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4. Title: Durability of Jet Grout Materials and Application Technology for the Subsurface Disposal Area

5. Summary: This summary briefly defines the problem or activity to be addressed in the EDF, gives a summary of the activities performed in addressing the problem and states the conclusions, recommendations, or results arrived at from this task.

Degradation of grout materials is due to volume change and/or chemical reaction in the natural environment. At the Idaho National Engineering and Environmental Laboratory Subsurface Disposal Area the environment is very benign. The jet grouted buried waste would lie beneath two or more meters of soil overburden. The soil temperature is virtually constant, freeze-thaw and wet-dry processes are absent. Grout composition can be chosen to be compatible with the natural environment. These facts indicate that the SDA buried waste site can be treated using the jet grout technology, and so treated will remain isolated from the natural environment for hundreds to thousands of years or more.

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Durability of Jet Grout Materials and Application Technology for the Subsurface Disposal Area

1. INTRODUCTION

This paper discusses the long-term durability and other aspects of potential grout materials used in the jet-grouting technology. Jet grouting is an in situ technology that may be used to stabilize and contain buried waste in the transuranic (TRU) pits and trenches of the Subsurface Disposal Area (SDA) at the Idaho National Engineering and Environmental Laboratory (INEEL). For this application, an appropriate grout material is injected directly into the buried waste in the waste pit or trench. This is done by using a modified rock core-drilling apparatus to drill into the buried waste and inject the grout material at high pressure (>6,000 psi). The in situ grouting (ISG) process is repeated until the open space in the buried waste is completely filled with grout material. After set and cure of the grout material, the result is a monolithic, coherent mixture of grout, soil, and waste materials. The goal is to decrease the risk to the environment and personal health caused by the contaminant materials to acceptable levels and to maintain that acceptable level of risk for a long time.

The specific time period required for grout performance is not well defined. For the purposes of this discussion, it is reasonable to suppose that the treated waste site will be under administrative control for one hundred years, but that the grout must perform to specification for a minimum of 1,000 years. This working assumption is based on the proposition that political environments are much less predictable than geological environments.

The degradation of grout in the natural environment involves exactly the same mechanical and chemical weathering processes that affect the stability of rock. Mechanical processes include volume increase due to salt crystal growth, freeze-thaw processes, and wet-dry cycling. Jiang and Roy point out that the survival of examples of cementitious material from antiquity is due to the absences of these processes.[1] Chemical weathering results from chemical reactions between the grout and the environment, particularly ground water. Chemical weathering can be completely avoided if the grout material is chosen so that it is in equilibrium, or nearly so, with the natural environment. If the grout is in equilibrium with the environment, it cannot degrade.

Examples of man-made cementitious grouts which survive from antiquity include[1]:

- Lime–soil mix from the Great Wall, China, 100-200 BC
- Pozzolanic mortar from Mole Pozzuoli, Italy, 100-200 BC
- Aluminous/Ferruginous/Silicious lime cement from the Roman Aqueduct in Lyon, France, 200-300 AD
- Gypsum mortar from the Great Pyramid in Giza, Egypt, 2500 BC

An example of grout durability in the United States is the mortar found in the Vauter Church, Tidewater, Virginia, constructed in 1705. The mortar is original and in excellent condition despite the hostile, semi-tropical, tide water environment.[2] The hydraulic cement component of the mortar was made by firing a mixture of oyster shells and locally quarried clay and sand.

2. GROUT REQUIREMENTS

Long-term durability of the grout material is clearly necessary, however, other properties are also required. The grout material performance requirements are listed here.

- The grout must have rheological and set properties that allow it to be applied using the jet-grouting apparatus. This is an obvious requirement: if the material can not be applied, then long durability and all other properties are not relevant.

- The grout must maintain *acceptable performance* for 1,000 years or more. Acceptable performance means that the grout material will allow no more than the acceptable limit of contaminant release and that the performance of the grout is predictable during the required period.

- The grout must have low permeability (and other properties) so that the hydraulic conductivity of the treated waste site is acceptable and the hydraulic conductivity of the site is predictable. At present, the buried waste sites at the SDA are physically unstable and subject to subsidence and other movement. Consequently, the long-term hydraulic properties of the untreated buried waste cannot be predicted with confidence and the long-term health and environment risk assessments based on such predictions are uncertain.

- The grout must not increase the mobility of contaminant materials. The ideal grout would destroy or lock the contaminants into an immobile form.

- The grout and application method must be cost effective.

3. PROPERTIES OF SUBSURFACE DISPOSAL AREA

The long-term behavior of all grout materials depends on several variables, including the environment in which they will function. The long-term durability of grout materials is affected by the properties of the INEEL SDA. The properties of the jet grout application and relevant characteristics of the SDA are discussed below.

The grout material would be injected by jet grouting into buried waste. This is mechanically identical to filling a swimming pool with water (or grout material). After set and cure, the grout is subjected only to compressive stresses due to the weight of the grout material and overburden. In general, the treated waste will not be subjected to either sheer stresses or bending forces. During the cure cycle, volume changes of the grout may produce tension (due to grout shrinkage) or compression (due to grout expansion) stresses. If the grout material is brittle, shrinkage may result in fractures. The frequency and width of such fractures are dependent on the amount of shrinkage and tensile strength of the grout material (brittle materials only). The *swimming pool* effect means that ISG materials are not required to have shear strength. This is true for the same reasons that water in a swimming pool requires no strength to stay in the pool and fill all void space. Therefore some ISG materials, such as paraffin, can be a fluid in the mechanical sense (i.e., a plastic material). Fractures can not exist in plastic materials over significant periods. The unsupported compressive strength test, ASTM-C-39-96 used by the cement industry and others to characterize structural concrete, is irrelevant for the ISG application, because much of the measured value is due to the sheer strength of the tested material and, as indicated above, shear strength is not a requirement of ISG materials.

Significant fracturing and change of the hydraulic properties of the grouted waste site due to future earthquakes is not expected. The man-made structures at the INEEL have survived two major earthquakes (Hebgon Lake, 1959, and Bora Peak, 1984) in the seismically relevant regions of Idaho without damage. Similarly, the delicate volcanic structures, which dot the area immediately around the SDA, show no evidence of mechanical disruption of any sort due to earthquakes within the past 2500 years or so. Therefore, seismic effects are inconsequential to the long-term durability of buried waste stabilized by jet grout processes. Plastic grout materials such as paraffin are not affected by seismic activity because any fractures which might appear are eliminated by plastic deformation of the grout material.

Degradation of the grout material due to climatic effects is very unlikely. The grouted buried waste will be beneath a soil overburden two or more meters thick. Soil temperature will be virtually constant at somewhat less than 60°F; therefore, no freeze-thaw degradation can occur. Inter-granular water tension is usually slightly less than saturation and virtually constant, therefore no degradation due to wet-dry cycling can occur. Ambient temperatures are low and reaction rates are slow compared to similar rates at ground surface. As a point of reference, natural reaction rates of rock weathering processes approximately double with every 18°F increase in temperature.

The natural waters at the SDA are unlikely to have a significant effect on the long-term durability of grout materials. Annual precipitation is less than 10 inches per year and the climate is semi-arid. The chemical properties of the ground water found at the SDA are benign. In general, the ground water is slightly alkaline, pH is about 8, and the oxidation-reduction potential is equivalent to oxygen in air. The ground water is saturated with respect to calcium and magnesium, nearly saturated with silica and other rock forming ions. The INEEL soils are regions of carbonate precipitation, not leaching. Observations by the author in the INEEL settling areas adjacent to the SDA indicate that calcite, $CaCO_3$, is being precipitated at all soils depths from the basalt bedrock to within less than one foot of ground surface. Only within the one foot zone at ground surface is leaching by rainwater affecting the calcite precipitation. These observations are relevant to the long-term durability of cementitious grout because any chemical degradation of such grout will be followed by the immediate precipitation of carbonate minerals within any available open space. Residence of the area without water softening systems in their homes are well aware of the speed and amount of carbonate deposition on faucets, shower heads, and sprinkler systems. Exactly the same chemical processes must occur in nature when cementitious grouts interact with the ground water found in the SDA.

4. KINDS OF GROUT AND THE SURVIVAL OF GROUT IN NATURE

The composition and properties of potential grout material are extremely diverse and range from organic waxes and resins, to siloxanes, oxides, silicates, phosphates, and other materials. A partial list of conventional cementitious materials includes Portland cement (five types), pozzolonic cements, high alumna cements, silica fume cements, fly ash cements, as well as cements modified with various exotic additives, such as latex, epoxy, and many others. The broad range of potential grout materials provides the designer with some latitude in selecting the grout to be compatible with the properties of the waste site.

The primary causes of grout mechanical degradation are the effects of salt crystal formation, freeze-thaw cycles, and wet-dry cycles.[1] Buried waste treated by the jet grout process is beneath at least two meters of overburden and is not subjected to these effects. Also chemical degradation is minimal. A grout at chemical equilibrium with the environment will not chemically degrade whatsoever, provided the climate and other factors of the environment do not significantly change over time. For example, a geologically fragile material such as limestone, i.e. calcite, $CaCO_3$, will last indefinitely in the SDA because the natural chemical system of the ground water in the SDA is chemically saturated with calcite and therefore cannot chemically degrade a calcite grout.

Representative examples of grout that have been considered for application at the SDA include the following materials[a]:

- Waxfix™ is a commercially available grout based on paraffin. It is a mechanically plastic material and has several very desirable properties for jet grout application at the SDA. Dr. Paul Blacker estimates that this material will function in the SDA as a grout for many thousands of years.[3] His analysis is based on the properties of the SDA, including temperature, the micro flora and fauna, and the properties of paraffin waxes. Dr. Blacker points out that bones and tissue are preserved in tar pits from around the world and are known to have ages up to the last ice age, at least 50,000 years.

- Silica suspensions, such as Ludox™ and polly-siloxane materials have been evaluated at the INEEL for jet grout application. These materials are man-made equivalents of the various natural silica (SiO_2) materials such as opal, flint, agate, and quartz. They have the same durability as ordinary beach sand because they are the same material. Some rocks formed from quartz sand are estimated at over one hundred million years old.

- An iron oxide-gypsum grout was developed at INEEL and is included in U.S. Patent 5980446, issued November 9,1999. It was specifically intended for applications at the SDA requiring long-term durability. Iron oxides, together with aluminum oxides, are the most durable rock forming materials found on, or in, the earth's crust. They are the insoluble materials found in the residual tropical soils and the testa rosa deposits left after limestone formations have been totally destroyed by leaching. They are the insoluble residues after all sodium, potassium, calcium, magnesium, and silicon have been leached from soil and bedrock. Some rocks formed from iron oxide are estimated at over one hundred million years old. The gypsum component of the grout is also expected to be durable in the SDA environment because gypsum grouts were used 2,700 years ago by the Egyptians and survive today.[1]

- The Saltstone grout is a pozzolanic cementitious grout developed at the Savanna River site. It is estimated to have a life-time in excess of 1,000 years in the semi-tropical climate of Savanna River, Georgia, a very severe test of the long-term durability of a grout material.[4]

- Cementitious grout similar to the Chalk River cement are also being evaluated. Systematic kinetic studies at the Chalk River Laboratories, Ontario, Canada, have shown that cementatious materials can have a life time in excess of 500 years when used for waste repository vaults.[5] In these studies, the 500-year life time refers to the length of time necessary for water to migrate to the iron reinforcement in the repository structure. It is not the time predicted for failure of the structure or released of hazardous materials into the environment, both of which would only occur after further, very severe and extensive, degradation of the structure.

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[a] The list of grout is representative, not inclusive.

5. SUMMARY AND CONCLUSIONS

Degradation of grout materials is due to volume change and/or chemical reaction in the natural environment. At the SDA, the environment is very benign. The jet grouted buried waste would lie beneath two or more meters of soil overburden. Soil temperature is virtually constant, freeze-thaw and wet-dry processes are absent. Grout composition can be chosen to be compatible with the natural chemical environment. Taken together, these observations indicate that the SDA buried waste site, after being properly stabilized by the jet grout technology, will remain isolated from the natural environment for a long period of time, hundreds to thousands of years or more.

6. REFERENCES

1. Jiang, W. and D. M. Roy, "Ancient Analogues Concerning Stability and Durability of Cementitious Wasteform," *Materials Research Society Symposium, Pennsylvania State University, University Park PA, 1994*, Proceedings Vol. 333.

2. Dr. Jerry Weidner, Personal observation by the author.

3. Dr. Paul Blacker, "On Natural Materials and Their Man-made Analogs for Radioactive Waste Confinement," Bechtel BWXT Idaho, LLC, Manuscript in Preparation, 2000.

4. Westinghouse Savannah River Company, *Radiological Performance Assessment for the Z-Area Saltstone Disposal Facility*, WSRC-RP-92-1360, 1992.

5. Philipose, Ken E. and Rolf F. Feldman, "Durability Aspects of High-Performance Concretes for a Waste Repository," *A.C.I. International Durability Conference, Singapore, 1994.*