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Laboratory Testing of Chemical Stabilizers for Control of Fugitive Dust Emissions from Uranium Mill Tailings

Prepared by M. R. Elmore, J. N. Hartley

Pacific Northwest Laboratory
Operated by
Battelle Memorial Institute

Prepared for
U.S. Nuclear Regulatory Commission

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Prepared by
M. R. Elmore, J. N. Hartley

Pacific Northwest Laboratory
Richland, WA 99352

Prepared for
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U.S. Nuclear Regulatory Commission
Washington, D.C. 20555
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ABSTRACT

Pacific Northwest Laboratory, under contract to the U.S. Nuclear Regulatory Commission's Office of Nuclear Regulatory Research, is investigating techniques to control fugitive dust emissions from active uranium mill tailings piles. This report describes laboratory tests conducted to evaluate 45 commercially available chemical stabilizers. Tests were conducted in a wind tunnel to evaluate the effectiveness and durability of the stabilizers under similar conditions. The effects of application rate, temperature (freeze/thaw) cycling, wet/dry cycling, and wind speed were determined. In addition, tests were conducted to determine the effects of ultraviolet light and water erosion on the durability of the stabilizers. Permeability tests were also conducted to determine the potential effect of each stabilizer on the overall stability of the tailings pile. Results of these laboratory tests indicated that 16 of the stabilizers were equally effective and more durable than the others.

SUMMARY

Wind erosion of unprotected uranium tailings piles is a growing concern because of the potential spread of tailings containing residual radioactivity to offsite areas. Pacific Northwest Laboratory, under contract to the U.S. Nuclear Regulatory Commission's Office of Nuclear Regulatory Research, is investigating methods to reduce fugitive dust emissions from uranium mill tailings.

One promising dust control method involves using chemical stabilizers as dust suppressants. Samples of 45 commercially available chemical stabilizers were tested in the laboratory for their effectiveness and durability under simulated weathering conditions expected at most mill sites. The effects of wind speed, application rate, temperature (freeze/thaw) cycling, and wet/dry cycling were investigated in a wind tunnel. In addition, tests were conducted to evaluate the effects of ultraviolet light exposure and water erosion on the durability of the stabilizers. The permeability of stabilized simulated tailings was evaluated to determine the overall effect on the stability of the tailings pile.

Based on the results of these laboratory tests, 16 chemical stabilizers were selected for field testing. One additional stabilizer, a wood fiber mulch with an organic binder commonly used for erosion control, was also chosen for the field test.

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INTRODUCTION

Dust control technology is receiving more and more attention within the scope of environmental programs. With growing awareness and concern over air quality, the effects of wind erosion and the suspension of fine particulates in the atmosphere are receiving more consideration. Of particular concern is the erosion of uranium tailings from unprotected tailings piles, since most of the radioactivity associated with the original ore remains in the tailings as unextracted radium and other radioisotopes.

Pacific Northwest Laboratory (PNL),[a] under contract to the U.S. Nuclear Regulatory Commission's (NRC) Office of Nuclear Regulatory Research, is investigating traditional and nontraditional techniques for controlling fugitive particulate emissions from uranium mill tailings piles. The overall objective of this project is to assess the effectiveness, durability, and practicality of interim stabilization techniques and strategies for the suppression of dust from exposed tailings surfaces under a full range of site and environmental conditions.

Laboratory and field studies have been conducted on the use of various chemical and physical soil stabilization techniques. The objective of the laboratory studies was to determine the effectiveness and durability of commercially available chemical stabilizers and to identify the more effective ones for field testing at a uranium mill tailings pile. The laboratory studies included: 1) a literature review to identify commercially available techniques and products, 2) material characterization studies to determine physical and chemical characteristics of both the stabilizers and the tailings to which they might be applied, and 3) stabilizer testing. A previous report by Li, Elmore, and Hartley (1983) describes the literature review and some material characterization studies that were conducted.

This report describes the laboratory tests conducted to evaluate the effectiveness and durability of commercially available chemical dust suppressants. Most of the studies were conducted in a wind tunnel to compare the relative resistance of treated simulated tailings (sand) samples to wind erosion. Various stabilizer dilution and application rates were tested. The laboratory tests also evaluated the resistance of the stabilizers to water erosion and other weathering forces: temperature (freeze/thaw) cycling, wet/dry cycling, and ultraviolet (UV) degradation. The effect of the chemical stabilizers on the permeability of the tailings pile was also investigated. Decreased permeability of the tailings is an important consideration for the overall stability and safety of the mill tailings impoundment.

(a) Operated for the U.S. Department of Energy (DOE) by Battelle Memorial Institute.

CONCLUSIONS

The laboratory tests included several types of stabilizers; for example, petroleum resin emulsions, synthetic resin emulsions, asphalt emulsions, lignin sulfonates, and hygroscopic salt solutions. No one type of material was superior to all others in the laboratory tests; and one material, a surfactant (wetting agent), proved to be a very ineffective dust suppressant under the test conditions.

The following specific conclusions were drawn from the results and observations of the laboratory tests:

- Sixteen of the 45 chemical stabilizers appeared to be equally effective and durable under identical test conditions and generally better than the rest of the tested materials.
- Fourteen chemical stabilizers were chosen from the initial laboratory testing for field testing. A wood fiber mulch was also selected for the field test but was not tested in the laboratory. Additional laboratory testing identified two other chemical stabilizers for field testing.
- The stabilizers were applied at the manufacturer's recommended rate and at one-half that rate; most stabilizers showed little difference. Two emulsions from Nalco Chemicals performed significantly worse at the one-half rate.
- The stabilizers were also applied at an equal material cost of $750/ha ($300/acre). Few differences were seen in the wind resistance of the samples.
- Most samples were resistant to temperature (freeze/thaw) cycling.
- Wet/dry cycling appeared to cause noticeable degradation of some of the stabilizers.
- The more severe wind conditions created by inclining the sample pan in the wind tunnel resulted in the failure of only one additional material.
- Diluting the stabilizers with more water than recommended increased the amount of sand eroded from the pans of the stabilizers tested.

- Based on test results, no significant decrease in permeability of the tailings pile is expected from using the chemical stabilizers.

- Some UV degradation of the chemical stabilizers will occur but should not be significant within the expected useful life of the stabilizer (<1 year).

- Although 16 of the tested stabilizers were eventually selected for field testing, it cannot be positively concluded that those chosen would always be more effective or durable than many of the others under actual site and environmental conditions.

CHEMICAL STABILIZERS

An earlier report presented an overview of fugitive dust control for uranium tailings piles (Li, Elmore, and Hartley 1983) and included a list of 39 commercially available chemical stabilizers. Since then, six more products have been identified. All of these products, with the exception of the wood fiber mulches, are applied to the tailings surface as water-based solutions and emulsions with some type of sprayer. The wood fiber mulches usually contain a soluble tackifier and are slurried with water and blown onto the tailings using special pumps and nozzles. One type of equipment commonly used is called a hydroseeder.

Manufacturers describe the majority of the chemical stabilizers as synthetic polymer emulsions. Other general types of stabilizers are petroleum resin emulsions, hygroscopic salt solutions, asphalt emulsions, wood and other organic processing by-products (for example, lignin sulfonates), sulfur products, and wood fiber mulches. More specific chemical composition information is available for some products; for most of the products, this information is proprietary. The available information on chemical compositions and recommended dilution and application rates is listed in Appendix A.

The method by which these chemicals stabilize a surface varies. Most form a membrane or surface crust with the tailings particles that resists wind erosion. Some form a very pliable crust; for example, the undiluted SP-400 forms a rubbery membrane on the surface with very little penetration (less than 0.2 cm). Others, such as Marloc, penetrate the tailings surface and form a very hard crust. Other materials are hygroscopic salt solutions that work in two ways. First, because they are hygroscopic, they absorb water from the air when the relative humidity is high enough. This "wetting" of the surface reduces the tendency for wind erosion through increased weight and cohesion of the particles. If the humidity is so low that the salts lose the absorbed water, most of these solutions then form a crust and continue to resist wind erosion.

Most products are diluted with water before use. Some of the products are sensitive to the chemistry (pH in particular) of the water. For example, some of the emulsions may be unstable if the dilution water is very acidic, high in salt content, or contaminated with oils or if it contains a large quantity of cations. The emulsion could coagulate, resulting in plugged spray equipment and decreased protection of the tailings surface from erosion. Except for tests where the water chemistry was purposely altered, deionized water was used to dilute the stabilizers for the laboratory tests. A few products required hot water to dissolve the materials, which appears to be a distinct disadvantage when used for tailings stabilization.

Many of the stabilizers require a curing period of a couple of days to reach their full strength as binders. Of these products, some require a period of time at moderate temperatures with no rain for proper curing. For the laboratory studies, all test specimens were allowed to cure for two days at room temperature before testing.

LABORATORY STUDIES

The laboratory tests were designed to simulate wind and other weathering conditions that might be expected at most of the existing uranium mill tailings sites. The laboratory tests had the advantages of being able to accelerate the weathering of the stabilizers and to control each of the test parameters separately (wind speed, temperature, moisture, etc.). The basic test conditions included:

- wind speeds up to 27 m/s
- 10 temperature cycles from -21°C to 45°C
- 5 cycles of simulated rain followed by drying at 45°C
- stabilizer application rates varying from the manufacturer-recommended amount to one-half that amount
- stabilizer application to the test pans at an equivalent material cost of $750/ha ($300/acre)
- inclining the test pans in the wind tunnel at a 30° angle to increase the wind force on the samples
- dilution factors different from those recommended by the manufacturers
- simulated rain and running water to test water erosion resistance (30° slope with 4 cm/h rainfall)
- intense UV light exposure (10 watts/cm^2) to study UV degradation of the stabilizers
- columns of treated sand placed under a constant head of water (60 cm) to compare differences in water permeability caused by the stabilizers.

The objectives of the laboratory tests were to: 1) study the effectiveness and durability of the chemical stabilizers under controlled conditions that simulated the effects of weathering and 2) rank the stabilizers to select the best products for field testing at a uranium tailings pile. Of the commercially available materials identified, it was expected that six or eight of the better products would be chosen for the field test. However, results of the laboratory tests eventually led to the selection of 16 stabilizers for field testing.

Selecting only a few of the better stabilizers for field testing was difficult because of the close test results. The laboratory tests were expected to result in a more definitive ranking of the stabilizers. However, for the majority of the laboratory tests, the differences in results were very small. Ranking of the stabilizers, and eventually the selection of the materials for the field test, was based on the results of wind tunnel tests, specifically on weight loss per unit area from the sample pans and on observed surface conditions. The ranking was often aided by observations made while working with the stabilizers; for example, ease of mixing, diluting, and applying the stabilizers and the ease of cleaning the spray equipment.

Detailed test results are presented in Appendix B; a summary of the test results is presented in Table 1. The weight loss per unit area from the sample pans after testing is shown, and the stabilizers are ranked according to their performance during the test. An average relative performance is signified by (A); materials that performed better or worse than average were assigned (+) or (-), respectively. The procedure used to rank the test results is explained in greater detail in the Stabilizer Selection for Field Testing section.

The primary tool used for the laboratory evaluation of the chemical stabilizers was a wind tunnel (Figure 1). The working section of the tunnel is ~8 m long with a 0.6-m x 0.6-m cross section, which was large enough to accommodate the 23-cm x 31-cm sample pans used in the tests. The recirculating-type wind tunnel is capable of wind speeds in excess of 27 m/s across the sample surface. A wind velocity profile for the working section of the wind tunnel is shown in Figure 2.

A wind velocity of 27 m/s (near the limit of the wind tunnel) was used for the studies. A test time of 10 min was sufficient to remove any erodible material from the test pans; longer test times generally produced no further erosion.

Sample pans were filled with a fine sand that simulated uranium tailings in size distribution (Figure 3). The sand was then leveled and sprayed with the diluted stabilizers using a small paint sprayer (Figure 4). The test pans were sprayed on an electronic balance. The stabilizer application was determined by the weight gain of the pans. Various dilution and application rates were studied. Once the treated sand had cured for two days in the sample pans, the pans were ready for testing. For most of the wind tunnel tests, the samples were inserted into a cutout floor section of the wind tunnel (Figure 5). For one series of tests, the pans were inclined in the wind tunnel at a 30° angle from horizontal to increase the incident wind force on the samples.

TABLE 1. Summary of Stabilizer Test Results

Product	Test[(a)] A	B	C	D	E	F	Cumulative Rank[(b)]
8803	A	---	A		A	-	-4
8820	A	---	A		-	-	-5
Aerospray-70	A	A	A	A		+	+1
AMS-2200	A	A	A	---	A	A	-3
Coherex	A	+	A	+	A	+	+3
CPB-12	+	+	A	A	A	A	+2
Dust Binder C-266	+	A	+	+	A	A	+3
Dust Gard	+	+	A	+	A	A	+3
Dust Loc VMX-50	A	A	+	+	A	+	+3
ESI-BOND	A	A	+	-	+	+	(+2)
Gantrez AN-119	A	A	A	A	A	A	0
Gantrez AN-139	+	A	A	A	A	--	-1
Gantrez AN-169	+	A	+	A	A	---	-1
Hercobind DS-3	+	+	A	+	A	---	0
Hydrodyne C	---			---			-6
IDA-656	A	A	A	+	A	A	+1
Liquid Dust Layer	+	-	-	-	A	A	-2
M-166	-	+	A	A	A	A	0
M-167	A	A	+	+	A	+	+3
Marloc	+	A	+	A	A	A	+2
Orzan A	+	A	A	A	A	A	+1
Orzan S	A	A	A	A	A	-	-1
Pentron DC-5	+	A	+	-	A	A	(+1)
Polyco 2151	A	+	+	+	A	A	+3
Rezasol 5411-B	+	A	A	A	A	-	0
Sandstill	A	A	A	A	A	-	-1
Sandstill II	A	+	A	A	A	A	+1
Soil Gard	A	A	A	A	A	+	+1
SP-301	A	+	A	--	+	+	(+1)
SP-400	A	+	+	+	A	A	+3
Suferm	A	+	---	A	A		-2
TPC 2245	A	A	-	A	---	A	-4
V-4100 Binder	A	A	A	A	A	A	0
Wallpol 40-133	+	+	+	A	A	+	+4

(a) Tests are identified as follows:
A - normal application rate tests
B - one-half normal application rate tests
C - temperature cycling tests
D - $750/ha rate tests
E - inclined sample tests
F - wet/dry cycling tests

(b) Individual test ranks were assigned based on the following values: (+) = +1, (A) = 0, (-) = -1, (--) = -2, (---) = -3.
Those ranks enclosed in parentheses indicate that the material had a negative score in one or more tests. Even though the cumulative rank was positive, the stabilizer was rejected from the field testing.

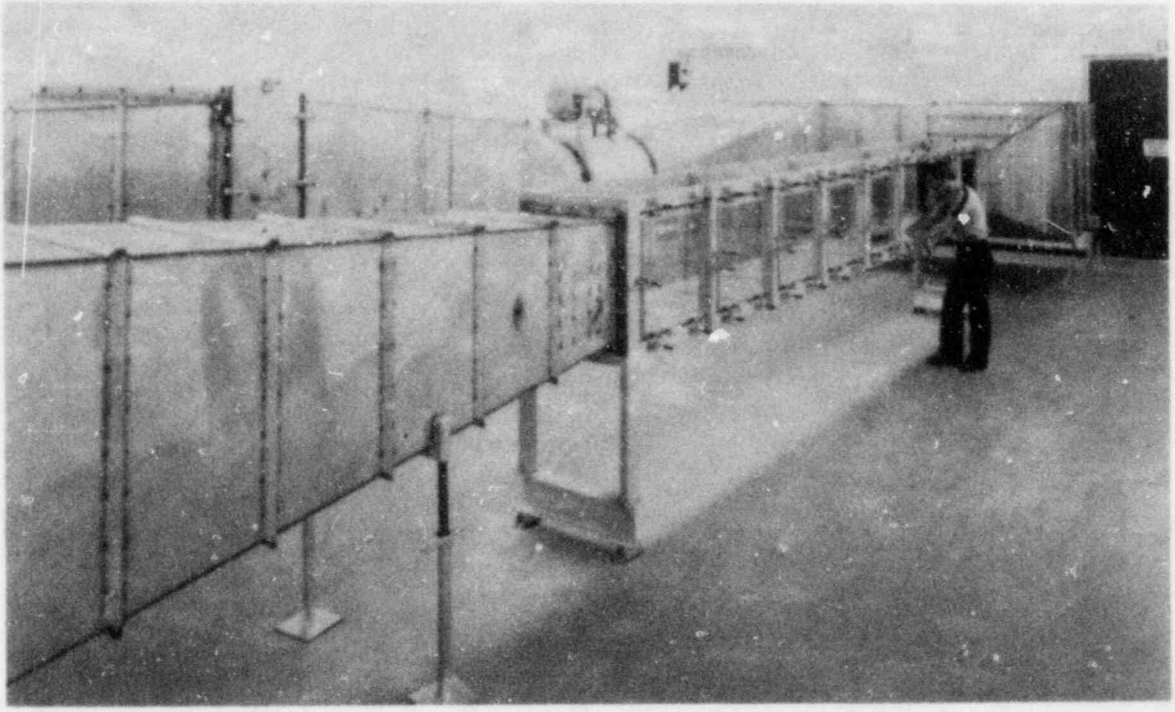

FIGURE 1. Wind Tunnel Used in Laboratory Tests

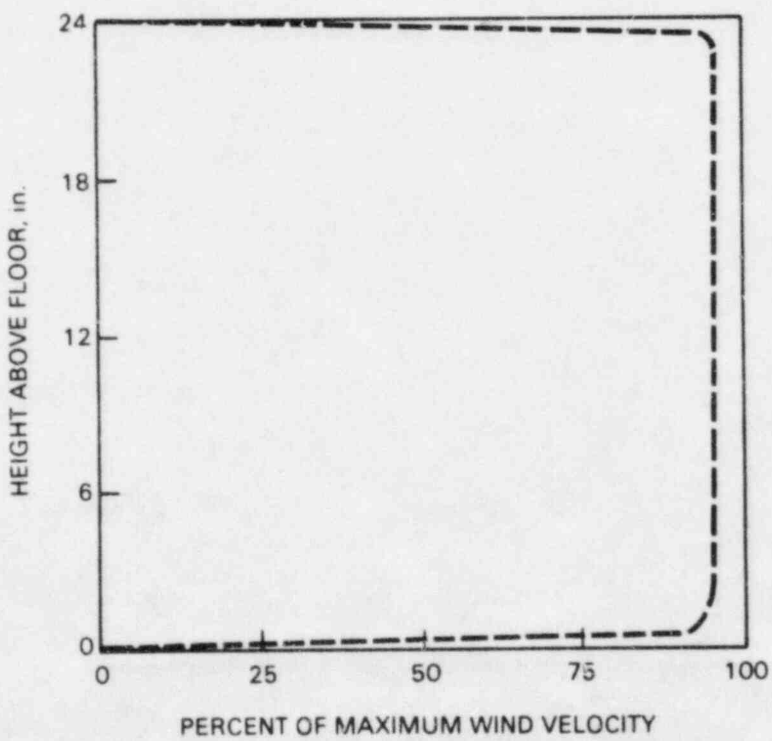

FIGURE 2. Velocity Profile of Wind Tunnel (note the very low drag losses next to the floor and the top of the tunnel)

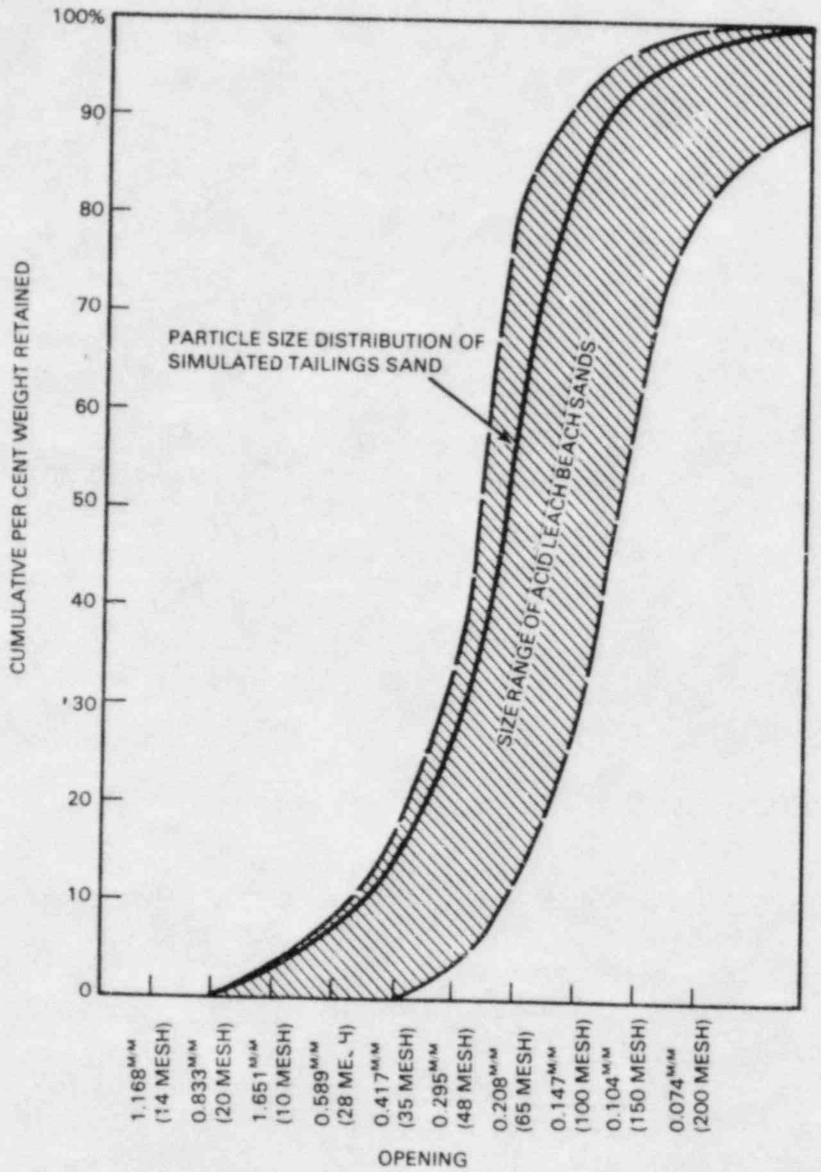

FIGURE 3. Average Size Distribution of Uranium Tailings and Simulated Tailings

The samples were subjected to varying wind speeds and times, and weight losses from the pans were recorded. Weight losses ranged from nil to nearly the entire contents of the pan. One of the more durable and one of the less durable stabilizers are shown in Figure 6 after wind tunnel testing. The effects of the test conditions on the durability of the stabilizers are discussed below. These results are quite subjective since actual field conditions cannot be exactly duplicated. However, they do provide a useful means of evaluating the products on a relative basis.

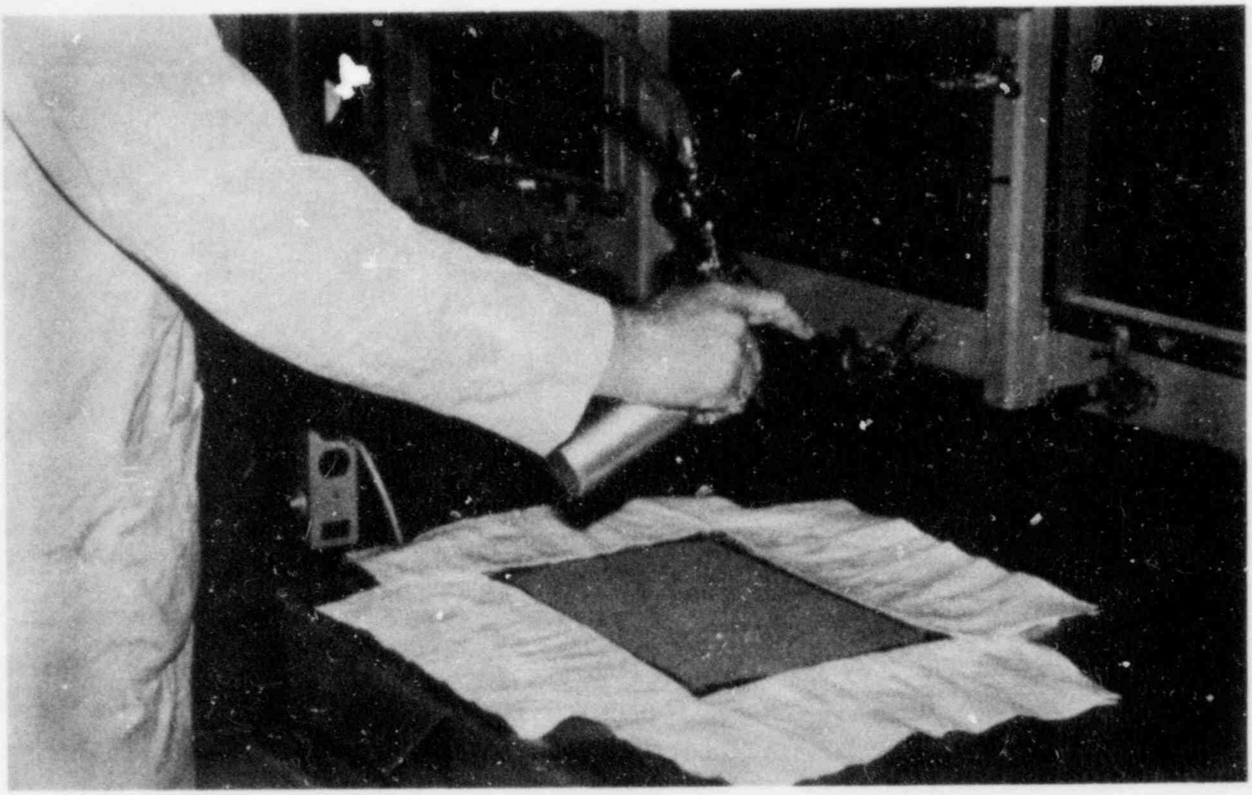

FIGURE 4. Spraying Stabilizers on Sand Samples for Wind Tunnel Tests

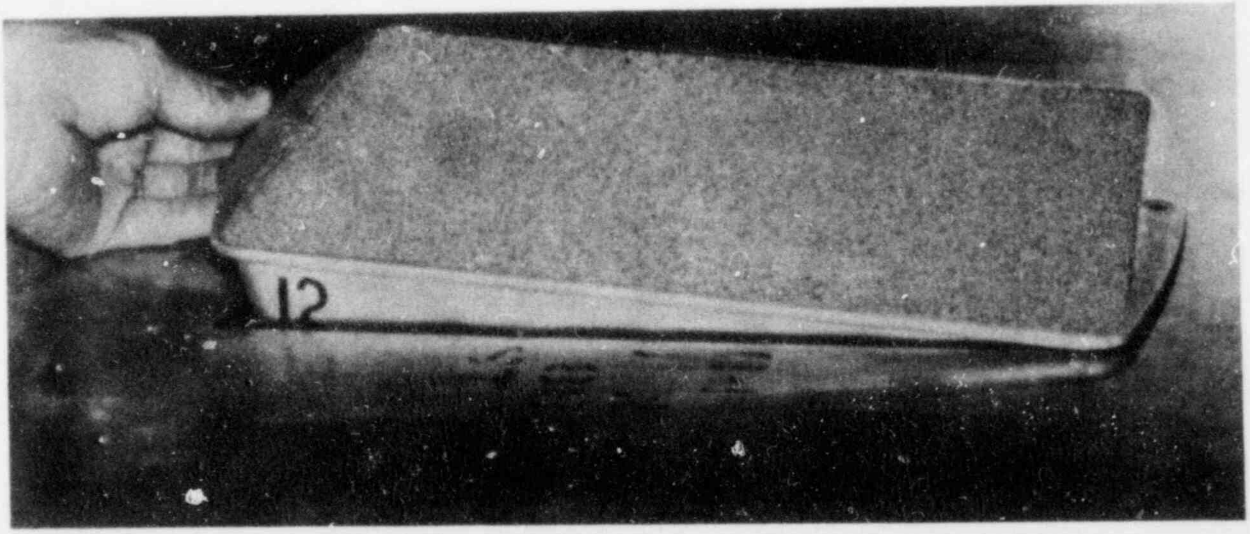

FIGURE 5. Sample Being Inserted in Cutout Floor Section of Wind Tunnel

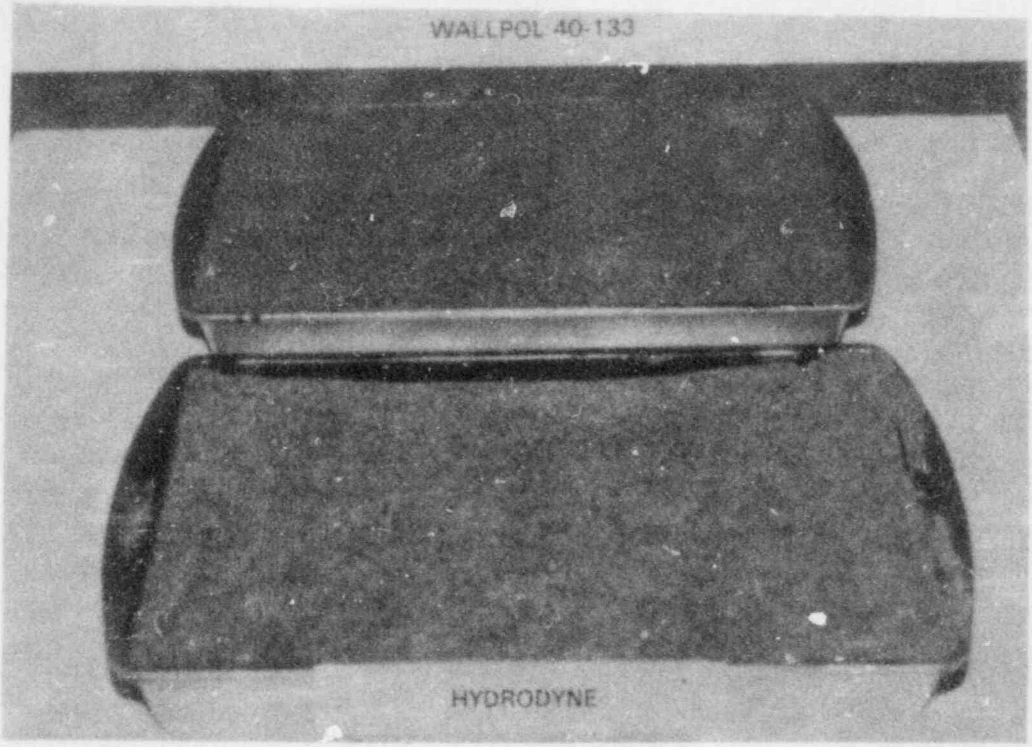

FIGURE 6. Sample Pans Stabilized with Wallpol 40-133 (more durable) and Hydrodyne C (less durable)

Some of the laboratory tests were not completed when selection of the candidate stabilizers had to be made to meet delivery schedules for the field test in August 1982 (Elmore and Hartley 1983). (A later field test might have been hampered by poor weather.) The tests completed included the initial wind tunnel tests: the variable application rate and dilution tests, temperature (freeze/thaw) cycling tests, and wet/dry cycling tests.

DILUTION FACTOR AND APPLICATION RATE TESTS

For the initial wind tunnel tests, the manufacturers' recommendations for dilution and application rates of the stabilizers were used. Based on the results of these tests, many of these materials appeared to be about equal in performance. To further reduce the list of candidate stabilizers for the field test, tests were conducted where the products were prepared and applied to the pans at one-half the recommended rate. Test results for both application rates are shown in Table B.1. In general, most of the stabilizers performed quite well, even at half the recommended rate. Two synthetic emulsions, Nalco-8803 and Nalco-8820, did not perform well.

Other tests were conducted where the full amounts of four stabilizers were applied to sample pans, but each had been diluted with two and four times the recommended amount of water. This dilution caused greater penetration of the stabilizers, with less remaining on the surface. These tests generally resulted in slightly larger sand losses but did not affect the general ranking of the materials that was established by the other tests (see Table B.2). Based on these results, further dilution testing was discontinued.

The stabilizers were also applied at a constant material cost of \$750/ha (~\$300/acre) for each stabilizer. This cost was based on the estimated 1982 delivered price of the products to central Wyoming in quantities sufficient to stabilize a 40-ha (typical size) tailings pile. The cost (\$750/ha) represented the approximate average material cost of the chemical stabilizers. Thus, some of the more expensive stabilizers were applied at a fraction of their recommended amount, while some of the less expensive ones could be applied at much more than recommended. Results of these tests are given in Table B.3. Only a few materials performed below the average for the group, indicating that most of the materials would be equally effective at this rate at the time of application. However, resistance to weathering following application may be different.

At this time, an attempt was made to increase the wind erosion losses from the samples by inclining the pans in the tunnel. Wind tunnel test results had shown only minor differences in effectiveness. The sample pans were supported at a 30° angle from horizontal in the tunnel to increase the wind force striking the sample. Results of these tests are presented in Table B.4; this method did not greatly increase the number of failures. The inclined tests were then discontinued, and the simpler horizontal tests were resumed for additional wind tunnel tests.

EFFECTS OF DILUTION WATER AND TAILINGS CHEMISTRY

As a separate part of the application and dilution tests, a later study was made to determine the effects, if any, of the chemical composition of the water used for diluting the stabilizers and the chemistry of the tailings on the effectiveness of the stabilizers. Tests were run where the stabilizers were diluted with water containing dissolved salts to match the chemical composition of the water supply used by the mill at the field test site for these purposes. The field test water supply was primarily runoff water and contained many dissolved minerals. Table 2 shows the composition of the water used to dilute the stabilizers for these tests, and results of the tests are presented in Table B.5. Most of the stabilizers exhibited no noticeable effects with the exception of Soil Gard, which tended to coagulate when diluted with this water. This problem was also noticed during the field test (Elmore and Hartley 1983) to a much worse degree than in the laboratory tests.

Locally available sand used for the laboratory tests was treated to more closely resemble tailings with high acid and salt content to determine whether this might have some effect on the stabilizers (manufacturers had little experience with these particular types of mineral wastes). The composition of the treated sand used for these tests is given in Table 3. Results of these tests (Table B.5) indicated that the chemistry of the tailings had no significant effect on the performance of the stabilizers.

TABLE 2. Composition of Simulated "Natural" Water Used to Dilute Stabilizers

Cation	Concentration, g/l	Anion	Concentration, g/l
Na	0.102	CO_3	0.200
Ca	0.053	SO_4	0.301
Mg	0.030		

TABLE 3. Average Water-Soluble Salt Composition of Tailings Samples Used for "Treated Sand" Composition

Cation	Concentration, mg/kg of tailings	Anion	Concentration, mg/kg of tailings
Al	308	SO_4	17,776
Ca	4460		
Fe	1016		
Mg	486		
Na	42		

TEMPERATURE (FREEZE/THAW) CYCLING TESTS

Freeze/thaw cycling was used to study accelerated weathering in the laboratory tests. For these tests, samples were prepared according to the manufacturers' recommended dilution and application rates. The cured samples were alternately placed in a drying oven at 45°C and a freezer at -21°C for 4- to 5-h intervals each. This procedure was repeated for 10 cycles. To determine how the freeze/thaw cycling affected the stabilizers, the samples were tested in the wind tunnel as described above, and weight losses were recorded. Results of these tests are presented in Table B.6. The sulfur-based product, Suferm, failed this test; and it was assumed that this failure was in some way due to its different chemical composition. Most other materials performed about average or better.

WET/DRY CYCLING TESTS

The wet/dry cycling tests were designed to investigate the effects of alternating wet and dry conditions on the stabilizers to simulate rainfall. The treated sample pans were prepared as before, allowed to cure, and then sprayed with ~50 g of water (0.07 g/cm^2) to thoroughly wet the stabilized surface. The wet samples were then placed in the drying oven at 45°C until the weight of the pans was constant, indicating dryness. The water spray and oven drying were then repeated for five complete cycles. Wind tunnel tests performed on these samples resulted in significant losses from the surface of at least four samples (Gantrez AN-139 and AN-169, Hercobind DS-3, and Rezasol 5411-B). This type of simulated weathering appears to be one of the more severe test conditions. Results are presented in Table B.6. Effects of these tests ranged from no change to substantial degradation due to the wet/dry cycling.

STABILIZER SELECTION FOR FIELD TESTING

Stabilizers were selected for the field test based on the results of these laboratory tests. A composite of the wind tunnel test results is presented in Table 1. Some of the materials scored below average for some of the individual tests but had a high cumulative score. These materials were not included in the field test. This procedure may have eliminated some materials from the list that may be nearly as good as some of those selected. However, this ranking procedure was adopted to limit the number of stabilizers to be field tested to a manageable size and to include representative materials from the different types of stabilizers.

Fourteen of the laboratory-tested chemical stabilizers had very close cumulative scores (Table 4). Due to time constraints for starting the field test, these 14 stabilizers were chosen for the 1982 field test. Further laboratory testing was limited to these 14 stabilizers and newly identified ones. Additional testing included determining the effects of UV radiation and water erosion and changes in permeability of the stabilized sand. These tests are described in the following sections.

One additional stabilizer was selected for the field test that had not been included in the laboratory testing. Hydromulch, a wood fiber mulch, represented a type of stabilizer commonly used for temporary erosion control, but one that was quite different from the other stabilizers that were tested in the laboratory. Hydromulch is slurried with water and sprayed onto the tailings surface, like the other chemical stabilizers. Because of the coarse wood fiber, a sprayer designed for these slurries must be used. For the laboratory tests, a suitable sprayer was not available that could evenly apply the Hydromulch to the small surface area of the pans, so the Hydromulch was used only in the field testing.

ULTRAVIOLET DEGRADATION TESTS

Many stabilizers (in particular, the latex emulsions) are subject to degradation by UV radiation from sunlight, which shortens their effective lifetimes. Most of the stabilizers control surface erosion by cross-linking of the polymers, which occurs when the emulsions break and bind to the surface of the sand particles. UV radiation can destroy the bonds of this cross-linking. For this reason, some manufacturers have added UV inhibitors to their products. Tests were designed to investigate the sensitivity of these materials to UV radiation. For these tests, duplicate samples were prepared in small (15-cm diameter) Petri dishes with recommended applications of the products.

TABLE 4. Chemical Stabilizers Selected for 1982 Field Test

Stabilizer	Manufacturer	Composition[a]
Aerospray-70	American Cyanamid Company	Synthetic emulsion
Coherex	Witco Chemical Company	Petroleum emulsion
CPB-12	Wen Don Corporation	Synthetic emulsion
Dust Binder C-266	Union Carbide Corporation	Synthetic emulsion
Dust Gard	Great Salt Lake Minerals & Chemicals	Hygroscopic salt solution
Dust Loc VMX-50	American Energy	Synthetic emulsion
Hydromulch	Conwed Corporation	Wood fiber mulch
M-167	Dowell/Dow Chemical	Synthetic emulsion
Marloc	Reclamare Corporation	Synthetic emulsion
Orzan A	Crown Zellerbach	Lignin sulfonate solution
Polyco 2151	Borden Chemicals	Synthetic emulsion
Sandstill II	Energy Systems	Petroleum emulsion
SP-400	Johnson-March Corp.	Synthetic emulsion
Soil Gard	Walsh Chemicals	Synthetic emulsion
Wallpol 40-133	Reichold Chemicals Inc.	Synthetic emulsion

(a) More specific information on the chemical composition of the stabilizers is given in Appendix A.

One of the duplicate samples of each stabilizer was irradiated with an intense UV light generated from a 1000-W Xe-Hg lamp. The surfaces of the irradiated and the duplicate unirradiated samples were then compared. To evaluate the degradation of the stabilizers, the duplicate samples were placed in a compressive test apparatus. Changes in the surface hardness of the samples were measured and correlated with the relative potential for degradation from sunlight. Decreased hardness readings indicate that the bonding of the polymers was being destroyed, rather than the stabilizer becoming more pliable.

A plot of the relative performance of the chemical stabilizers during the UV exposure tests is shown in Figure 7. For some samples, the surface hardness changed little with time, indicating low susceptibility to UV damage. Others initially increased in hardness, which would be advantageous to resisting wind erosion. However, at some point, the hardness readings rapidly decreased, indicating degradation. Some of the stabilized samples showed steadily increasing signs of damage (decreased hardness) with time from initial UV exposure. Results of the UV exposure tests are shown in Table B.7. Changes in the surface characteristics of the treated samples ranged from very little effect to extensive UV-induced degradation.

WATER EROSION TESTS

The primary objective of these tests was to evaluate the resistance of the chemical stabilizers to water erosion, particularly on the sloped sides of tailings piles. Tests were performed to compare the resistance of stabilized sand samples to water erosion. In these tests the treated pans of sand were inclined to a 30° slope and water was pumped through a perforated tube held over the pan at ~4 cm/h, which created a rain-like effect on the surface of the sample (Figure 8). Erosion of the samples ranged from none after 1 h to complete failure immediately after the water flow started. Results of these tests are given in Table B.8.

PERMEABILITY TESTS

One concern with repeatedly spraying chemical stabilizers onto a tailings pile surface is how several applications might affect the permeability of the tailings impoundment. Decreased permeability of the pile could seriously affect its stability as more water is retained in the tailings. Therefore, a series of tests was conducted to look for possible changes in the permeability of chemically stabilized sand (simulated tailings). Small columns of sand were treated with the stabilizers and then placed under a constant and equal head of water (60 cm). The test apparatus constructed for these tests is shown in Figure 9. Water flow through the treated samples was compared with water flow through untreated columns; decreased water flow indicated a decrease in permeability.

Results of these tests are presented in Table B.9. No significant decrease in permeability was seen during these tests; and because of the expected degradation of the chemical stabilizers with time in mill tailings applications, the risks of tailings impoundment instability should be negligible.

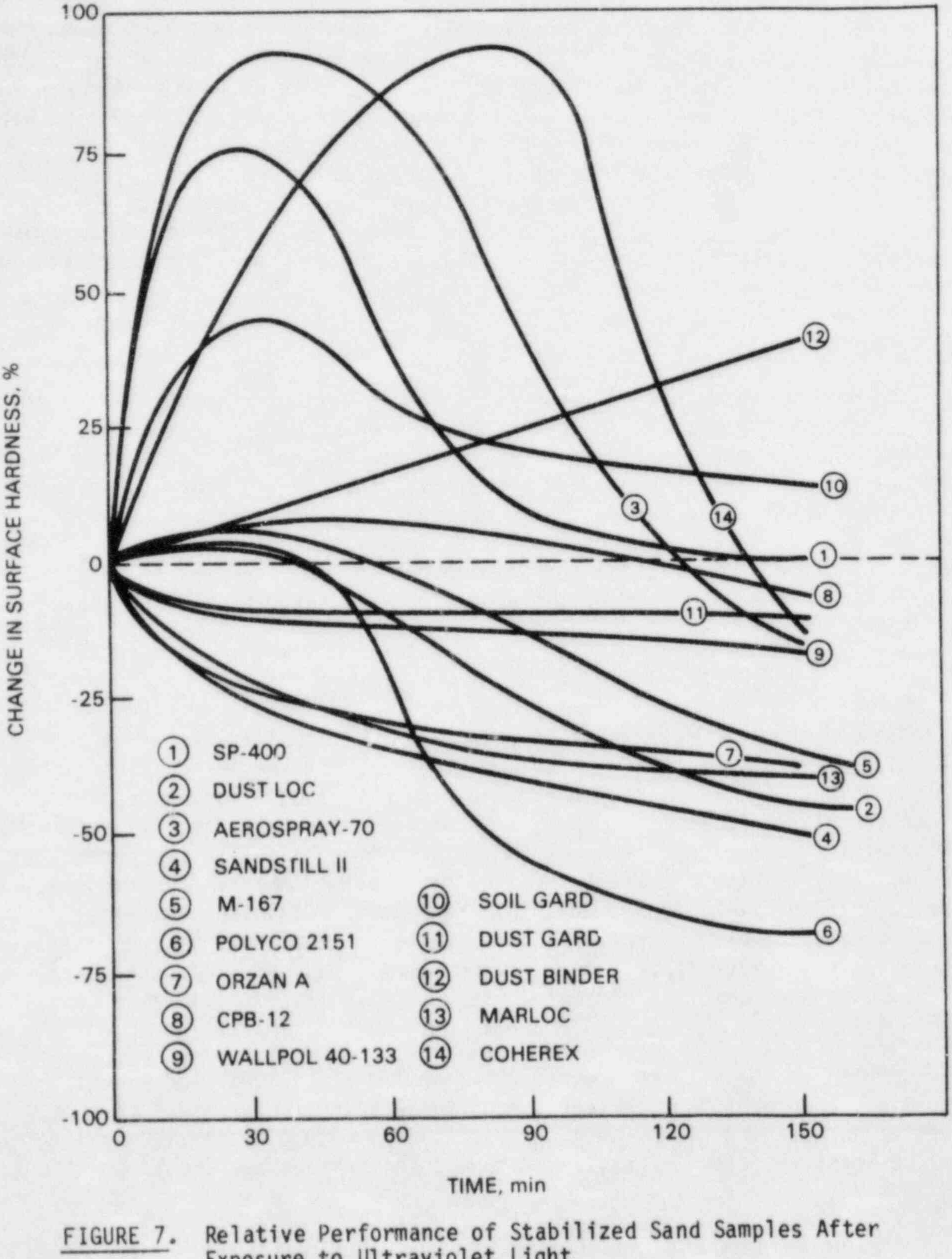

FIGURE 7. Relative Performance of Stabilized Sand Samples After Exposure to Ultraviolet Light

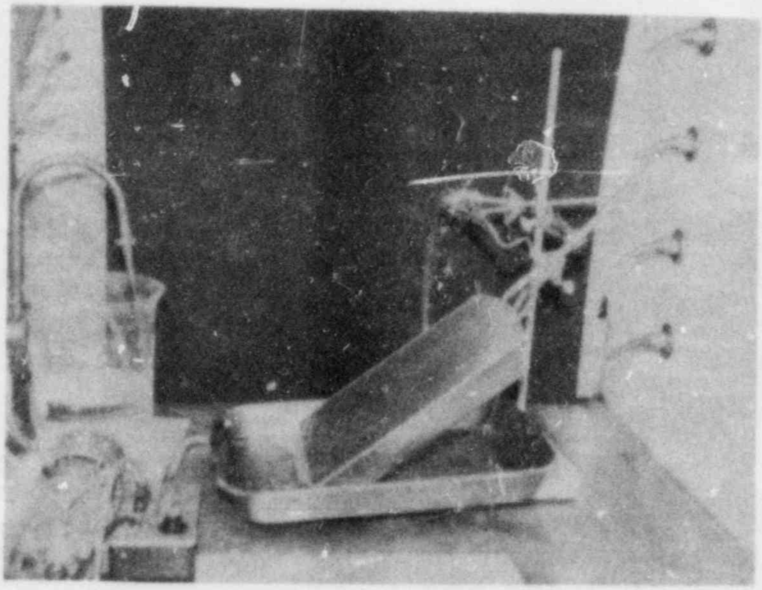

FIGURE 8. Inclined Sample Pans in Water Erosion Tests

DEFECT TESTS

The effect of surface defects on the ability of the stabilizer to control erosion was investigated. In these tests the surfaces of stabilized sand were scored diagonally across the pan, penetrating the crust. Samples were then tested in the wind tunnel. In general, the results were no different from earlier tests, which would indicate that wind erosion will be effectively controlled, even with some cracking. However, these tests do not simulate areas where the application of the stabilizer may be too thin or where cracking occurs as a result of other weathering conditions.

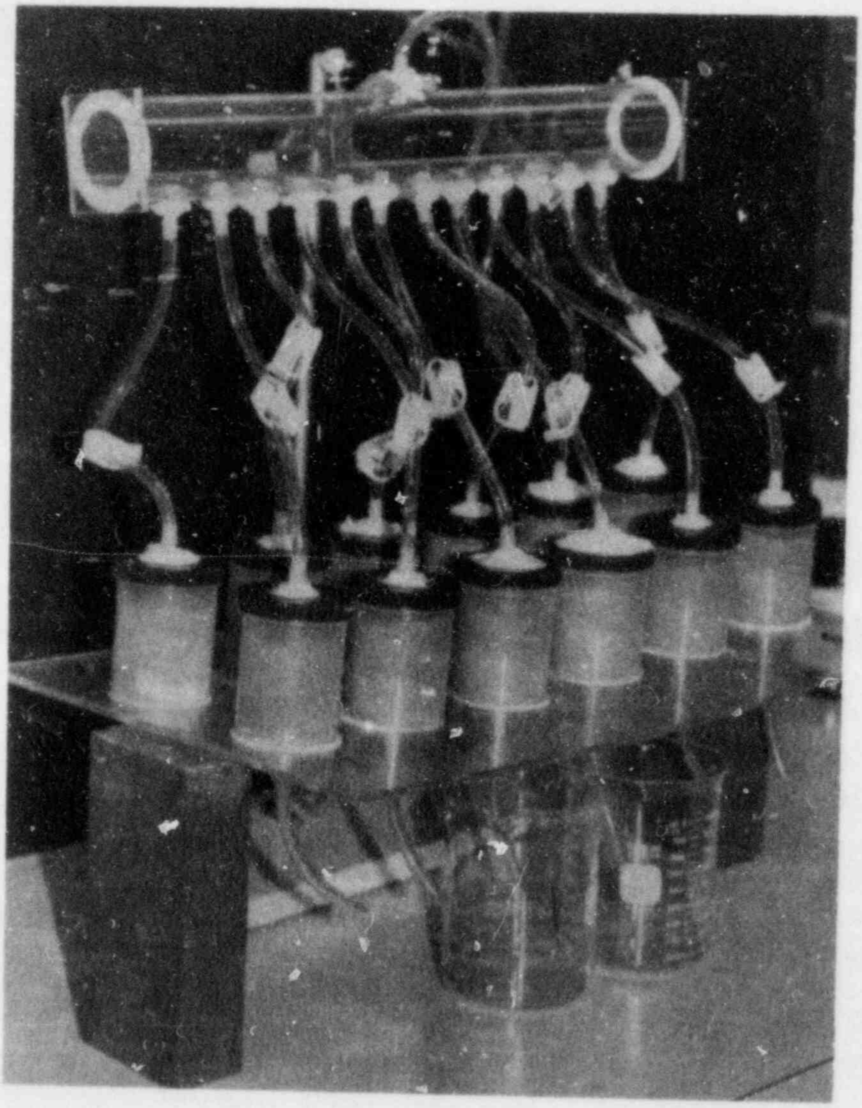

FIGURE 9. Permeability Test Samples Under Constant Head of Water

CONTINUED LABORATORY TESTING

As mentioned earlier, the same types of tests were repeated on several stabilizers that were identified after the initial laboratory testing and field test selection. An attempt was made to give each new stabilizer (Retain, Soil Sement, ITT Lignin-Sulfonate, and Attach DC) an evaluation that was comparable with that for previous stabilizers. Based on these test results, Retain and Soil Sement were then chosen for application to the field test plots. Retain was also selected because it was the only asphalt emulsion stabilizer tested in this study.

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APPENDIX A

CHEMICAL STABILIZERS FOR POTENTIAL USE ON URANIUM MILL TAILINGS

APPENDIX A

CHEMICAL STABILIZERS FOR POTENTIAL USE ON URANIUM MILL TAILINGS

Commercially available chemical stabilizers, their manufacturers, and chemical compositions are presented in this appendix. Recommended dilution factors and application rates as suggested by the manufacturers are also included.

TABLE A.1. Chemical Stabilizers

Product	Manufacturer/ Distributor	Dilution Factor	Application Rate	Material Composition
8803	Nalco Chemical Company	1:50 with water	0.4 l/m^2	Synthetic polymer emulsion (vinyl polymer/ethylene glycol)
8820	Nalco Chemical Company	1:20 with water	0.5 l/m^2	Synthetic polymer emulsion (vinyl polymer/ethylene glycol)
Aerospray-70	American Cyanamid Company	1:10 with water	2.0 l/m^2	Synthetic polymer emulsion (polyvinyl acetate)
AMS-2200	ARCO Mine Sciences	1:10 with water	3.2 l/m^2	Petroleum resin emulsion
ATTACH DC	Soil Systems Technology Corporation	1:3 with water	0.4 l/m^2	Peat-derived product
Coherex	Witco Chemicals	1:5 with water	2.0 l/m^2	Petroleum resin emulsion
CPB-12	Wen Don Corporation	1:10 with water	2.0 l/m^2	Synthetic polymer emulsion (acrylic latex, conditioners)
Dust Binder C-266	Union Carbide Corporation	1:20 with water	0.4 l/m^2	Synthetic polymer emulsion
Dust Down 70	Soil Systems	1:3 with water	0.4 l/m^2	Peat-derived product
Dust Gard	Great Salt Lake Minerals & Chemicals	Undiluted	2.0 l/m^2	MgC_{12} brine solution
Dust Loc VMX-50	American Energy	1:8 with water	1.5 l/m^2	Synthetic polymer emulsion (acrylic latex)

TABLE A.1. (Contd)

Product	Manufacturer/ Distributor	Dilution Factor	Application Rate	Material Composition
ESI-BOND	Environmental Stabilizers International	1:2 with water	0.1 l/m^2	Synthetic polymer emulsion
Gantrez AN-119	General Analine and Film Corporation	2% with hot water	2.0 l/m^2	Water-soluble polymer
Gantrez AN-139	G.A.F.	2% with hot water	2.0 l/m^2	Water soluble polymer
Gantrez AN-169	G.A.F.	2% with hot water	2.0 l/m^2	Water-soluble polymer
Hercobind DS-3	Hercules	1:10 with water	0.3 l/m^2	Wood-derived resin emulsion
Hydromulch	Conwed Corporation	1-kg:17-l with water	0.6 l/m^2	Wood fiber mulch
Hydromulch-2000	Conwed Corporation	1-kg:17-l with water	0.6 l/m^2	Wood fiber mulch with tackifier
Hydrodyne C	Motomco Inc., Aquadyne Division	1:3000 with water	0.3 l/m^2	Surfactant
IDA-656	Nalco Chemical Company	1:200 with water	1.6 l/m^2	Synthetic polymer emulsion (vinyl polymer/ethylene glycol)
ITT Lignin A+B	ITT Rayonier Inc.	3A:1B; no water	2.0 l/m^2	Lignin sulfonate and catalyst
J-TAC	Reclamare Co.	Viscous liquid	22 kg powder/ ha	Natural plant gum tackifier

TABLE A.1. (Contd)

Product	Manufacturer/ Distributor	Dilution Factor	Application Rate	Material Composition
Liquid Dust Layer	Morton Chemicals	Undiluted	2.0 l/m^2	MgCO3 brine solution
M-166	Dow Chemical/ Dowell Division	1:20 with water	0.3 l/m^2	Synthetic polymer emulsion (latex, propylene glycol)
M-167	Dow Chemical/ Dowell Division	1:20 with water	0.3 l/m^2	Synthetic polymer emulsion (latex, propylene glycol)
Marloc	Reclamare	1:16 with water	0.5 l/m^2	Synthetic polymer emulsion (polyvinyl acetate)
Orzan A	Crown Zellerbach	1:3 with water	2.0 l/m^2	Ammonium lignin sulfonate solution
Orzan G	Crown Zellerbach	1:3 with water	2.0 l/m^2	Calcium lignin sulfonate solution
Orzan S	Crown Zellerbach	1:3 with water	2.0 l/m^2	Sodium lignin sulfonate solution
Pentron DC-5	Apollo Technologies	1:10 with water	0.3 l/m^2	Synthetic polymer emulsion (acrylic latex)
Polyco 2151	Borden Chemicals	1:40 with water	2.0 l/m^2	Synthetic polymer emulsion (vinyl acetate/acrylic latex)
Retain	Dubois Industrial Chemicals	1:5 with water	0.1 l/m^2	Asphalt emulsion
Rezasol 5411-B	E. F. Houghton and Company	1:30 with water	1.6 l/m^2	Synthetic polymer emulsion

TABLE A.1. (Contd)

Product	Manufacturer/ Distributor	Dilution Factor	Application Rate	Material Composition
Sandstill	Energy Systems	1:10 with water	2.0 l/m^2	Petroleum resin emulsion
Sandstill II	Energy Systems	1:10 with water	2.0 l/m^2	Petroleum resin emulsion
Silva Fiber	Weyerhauser Company	1-kg:17-l water	0.6 l/m^2	Wood fiber mulch
Soil Gard	Walsh Chemical Corp	1:15 with water	1.2 l/m^2	Synthetic polymer emulsion (styrene butadiene)
Soil Seal	Soil Seal Corp.	1:33 with water	0.3 l/m^2	Synthetic polymer emulsion (acrylic latex)
Soil Sement	Midwest Industrial Supply Inc.	1:5 with water	0.1 l/m^2	Synthetic polymer emulsion
SP-301	Johnson and March Corporation	Undiluted	0.4 l/m^2	Synthetic polymer emulsion
SP-400	Johnson March	Undiluted	0.4 l/m^2	Synthetic polymer emulsion
Suferm	Chevron Chemicals	Undiluted	0.9 l/m^2	Polysulfide emulsion
TPC 2245	ESCHEM	1:5 with water	0.4 l/m^2	Technical protein colloid
V-4100 Binder	Wedco Products	1:8 with water	0.1 l/m^2	Synthetic polymer emulsion
Wallpol 40-133	Reichold Chemicals	1:5 with water	2.0 l/m^2	Synthetic polymer emulsion (vinyl acetate/acrylic latex)

APPENDIX B

COMPILATION OF LABORATORY TEST RESULTS

APPENDIX B

COMPILATION OF LABORATORY TEST RESULTS

The results of laboratory tests performed to evaluate the effectiveness and durability of the chemical stabilizers listed in Appendix A are tabulated in this appendix. Not all tests were performed on all of the stabilizers. Some of the stabilizers were not suited to small-scale laboratory tests (for example, the wood fiber mulches); and some tests were conducted after the selection of stabilizers for the 1982 field test was made. For the latter tests, results are given only for those products that were chosen for the field test.

In the tables, an average relative performance is signified by (A); materials that performed better or worse than average were assigned (+) or (-), respectively.

TABLE B.1. Comparison of Stabilizers Based on Application Rate[a]

Product	Normal Application Rate: Weight Loss, g/m^2	Normal Application Rate: Ranking (+,A,-)	One-Half Normal Application Rate: Weight Loss, g/m^2	One-Half Normal Application Rate: Ranking (+,A,-)
8803	5.6	A	8555.4	---
8820	5.6	A	4768.6	---
Aerospray-70	1.4	A	1.4	A
AMS-2200	1.4	A	2.8	A
ATTACH DC	63.1	-		
Coherex	11.2	A	0.0	+
CPB-12	0.0	+	0.0	+
Dust Binder C-266	0.0	+	2.8	A
Dust Gard	0.0	+	0.0	+
Dust Loc VMX-50	8.4	A	5.6	A
ESI-BOND	1.4	A	2.8	A
Gantrez AN-119	1.4	A	2.8	A
Gantrez AN-139	0.0	+	8.4	A
Gantrez AN-169	0.0	+	7.0	A
Hercobind DS-3	0.0	+	0.0	+
Hydrodyne C	Total	---		
IDA-656	4.2	A	1.4	A
ITT Lignin A+B	25.3	-		
Liquid Dust Layer	0.0	+	22.4	-
M-166	15.4	-	0.0	+
M-167	0.0	+	1.4	A
Marloc	4.2	A	4.2	A
Orzan A	0.0	+	15.4	A
Orzan G	5.6	A		
Orzan S	8.4	A	2.8	A
Pentron DC-5	0.0	+	4.2	A
Polyco 2151	1.4	A	0.0	+
Retain	5.6	A		
Rezasol 5411-B	0.0	+	4.2	A
Sandstill	2.8	A	4.2	A
Sandstill II	1.4	A	0.0	+
Soil Gard	1.4	A	2.8	A
Soil Sement	9.8	A		
SP-301	4.2	A	0.0	+
SP-400	2.8	A	0.0	+
Suferm	2.8	A	0.0	+
TPC 2245	1.4	A	12.6	A
V-4100 Binder	1.4	A	1.4	A
Wallpol 40-133	0.0	+	0.0	+

(a) Wind speed = 27 m/s; test time = 10 min.

TABLE B.2. Dilution Factor Test Results[a,b]

Product	Weight Loss, g/m^2	Ranking
Coherex	14.0	Average
Dust Gard	36.5	Average
M-166	12.6	Average
Orzan A	15.4	Average

(a) The recommended amount of each stabilizer was diluted with twice the recommended amount of water and applied to the sample pans.
(b) Wind speed = 27 m/s; test time = 10 min.

TABLE B.3. Constant Material Cost Test Results[a,b]

Product	Weight Loss, g/m^2	Ranking (+,A,-)
8803		
8820		
Aerospray-70	5.6	A
AMS-2200	Total	---
Coherex	0.0	+
CPB-12	1.4	A
Dust Binder C-266	0.0	+
Dust Gard	0.0	+
Dust Loc VMX-50	0.0	+
ES.-BOND	16.8	-
Gantrez AN-119	4.2	A
Gantrez AN-139	2.8	A
Gantrez AN-169	4.2	A
Hercobind DS-3	0.0	+
Hydrodyne C	Total	---
IDA-656	0.0	+
Liquid Dust Layer	22.4	-
M-166	1.4	A
M-167	0.0	+
Marloc	1.4	A
Orzan A	15.4	A
Orzan S	2.8	A
Pentron DC-5	16.8	-
Polyco 2151	0.0	+
Rezasol 5411-B	4.2	A
Sandstill	5.6	A
Sandstill II	4.2	A
Soil Gard	2.8	A
SP-301	77.1	--
SP-400	0.0	+
Suferm	4.2	A
TPC 2245	12.6	A
V-4100 Binder	1.4	A
Wallpol 40-133	2.8	A

(a) Stabilizers were applied at a constant material cost of $750/ha ($300/acre).

(b) Wind speed = 27 m/s; test time = 10 min.

TABLE B.4. Inclined Sample Test Results[a]

Product	Weight Loss, g/m^2	Ranking (+,A,-)
8803	7.0	A
8820	28.1	-
Aerospray-70	11.1	A
AMS-2200	18.2	A
Coherex	5.6	A
CPB-12	5.6	A
Dust Binder C-266	2.8	A
Dust Gard	21.0	A
Dust Loc VMX-50	4.2	A
ESI-BOND	0.0	+
Gantrez AN-119	8.4	A
Gantrez AN-139	2.8	A
Gantrez AN-169	11.2	A
Hercobind DS-3	12.6	A
Hydrodyne C		
IDA-656	7.0	A
Liquid Dust Layer	7.0	A
M-166	2.8	A
M-167	2.8	A
Marloc	2.8	A
Orzan A	4.2	A
Orzan S	4.2	A
Pentron DC-5	2.8	A
Polyco 2151	2.8	A
Rezasol 5411-B	8.4	A
Sandstill	18.2	A
Sandstill II	5.6	A
Soil Gard	5.6	A
SP-301	0.0	+
SP-400	1.4	A
Suferm	2.8	A
TPC 2245	Total	---
V-4100 Binder	2.8	A
Wallpol 40-133	1.4	A

(a) Angle = 30°; wind speed = 27 m/s; test time = 10 min.

TABLE B.5. Effects of Dilution Water and Tailings Chemistry[a]

Product	Treated Sand and Water Tests		Treated Sand Tests	
	Weight Loss, g/m^2	Ranking (+,A,-)	Weight Loss, g/m^2	Ranking (+,A,-)
Aerospray-70	2.8	A	14.0	A
Coherex	7.0	A	42.1	-
CPB-12	0.0	+	7.0	A
Dust Binder C-266	1.4	A	0.0	+
Dust Gard	625.5	--	669.0	--
Dust Loc VMX-50	6.3	-	8.4	A
ITT Lignin A+B	25.2	-		
M-167	1.4	A	2.8	A
Marloc	248.2	--	35.1	-
Orzan A	7.0	A	2.8	A
Orzan S	5.6	A	14.0	A
Polyco 2151	42.1	-	28.1	-
Sandstill	7.0	A	9.8	A
Sandstill II	43.8	A	0.0	+
Soil Gard	8.4	A	9.8	A
SP-400	0.0	+		
Wallpol 40-133	2.8	A	2.8	A

(a) Wind speed = 27 m/s; test time = 10 min.

TABLE B.6. Temperature Cycling and Wet/Dry Cycling Test Results

Product	Temperature Cycling Tests[(a)]		Wet/Dry Cycling Tests[(b)]	
	Weight Loss, g/m^2	Ranking (+,A,-)	Weight Loss, g/m^2	Ranking (+,A,-)
8803	9.8	A	19.6	-
8820	1.4	A	14.0	-
Aerospray-70	1.4	A	0.0	+
AMS-2200	2.8	A	4.2	A
Coherex	7.0	A	0.0	+
CPB-12	2.8	A	4.2	A
Dust Binder C-266	0.0	+	1.4	A
Dust Gard	5.6	A	8.4	A
Dust Loc VMX-50	0.0	+	0.0	+
ESI-BOND	0.0	+	0.0	+
Gantrez AN-119	4.2	A	2.8	A
Gantrez AN-139	5.6	A	293.1	--
Gantrez AN-169	0.0	+	1220.2	---
Hercobind DS-3	1.4	A	Total	---
IDA-656	5.6	A	7.0	A
Liquid Dust Layer	33.7	-	11.2	A
M-166	1.4	A	1.4	A
M-167	0.0	+	0.0	+
Marloc	0.0	+	4.2	A
Orzan A	4.2	A	1.4	A
Orzan S	0.0	A	21.0	-
Pentron DC-5	0.0	+	1.4	A
Polyco 2151	0.0	+	1.4	A
Rezasol 5411-B	4.2	A	409.5	--
Sandstill	4.2	A	14.0	-
Sandstill II	8.4	A	8.4	A
Soil Gard	5.6	A	0.0	+
SP-301	2.8	A	0.0	+
SP-400	0.0	+	2.8	A
Suferm	Total	---		
TPC 2245	96.8	-	11.2	A
V-4100 Binder	4.2	A	1.4	A
Wallpol 40-133	0.0	+	0.0	+

(a) Wind speed = 27 m/s; test time = 10 min; 10 cycles at -21°C to 45°C.
(b) Wind speed = 27 m/s; test time = 10 min; 5 wet and dry cycles.

TABLE B.7. Effect of Ultraviolet Radiation on Durability of Chemical Stabilizers[a]

Product	Change in Surface Hardness, %			Ranking[b]
	Exposure Time, min			(+,A,-)
	30	90	150	
8820	-25	-39	-50	-
Aerospray-70	(c)	(c)	-15	-
Coherex	+85	+61	+9	+
CPB-12	-2	+6	-6	A
Dust Binder C-266	+9	+24	+41	+
Dust Gard	-11	+5	-11	A
Dust Loc VMX-50	+2	-26	-42	-
M-167	+5	-43	-35	-
Marloc	-23	-37	-13	-
Orzan A	-24	-33	(c)	-
Polyco 2151	+3	-54	-8	-
Soil Gard	+43	+22	+14	+
SP-400	+74	+10	+56	+
Wallpol 40-133	-10	-13	-15	A

(a) Percent change in surface hardness after various exposures to UV light from 1000-W Xe-Hg lamp measured with respect to cured but unexposed sample.

(b) A = relatively unchanged surface hardness during test
+ = increased surface hardness over test duration
- = decreased surface hardness with time, indicating degradation of polymer cross-linking.

(c) Readings were off the scale of the instrument.

TABLE B.8. Water Erosion Test Results[(a)]

Product	Exposure Time, s	Results	Ranking (+,A,-)
Aerospray-70	5400	No erosion	+
Coherex	120	Washed out	A
CPB-12	420	Washed out	A
Dust Binder C-266	3600	No erosion	+
Dust Gard	1	Washed out	-
Dust Loc VMX-50	1860	Washed out	+
ITT Lignin A+B	1	Washed out	-
M-167	120	Washed out	A
Marloc	1140	Washed out	+
Orzan A	30	Washed out	-
Orzan S	10	Washed out	-
Polyco 2151	1200	Washed out	+
Sandstill	1	Washed out	-
Sandstill II	1	Washed out	-
Soil Gard	120	Washed out	A
SP-400	60	Washed out	A
Wallpol 40-133	3600	No erosion	+

(a) Water spray rate = 60 $ml/m^2/min$; test pan inclined 30°.

TABLE B.9. Water Permeability Test Results[(a)]

Product	Change in Permeability,[(b)] %	Ranking (+,A,-)
Aerospray-70	57.8	-
Coherex	13.4	A
CPB-12	11.1	A
Dust Binder C-266	15.1	A
Dust Gard	30.5	-
Dust Loc VMX-50	4.5	+
ITT Lignin A+B	80.8	-
M-167	6.3	+
Marloc	29.0	-
Orzan A	23.3	A
Orzan S	67.7	-
Polyco 2151	19.2	A
Sandstill	13.8	A
Sandstill II	13.3	A
Soil Gard	23.4	A
SP-400	7.2	+
Wallpol 40-133	32.7	-

(a) Water head = 60 cm; one application of stabilizer at recommended rate.
(b) With respect to untreated sand sample.

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M. G. Foley
G. W. Gee
J. N. Hartley (15)
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16. ABSTRACT (200 words or less)

Pacific Northwest Laboratory, under contract to the U.S. Nuclear Regulatory Commission's Office of Nuclear Regulatory Research, is investigating techniques to control fugitive dust emissions from active uranium mill tailings piles. This report describes laboratory tests conducted to evaluate 45 commercially available chemical stabilizers. Tests were conducted in a wind tunnel to evaluate the effectiveness and durability of the stabilizers under similar conditions. The effects of application rate, temperature (freeze/thaw) cycling, wet/dry cycling, and wind speed were determined. In addition, tests were conducted to determine the effects of ultraviolet light and water erosion on the durability of the stabilizers. Permeability tests were also conducted to determine the potential effect of each stabilizer on the overall stability of the tailings pile. Results of these laboratory tests indicated that 16 of the stabilizers were equally effective and more durable than the others.

17. KEY WORDS AND DOCUMENT ANALYSIS
Chemical stabilizers
Soil stabilizers

17a. DESCRIPTORS
Radioactive particulates
Fugitive dust
Uranium mill tailings

17b. IDENTIFIERS/OPEN-ENDED TERMS

18. AVAILABILITY STATEMENT
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