview of the failure mechanisms associated with this material. The primary concerns are improper mixing of the fibers with the concrete ingredients and the "pull-out" strength of the fibers from the cured concrete. In the former case, the concern relates to "fiber-poor" regions in highly stressed sections leading to a reduction in overall material strength. Fiber "pull-out" is only of concern near cracks in the concrete (the fracture toughness properties are locally reduced). This phenomenon seems to be more severe for glass and plastic fibers which are smoother and have less frictional resistance than steel fibers. Reference 9, depicts instances of major failure due to loss of "aggregate interlock". This phenomenon has occurred when polypropylene fibers were substituted for wire mesh, and very large concrete cracks resulted.

Reference 9 is manufacturer's information, and clearly has a negative bias. However, it indicates that test and development are needed. Also, References 1 and 10 indicate that fiber-cement material compatibility can be a problem - - - but that too is believed to be surmountable with proper design and qualification testing.

3.0 CONCLUSIONS

Fundamentally, polymer concrete and fiber reinforced concrete represent the substitution of various ingredients in the concrete formulation and material matrix. They represent an opportunity to improve certain key material properties currently experienced with conventional, Portland cement based, concretes. Their use does not change the key advantages of the triple-safe design.

Consideration should still be given for eventual use in the disposal facility design due to key advantages which are:

- Permeability - Polymer additions make concrete water resistant and virtually impermeable to water. This could eliminate the concern of possible long-term overpack failure following any sustained water exposure.
- High Strength - The addition of both polymers and fibers results in compressive and tensile strengths being increased. Cost efficient designs for the concrete components may be possible.

It should be noted that there are other means of modifying concrete to obtain impermeability, erosion resistance, and high strength properties. For example, a concrete overpack fabrication with conventional concrete could be used in conjunction with a polyethylene liner which was sealed prior to disposal. There is little question that this option would have high erosion resistance and zero permeability. Similarly, high strength concretes, with 15-20,000 psi compressive strengths, have been employed for high-rise buildings. Typically, these strengths were obtained using low water content concretes with silica fume additives. In order to quality these high strength concretes, vigorous building code requirements had to be successfully met. These design options could be directly applied to our LLW design. However, they are costly, and probably not needed as enhancements to an already "safe" facility design, which can be obtained with conventional concrete.

In summary, the selection of the most advantageous concrete type primarily involves routine comparisons of technical properties, construction costs, and in the near term - - - schedule restraints related to the time required to qualify the material. None of the technical or cost conditions are so overwhelming that they would either disqualify these advanced concrete alternatives, or force their use. However, schedule constraints would favor conventional concrete which has been previously qualified for similar applications. The advantages of polymer and fiber reinforced concretes are still sufficient to merit continued examination. Since these materials are in an earlier stage of development than conventional concretes, it is Chem-Nuclear's position that qualification for near term use is not practical.

It is expected that nuclear waste disposal technology will continue to improve during the operating lifetime of the facility. Certainly, every effort will be made by Chem-Nuclear as designer-operator of the North Carolina LLW Disposal Facility, to use concretes which will improve operations and safety. Research on improved materials should be, and will be, a continuing effort of the facility staff.

4.0 REFERENCES

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8. ACI-SP-105-1, Gopalaratnam, V, et al, Failure Mechanisms and Fracture of Fiber Reinforced Concrete, 1987

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