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OAK RIDGE NATIONAL LABORATORY
MANAGED BY LOCKHEED MARTIN ENERGY RESEARCH CORPORATION
FOR THE U.S. DEPARTMENT OF ENERGY

POST OFFICE BOX 2008
OAK RIDGE, TN 37831-8003

NRC Programs Office
PHONE: (423) 574-0422
FAX: (423) 241-5005
INTERNET: pug@ornl.gov

September 26, 1996

Dr. Andrew J. Murphy
Chief, Structural and Geological Engineering Branch
Division of Engineering Technology
Office of Nuclear Regulatory Research
U. S. Nuclear Regulatory Commission
Mail Stop TWFN 10 L1
Washington, DC 20555-0001

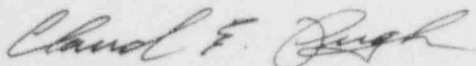
Dear Dr. Mruphy:

Review of Information Provided Relative to Millstone-3 Plant Sump Discharge

The attached document provides the subject review that was requested by Dr. Wallace Norris of your staff via a letter to me dated September 24, 1996. The review was headed by Mr. Barry Oland of the Oak Ridge National Laboratory's Engineering Technology Division.

We trust this review is helpful, and we will be happy to respond to questions that you may have. Mr. Oland can be reached by telephone at (423) 574-0659 or telefax at (423) 574-0651.

Sincerely,



Claud E. Pugh, Director
ORNL NRC Programs

Attachment

c: C. B. Oland
D. J. Naus
W. G. Craddick
W. E. Norris, NRC/RES-SGEB
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bedrock surface to create a smooth, level working surface. This fill material was also cast against the bedrock sidewall to create a smooth cylindrical-shaped vertical surface around the perimeter of the excavation. Next, a 254-mm (10-in.) thick by 48.5-m (159-ft) diameter porous concrete layer was cast on top of the concrete fill. The mixture for this concrete included ASTM C 150, Type II, low-alkali portland cement (Ref. 7), #57 coarse aggregate, and water. No fine aggregate was used so the void content of this concrete was relatively high making it very permeable to both air and water. Irregularities in the top surface of this porous concrete layer was sealed with a mortar made using ASTM C 150, Type II, low-alkali portland cement, fine aggregate, and water.

A 1.6-mm (1/16-in.) thick layer of butyl rubber was glued to the top of the sealed porous concrete surface and extended up the sides of the cylindrical concrete wall. Joints were lapped and sealed with butyl rubber tape with polyethylene backing. Portland cement mortar consisting of ASTM C 150, Type II, low-alkali portland cement, fine aggregate, and water was placed on top of the butyl rubber membrane to a depth of 51 mm (2 in.). A hollow concrete block wall with drainage holes near the bottom was then constructed around the perimeter of the excavation. The concrete blocks were supported at the bottom by the portland cement mortar surface and placed directly against a protective board material located just inside the butyl rubber membrane. This wall served as formwork for the base slab and provided a means for water that penetrated the butyl rubber membrane to flow downward along the outside of the base slab.

Porous concrete drain pipes were then placed above the portland cement mortar surface. These 152-mm (6-in.) diameter pipes were arranged in a prescribed pattern so that water would flow to two different sumps. Each sump includes a pump that moves water out of the subbase and to a storm drainage system. Before the base slab was cast, a 229-mm (9-in.) thick layer of porous concrete was placed on top of the portland cement mortar surface and around the porous concrete drain pipes. This drainage layer, which consisted of concrete made using high-alumina (calcium aluminate) cement, #57 coarse aggregates, and water, was installed to provide a media for collecting water that somehow found its way inside the butyl rubber membrane. The type of coarse aggregate used in the mixture was not identified in the information that was provided for review. Fine aggregate was not used in this concrete so that it would be porous and permeable to air and water. Irregularities in the top surface of the porous high-alumina cement concrete were sealed with a high-alumina cement mortar to prevent cement paste from the base slab concrete from infiltrating and clogging the large voids in the porous concrete. Although the thickness of this mortar layer was not specified, it is assumed to be very thin. The mortar mixture consisted of high-alumina cement, fine aggregate, and water. It was reported that high-alumina cement was used instead of portland cement because portland cement was not readily available at the time of construction (Ref. 4). Upon completion, the overall height of the subbase was 533 mm (21 in.).

Construction of the base slab began once the subbase was completed. Deformed steel reinforcing bars were installed and structural concrete was placed. The concrete had a specified 28-day compressive strength of 20.7 MPa (3,000 psi) and was made using ASTM C 150, Type II, low-alkali portland cement, #4 coarse aggregate, #67 coarse aggregate, fine aggregate, an air entraining admixture, and water.

Construction Above the Top of the Base Slab

After the base slab was cast, the bottom section of the containment wall was constructed. Fiberglass boards and a 50-mm (2-in.) thick foam material were then installed on the outside surface of the containment wall. Next, a 102-mm (4-in.) thick layer of #4 graded stone was placed on top of the base slab outside the containment wall, and a polyethylene membrane was placed on top of the stone. Portland cement mortar consisting of ASTM C 150, Type II, low-alkali portland cement, fine aggregate, and water was placed on top of the polyethylene membrane to serve as a smooth bearing surface for the butyl rubber membrane that was extended inward along the top of

the base slab and then upwards along the outside surface of the containment wall for a distance of about 1.2 m (4 ft).

Drainage System

The subbase, which included the porous concrete layers, membranes, and drainage materials just described, was installed to permit removal of rain and ground water from below the containment base slab. Based on information provided by Northeast Utilities Energy Co. (Ref. 2), the subbase drainage system continues to function as intended. On average about 6,800 liters (1,500 gallons) of water are removed each day from the two sumps. Data suggests that the volume of water removed daily is highly dependent on the ground water level and the precipitation intensity.

Most of the water from the two sumps flows from the concrete pipes embedded in the porous high-alumina cement concrete layer located just below the base slab. Although other potential sources of water have been identified, Northeast Utilities Energy Co. indicated that amounts from these other sources are small in comparison (Ref. 2). Chemical analysis results for water samples obtained from the sumps indicate that the water has a pH greater than 10. This value is greater than acidic rain water which has a pH below 7, but it is somewhat less than concrete which has a pH of 12 or higher. These results suggest that the water chemistry is being altered as the water flows through the subbase, possibly by the cement or aggregate particles used to construct the porous high-alumina cement concrete layer.

Residue consisting of a homogeneous grayish-white granular material collected from the two sumps was also analyzed to help identify the source(s) of the water and the residue (Refs. 1, 5, and 6). Since 1987, approximately 36 kg (80 lb) per year of residue (dry weight) has been collected (Ref. 2). Results of laboratory analyses performed for Northeast Utilities Energy Co. by ABB Combustion Engineering Nuclear Power in 1991 (Refs. 1 and 5) and 1996 (Ref. 6) reveal that there are significant concentrations of calcium, carbon, and magnesium in the residue suggesting that the source of the residue could be the porous high-alumina cement concrete layer. Unfortunately, results of these laboratory analyses are not conclusive.

CONCRETE PERFORMANCE CHARACTERISTICS

Two fundamentally different types of porous concrete were used to construct the subbase for the Millstone, Unit 3 containment. One concrete was made using portland cement that conformed to requirements provided in ASTM C 150 for Type II, low-alkali cement. The other was made using high-alumina cement for which no ASTM material specification has been adopted.

The subbase is required to provide support for the gravity loads from the containment and to allow free drainage of water from under the base slab. The ability of the porous concrete subbase layers to support the applied loads is primarily influenced by the angle of internal friction of the aggregate particles (Refs. 8 and 9). Sizes of individual aggregate particles and mechanical properties of the porous concretes do not significantly affect the angle of internal friction. Consequently, the ultimate bearing capacity of the porous concrete subbase layers does not depend on the presence or magnitude of the bond between the cement paste and the aggregate particles.

In spite of this fact, both porous concretes were required to have a 28-day compressive strength of 6.9 MPa (1,000 psi). This specification was selected to facilitate construction and was not based on structural considerations. Concrete with this minimum level of strength provided assurance that the coarse aggregate particles would remain in place during subsequent construction operations and that suitable porous concrete could be mixed and placed under field conditions (Ref. 10).

Portland Cement Concrete

Concrete made using portland cement, aggregate particles, and water is a very durable construction material that has been used for over 150 years in building applications. Its properties as a structural material are excellent and its permeability is usually quite low. Although versatile, the durability and long-term performance of this type concrete can be adversely affected by chemical attack. All portland cement concrete that contains aggregate can potentially degrade as a result of alkali-aggregate reactions. When alkalis in the cement (sodium or potassium) react with certain constituents in some aggregate particles, deleterious expansion of the concrete and microcracking of the aggregate particles can result. Exposure of concrete to ground water that contains sulfate ions can result in expansion of the concrete provided the sulfates react with the calcium hydroxide and the calcium aluminate hydrate. Damage caused by sulfate attack usually starts at exposed surfaces and produces spalling. One reliable source of sulfate ions is sea water. Acids usually attack the surface of concrete by dissolving and removing part of the cement leaving behind a soft mass. Degradation caused by dilute acid solutions such as acid rain is generally very slow. Chloride ions in deicing salts and sea water can also contribute to reinforced concrete deterioration by causing corrosion of the reinforcing steel bars embedded in the concrete (Refs. 11 and 12).

No-fines concrete is a special type of concrete made using portland cement, coarse aggregates, and water. This type of concrete is not often used as a structural material because it has relatively low tensile and compressive strength, and it is very permeable (Ref. 10). However, these limitations make it a suitable material for drainable subbase applications. During placement, no-fines concrete is self-compacting and can be consolidated by gravity alone in the same way that coarse aggregate particles are self-compacting when deposited and leveled. After curing, no-fines concrete shrinks very little because the cement paste and aggregate matrix is not completely continuous. Compressive strength of no-fines concrete is derived primarily from point contact between adjacent aggregate particles and to a lesser extent by the chemical and mechanical bond developed between the cement paste and the aggregate particles.

Although possible, the potential for alkali-aggregate attack of the subbase portland cement concretes used at Millstone, Unit 3 has been minimized by the use of low-alkali portland cement. In addition, any aggregate microcracking that may occur as a result of alkali-aggregate reactions should not cause detectable uplift of the containment due to the large void volume present in the porous concrete, and the ultimate bearing capacity of the subbase material is not meaningfully influenced by minor changes in size of the affected aggregate particles. Effects of sulfates, acids, and chloride ions on the no-fines portland cement concrete is also not expected to be significant because the subbase does not contain embedded reinforcing steel and degradation of the cement paste coating by sulfate or acid attack will not influence the bearing capacity of the subbase material.

Erosion of aggregate particles in the no-fines concrete could potentially result in loss of subbase material. However, erosion, which involves the progressive disintegration of the solid aggregate particles by the abrasive or cavitation action of gases, fluids, or solids in motion, is not considered likely. The velocity of water that flows through the porous concrete is very slow, and local conditions are probably not turbulent. Although settlement of the containment due to loss of subbase material by erosion may be possible, detectable settlement that could adversely impact the structural performance or leaktight integrity of the containment would require removal of a significant volume of subbase material. For example, uniform settlement of the containment by 2.5 mm (0.1 in.) would require removal of at least 7,000 kg (16,000 lb) of aggregate material from under the base slab. This estimate is based on the specified diameter of the concrete base slab and the approximate unit weight of the aggregate particles of 1,600 kg/m³ (100 lb/ft³).

High-Alumina Cement Concrete

Invented in France, high-alumina cement was developed as a solution to the problem of decomposition under sulfate attack. In addition to showing good performance in sulfate-bearing ground water and sea water, high-alumina cement concrete is resistant to many forms of dilute acids. However, caustic alkalis, even in dilute solutions, attack all aluminous cements by dissolving the alumina gel. High-alumina cement develops strength very rapidly making it a useful material in special construction applications where strength gain is critical. However, following rapid hydration of monocalcium aluminate, high-alumina cement exhibits a slow decomposition reaction commonly called conversion. Conversion of the unstable hexagonal aluminate hydrates to cubic hydrates results in loss of strength (Ref. 12). In addition, the strength of hardened concrete made using high-alumina cement is adversely affected by a rise in temperature at later ages when the concrete is stored under moist conditions. After conversion, its resistance to sulfate attack decreases rapidly (Refs. 11-15). High-alumina cement concrete was used primarily in Great Britain from the 1950s until about 1974, but when a roof system made from this material collapsed, its use as a structural material essentially stopped. Use of high-alumina cement in the United States for building applications has not been common.

Results of a 20-year testing program revealed that high-alumina cement concretes convert with time at rates that depend to some extent on the exposure temperature and moisture conditions (Ref. 16). Conversion occurs most rapidly under moist conditions at elevated temperatures, and strength loss resulting from conversion can be significant. For example, after outdoor storage for 21 years, high-alumina cement concrete specimens with a water-to-cement ratio of 0.40 exhibited only 31 percent of their peak strength (Ref. 11). Because high-alumina cement tends to lose strength over time when exposed to moisture, it is not well suited for use as a structural material. Use of high-alumina cement concrete as formwork for portland cement concrete was also found unsuitable as the heat generated by the hydration of the portland cement caused rapid conversion of the high-alumina cement concrete making the surface of the formwork soft and loose (Ref. 13).

At Millstone, Unit 3 where no-fines, high-alumina cement concrete was used to create a porous subbase layer just below the base slab, at least partial conversion of the high-alumina cement with accompanying loss of strength is to be expected. Partial conversion is considered likely because the concrete has been exposed to moist conditions for over 20 years. Although the exposure temperatures have not been elevated (which would make complete conversion almost certain), significant strength loss of the cement paste has probably occurred, and part of the cement paste coating on the surface of the aggregate particles is undoubtedly soft and loose. Effects of high-alumina cement paste degradation are not expected to adversely affect the ultimate bearing capacity of the subbase because the bond between the cement paste and the aggregate particles has no significant influence on the angle of internal friction of the aggregate particles.

FINDINGS

A review of technical information related to use of high-alumina cement concrete at the Millstone, Unit 3 nuclear power plant has been performed. The review focused on erosion of the subbase cementitious materials, containment settlement, loss of ultimate bearing capacity of the containment subbase, and interactions between the various subbase cementitious materials. Relevant information provided to ORNL by the NRC (Refs. 1-6) for the review were examined, and documentation contained in other reports and publications was considered. Based on the limited information that was provided, only general remarks about the four review topics can be provided. These remarks are presented in the following sections.

Erosion of the Subbase Cementitious Materials

Residue that accumulates in the sumps at Millstone, Unit 3 may be originating from the porous high-alumina cement concrete that was used to construct the containment subbase. Chemical analysis and laboratory test results are not conclusive. However, loss of only 36 kg (80 lb) per year (dry weight) from this layer is not considered significant when compared to the amount of high-alumina cement that was used in its construction. According to information provided in Reference 2, approximately 136,000 kg (300,000 lb) of high-alumina cement were used to prepare the 420 m³ (550 yd³) of concrete required to construct the 229-mm (9-in.) thick by 48.5-m (159-ft) diameter porous concrete layer. High-alumina cement was added at a rate of 330 kg/m³ (560 lb/yd³). At the current rate of residue accumulation, it would take about 3,750 years to remove all of the high-alumina cement that was used in the construction of this porous concrete layer. Erosion of high-alumina cement from the aggregate particle surfaces is probably not occurring because the velocity of the water through the porous concrete is very slow and local conditions are most likely not turbulent. The residue can probably be attributed to conversion of the high-alumina cement and the subsequent softening and loosening of the cement paste that coats the surface of the aggregate particles. Water flowing through the porous layer may be leaching the degraded cement paste, and some of the loose or dissolved material may eventually find its way into the sumps.

Periodic collection and weighing of residue that accumulates in the sumps is justified because the data may be useful in the future in identifying the source(s) of the residue. Significant changes in the amount of residue collected from one time period to the next may be meaningful, particularly if it can be related to a unique event. Testing and analysis of additional residue samples by other laboratories that are more familiar with cement and concrete chemistry may also be justified to help identify the exact source(s) of the residue.

Containment Settlement

Detectable settlement of the containment due to loss of material from the porous high-alumina cement concrete layer is probably not likely during the remaining licensing period. In order for the containment to uniformly settle 2.5 mm (0.1 in.), at least 7,000 kg (16,000 lb) of aggregate material with a unit weight of 1,600 kg/m³ (100 lb/ft³) would need to be removed from under the 47.9-m (157-ft) diameter base slab. Based on the limited information provided, the only way for removing material from under the base slab is by pumping water from the two sumps.

To verify that significant settlement is not occurring, it may be necessary to consider implementing two separate actions. Thorough visual examination of the outside surfaces of the containment should be performed at regular time intervals to detect concrete cracking that could be related to uniform or differential settlement. As part of this examination, areas where pipes and other mechanical and structural components interface with the containment should be carefully examined for indications of relative movement, offset, or misalignment. Periodic elevation measurements should also be taken to quantify the settlement, if any. These measurements could be used to support and complement the visual examination results.

Loss of Ultimate Bearing Capacity of the Containment Subbase

The ability of the porous high-alumina cement concrete subbase layer to support the applied loads from the containment is primarily influenced by the angle of internal friction of the aggregate particles. Sizes of individual aggregate particles and mechanical properties of the concrete do not significantly affect the angle of internal friction. Consequently, the ultimate bearing capacity of the porous concrete subbase layer does not depend on the presence or magnitude of the bond between the high-alumina cement paste and the aggregate particles. Based on this assessment, the

ability of this subbase layer to support the applied loads from the containment has not changed since it was constructed.

Interactions between Portland and High-Alumina Cement Concretes

Degradation of the portland cement mortar located below the high-alumina cement concrete layer, and degradation of the portland cement concrete base slab located above the high-alumina cement concrete due to chemical interaction between the cementitious materials is not considered likely. The high-alumina cement concrete is not a source of alkalis that could contribute to alkali-aggregate reactions of the portland cement concrete or mortar. In addition, the alkalis in the low-alkali portland cement concrete and mortar should not attack the high-alumina cement concrete because these cementitious materials only have one common interface.

Although high-alumina and portland cement were not used in the same concrete mixture, casting the portland cement base slab concrete directly on top of the sealed, porous high-alumina cement concrete subbase layer may have resulted in an inadvertent interaction between the two concretes. Heat produced by the hydration of the portland cement and the presence of moisture in the fresh concrete may have accelerated the conversion of the high-alumina cement concrete making the high-alumina cement paste on the surfaces of the aggregate particles soft and loose at an early stage in the plant's life.

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