NUREG/CR-4089
PNL-5340

Evaluation of Field-Tested Fugitive Dust Control Techniques for Uranium Mill Tailings Piles

Final Report

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

Pacific Northwest Laboratory
Operated by
Battelle Memorial Institute

Prepared for
U.S. Nuclear Regulatory
Commission

NOTICE

Availability of Reference Materials Cited in NRC Publications

Most documents cited in NRC publications will be available from one of the following sources:

1. The NRC Public Document Room, 1717 H Street, N.W.
   Washington, DC 20555
2. The NRC/GPO Sales Program, U.S. Nuclear Regulatory Commission,
   Washington, DC 20555
3. The National Technical Information Service, Springfield, VA 22161

Although the listing that follows represents the majority of documents cited in NRC publications, it is not intended to be exhaustive.

Referenced documents available for inspection and copying for a fee from the NRC Public Document Room include NRC correspondence and internal NRC memoranda; NRC Office of Inspection and Enforcement bulletins, circulars, information notices, inspection and investigation notices; Licensee Event Reports; vendor reports and correspondence; Commission papers; and applicant and licensee documents and correspondence.

The following documents in the NUREG series are available for purchase from the NRC/GPO Sales Program: formal NRC staff and contractor reports, NRC-sponsored conference proceedings, and NRC booklets and brochures. Also available are Regulatory Guides, NRC regulations in the *Code of Federal Regulations*, and *Nuclear Regulatory Commission Issuances*.

Documents available from the National Technical Information Service include NUREG series reports and technical reports prepared by other federal agencies and reports prepared by the Atomic Energy Commission, forerunner agency to the Nuclear Regulatory Commission.

Documents available from public and special technical libraries include all open literature items, such as books, journal and periodical articles, and transactions. *Federal Register* notices, federal and state legislation, and congressional reports can usually be obtained from these libraries.

Documents such as theses, dissertations, foreign reports and translations, and non-NRC conference proceedings are available for purchase from the organization sponsoring the publication cited.

Single copies of NRC draft reports are available free, to the extent of supply, upon written request to the Division of Technical Information and Document Control, U.S. Nuclear Regulatory Commission, Washington, DC 20555.

Copies of industry codes and standards used in a substantive manner in the NRC regulatory process are maintained at the NRC Library, 7920 Norfolk Avenue, Bethesda, Maryland, and are available there for reference use by the public. Codes and standards are usually copyrighted and may be purchased from the originating organization or, if they are American National Standards, from the American National Standards Institute, 1430 Broadway, New York, NY 10018.

GPO Printed copy price: $4.50

NUREG/CR-4089
PNL-5340
RU

Evaluation of Field-Tested Fugitive Dust Control Techniques for Uranium Mill Tailings Piles

Final Report

Manuscript Completed: December 1984
Date Published: January 1985

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

Pacific Northwest Laboratory
Richland, WA 99352

Prepared for
Division of Radiation Programs and Earth Sciences
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555
NRC FIN B2370

ABSTRACT

Potential wind erosion of uranium mill tailings is a concern for the surface disposal of tailings at uranium mills. Windblown tailings may subsequently be redeposited on areas outside the impoundment. Pacific Northwest Laboratory (PNL), under contract to the U.S. Nuclear Regulatory Commission, has investigated techniques for fugitive dust control at uranium mill tailings piles.

Seventeen chemical stabilizers, rated as the most promising of those tested in earlier laboratory studies, were applied to test plots on a uranium tailings pile at the American Nuclear Corporation-Gas Hills Project mill site in central Wyoming. The durability of these materials when exposed to actual site conditions was evaluated over time. In addition, field testing of eight commercially available windscreens was conducted. Test panels of the eight different materials were constructed at the Wyoming test site to compare their relative durability to weathering. A second test was established near PNL to evaluate the effectiveness of three windscreens at reducing wind velocity, and thereby reduce the potential for wind erosion of uranium mill tailings. Results of the field tests of chemical stabilizers and windscreens are presented, along with observed effectiveness and durability versus cost information. Direct comparison of these two techniques is difficult due to the dependence of each on many site-specific factors. However, simplified model case studies were developed to assess the cost of chemical stabilization versus windscreen systems for a hypothetical, recently inactive tailings pile.

EXECUTIVE SUMMARY

Uranium milling generates large quantities of solid wastes, or tailings, that contain radionuclides and other toxic substances. The more conventional, above-ground, open-pond disposal method subjects the tailings piles to potential wind erosion as the tailings dry. Pacific Northwest Laboratory (PNL), under contract to the U.S. Nuclear Regulatory Commission, has investigated techniques to control fugitive dust emissions from uranium mill tailings piles.

This report presents the results of the field tests established to evaluate the effectiveness and durability of chemical stabilizers and windscreens in controlling fugitive dust emissions from active and recently inactive tailings piles. Field tests were conducted at the American Nuclear Corporation-Gas Hills Project mill site in central Wyoming to evaluate seventeen chemical stabilizers and eight commercial windscreens under actual site conditions. In addition, a second field test was conducted near PNL to evaluate the relative ability of three typical windscreens to reduce wind velocity and thereby to reduce the potential for dust emissions from the tailings surface downwind of the screens.

The effectiveness and durability of the chemically stabilized test plots were determined by observing the condition of the field-test plots during periodic site visits for about one year. Cost effectiveness of chemical stabilization was then determined by comparing the relative durability of the chemical stabilizers with the estimated cost to apply them on a large scale. The analysis is based on the recorded weather conditions at the Wyoming test site, the delivered cost of the stabilizers to that location, and other site-specific factors. The durability of the windscreens was determined by observing the condition of the windscreens at the Wyoming test site through nine months of weathering from September 1983 to June 1984. The effectiveness of three windscreens was determined by measuring the wind velocity at various locations downwind of each screen, and comparing (normalizing) it to the corresponding upwind velocity. The relative cost effectiveness of windscreens was not determined for the field test, but an example "case study" was developed to compare the cost of windscreen systems to chemical stabilization for a hypothetical inactive tailings pile.

The estimated cost to chemically stabilize the hypothetical 40-ha inactive tailings pile ranged from about \$1700 to \$19,000/ha/yr for the tested stabilizers. Although the initial cost of a windscreen system is generally greater than that of most chemical stabilizers, the longer-term cost would likely be less. With proper maintenance most windscreen systems should last a minimum of three to five years. The estimated annual cost for windscreen systems for the example site ranged from \$400 to \$750/ha/yr (a factor of 2 to 50 less than for chemical stabilization). These comparisons of chemical stabilizers and windscreens are highly simplified; however, the assumptions made for the example are realistic. The analysis does serve to illustrate that the use of a windscreen system for wind erosion control may be more cost effective than chemical stabilization for an inactive tailings pile. However, during the operational period for the tailings pond chemical stabilization, or possibly a combined stabilizer/windscreen system, may be the more cost-effective approach.

CONTENTS

FIGURES

TABLES

ACKNOWLEDGMENTS

The authors wish to acknowledge the management and personnel of the American Nuclear Corporation-Gas Hills Project for their help and cooperation in the research work, in particular Ken Watts and Jerry Lucas. The authors also wish to thank Bob Lawrence, president of KPN International, and other PNL staff who assisted in the field test installations, and Dr. Ron Tabler, Rocky Mountain Forest and Range Experiment Station, for his advice concerning the evaluation of windscreens.

INTRODUCTION

The uranium milling process generates large quantities of solid wastes, or tailings, that contain radionuclides, toxic elements present in the original ore, and residual chemicals used in the milling process (Schwendiman et al. 1980). The most common method of tailings disposal is to deposit the waste material from a slurry into open ponds. In most cases, a raised pile is formed over time by the repeated deposition of the spigotted tailings slurry.

Many active and inactive uranium mill tailings piles are subject to potentially severe wind erosion if the surface of the tailings pile is not properly stabilized. Windblown tailings have been found at distances up to several kilometers from the impoundment site. Excluding radon, these fugitive dust emissions are the largest potential source of offsite radiation exposure and the proper selection of erosion control techniques is necessary to reduce the emissions to "as low as reasonably achievable" (ALARA) levels.

Pacific Northwest Laboratory (PNL)[a] has investigated the effectiveness, durability, practicability and costs of methods to minimize the wind erosion of exposed tailings surfaces. Results of this study, sponsored by the Office of Nuclear Regulatory Research of the U.S. Nuclear Regulatory Commission (NRC), will provide technical information needed in formulating plans for the interim stabilization of uranium mill tailings over a wide range of site and environmental conditions.

This report reviews the results of chemical stabilizer field tests that are discussed in detail in a previous report (Elmore and Hartley 1983). It also describes the activities conducted in two field tests of windscreen systems. The results and overall findings of the chemical stabilizer and windscreen evaluations are presented, and a cost comparison is made of the use of chemical stabilization and windscreen techniques on a hypothetical inactive tailings pile.

(a) Operated for the U.S. Department of Energy by Battelle Memorial Institute under Contract DE-AC06-76RLO 1830.

CONCLUSIONS

Chemical stabilizers and windscreens have been shown to be effective in controlling fugitive dust emissions from uranium mill tailings. Results of this study will help NRC staff to conduct performance assessments of industry plans for the interim stabilization of mill tailings. The following specific conclusions were drawn from the results of field tests in which both chemical stabilizers and windscreens were evaluated.

- The 17 chemical stabilizers field tested at the Wyoming site were generally effective at reducing fugitive dust emissions over the short term (~1 year). However, their durability ranged widely and was not proportional to their cost.
- The three most effective stabilizers were found to be Wallpol 40-133, SP-400, and CPB-12.
- The cost to chemically stabilize a tailings pile with the field-tested chemical stabilizers is estimated to range from \$1700 to \$19,000/ha/yr under conditions similar to the Wyoming test site.
- A cost-effectiveness analysis illustrated that some of the less durable but less costly stabilizers may be as cost effective as the more durable but more expensive stabilizers.
- The three windscreen systems tested near PNL were effective at reducing wind velocity across a surface downwind of the screen, thereby reducing fugitive dust emissions.
- The durability of the eight field-tested windscreens ranged widely, and was not directly proportional to their cost.
- The cost of a windscreen system is highly dependent on site-specific factors. A detailed cost analysis should be made for actual site and weather conditions at each particular location.
- The expected costs for the field-tested windscreen systems range from \$400 to \$750/ha/yr, including maintenance, based on a three- to five-year life and the conditions assumed for the 40-ha hypothetical tailings pile.
- Windscreens are probably better suited to an inactive tailings pile, or in locations where they will not be frequently moved, such as to protect a berm from wind erosion.

- Under certain circumstances, careful analysis for a particular mill site may indicate that some combination of chemical stabilizers and windscreens may provide the optimal combination of dust control techniques.

WIND EROSION CONTROL BY SURFACE STABILIZATION

A number of techniques have been tried for controlling wind erosion of tailings piles. The simplest concept often used for surface stabilization is water sprinkling. Some mill operators use irrigation-type sprinkler systems distributed across the tailings surface. The binding action from increased surface tension of the wetted particles, however, is often not sufficient to prevent wind erosion entirely. The wetting and drying from cyclic sprinkling also tends to make the surface more fragile, actually increasing the wind erosion potential in many cases. In addition, maintenance and operation of sprinklers can be expensive, and the arid climate at most uranium mill sites often limits the availability of water.

Another stabilization method is to cover the tailings with a layer of straw, bark, soil, or rocks to protect the fine tailings from direct exposure to the wind. This method may be suitable for an inactive tailings pile, but is not considered cost effective for the short-term stabilization requirements of active tailings piles. Manmade materials such as plastic films and woven fabrics, or geotextiles, have been developed for the same purpose, but have not been demonstrated to be practical.

Vegetation has often been used to stabilize windblown soils, and a significant research effort has focused on developing methods to revegetate mine spoils and tailings piles (Leroy 1973; Dean and Havens 1973; Johnson and Bradshaw 1977). However, vegetative covers are generally more useful for longer-term stabilization of inactive areas because of the time, effort, and soil conditions required to establish and maintain plant cover.

Perhaps the most widely used control method is to treat the surface with some form of erosion-resistant binder. Chemical stabilizers are generally available and have been employed at many mill sites. These stabilizers bind the surface particles either by forming protective continuous films over the surface or by adhering to the particles to form a crust or large agglomerates of particles that resist blowing. Chemical stabilizers that are sold commercially include surfactants (wetting agents), hygroscopic salt solutions, petroleum resin emulsions, asphalt products, wood pulp by-products, and synthetic resin emulsions (Li, Elmore, and Hartley 1983).

The typical method of applying chemical stabilizers is to dilute the commercial concentrates with water at the site and spray the solution onto the tailings surface. The dilution factors and rates of application depend on the specific requirements of the site, including the characteristics of the blowing material. Although the chemicals are often expensive, the advantage of spray-on chemical stabilizers is the relatively simple application method, which usually involves commonly available spray equipment. In general, the major disadvantage of surface stabilization is that the stabilizers must frequently be renewed.

Initially, laboratory testing was conducted to evaluate the relative durability and effectiveness of the many commercially available chemical stabilizers under controlled laboratory conditions (Elmore and Hartley 1984). Samples of 45 commercially available chemical stabilizers were tested in the laboratory under simulated weathering conditions expected at most uranium mill sites. The effects of wind speed, application rate, dilution factor, 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 (UV) light and water erosion on the durability of the stabilizers. The permeability of stabilized simulated tailings was evaluated to determine the overall effect of these chemicals on the stability of a tailings pile. As a result of the laboratory studies, 15 chemical stabilizers were initially selected for field testing under actual site and environmental conditions; later, two additional stabilizers were selected for the field testing.

FIELD TESTING

The durability of the more promising chemical stabilizers was field tested at the American Nuclear Corporation-Gas Hills Project uranium mill in central Wyoming. Fifteen stabilizers selected from the laboratory tests were initially applied to test plots in August 1982. In September 1983 two more recently identified materials along with the most effective stabilizer from the previous year's test were applied to similar test plots, providing a means of comparing the stabilizers applied during both years. The new materials were Retain (Dubois Chemicals), an asphalt emulsion, and Soil Sement (Midwest Industrial Supply), a latex emulsion. The test plots were each then periodically monitored for approximately nine months.

Figure 1 shows the surface of the test plot soon after application of the Retain asphalt emulsion. Figure 2 shows the same test plot after nine months of weathering. The contrasting colors of the asphalt and tailings clearly illustrate the change in condition of the stabilizer with time. The deterioration of the surface crust is readily apparent. Many of the other stabilizers from both years' field tests behaved similarly. Appendix A contains photographs of both test plots of the two newer stabilizers, Retain and Soil Sement, and of the Wallpol 40-133 test plot from the 1983 field test. The first figure of each test plot was taken soon after application of the stabilizer. The second photograph shows the same area after nine months of exposure at the test site.

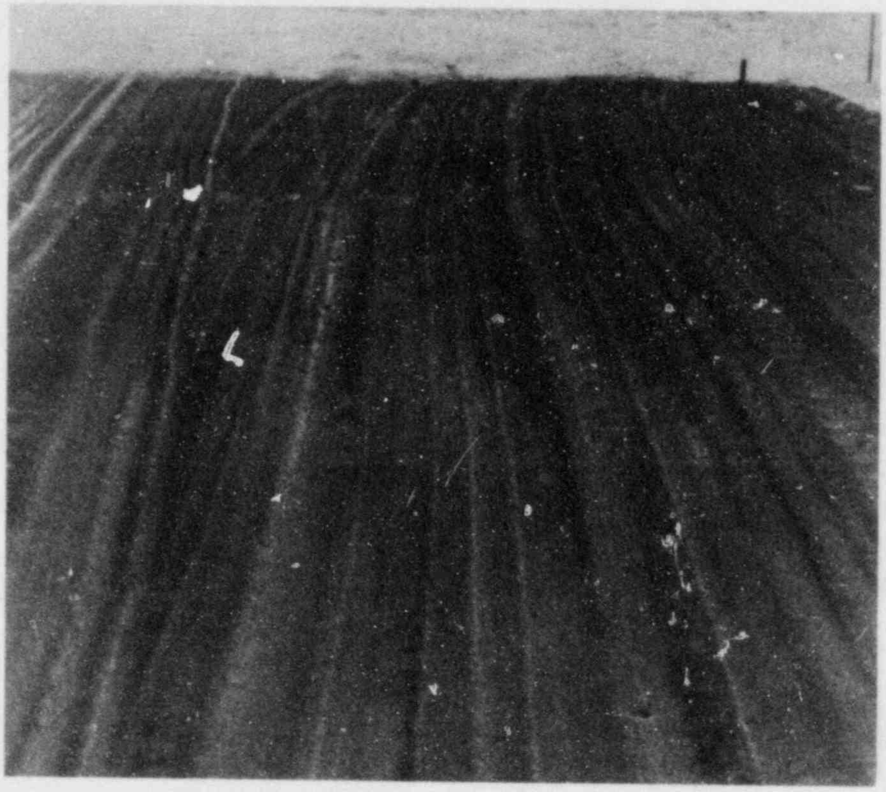


FIGURE 1. Test Plot at the Wyoming Test Site After Application of Retain Asphalt Emulsion Stabilizer

FIGURE 2. Deterioration of the Stabilized Tailings Surface Initially Treated with Retain After Nine Months of Weathering

The results of the first year's field test were presented in an earlier report (Elmore and Hartley 1983). Three synthetic polymer emulsions were found to be the most effective at the Wyoming test site: Wallpol 40-133 (Reichold Chemicals), SP-400 (Johnson and March Corporation), and CPB-12 (Wen Don Corporation). Results of the second year's field testing of the two additional products indicated that both the Retain and Soil Sement were less effective than the top-rated materials of the previous year's field test. A problem that occurred during application of the Retain was that the emulsion prematurely broke during mixing in the spray tank. As a result not all of the test plot received the recommended application of the stabilizer. However, an area that did receive the recommended amount was used for the evaluation. The relative effectiveness of all the field-tested chemical stabilizers is shown in Table 1. The durability rating assigned to each stabilizer in the table was based on the observed amount of stabilized surface remaining on each test plot after approximately one year of exposure. The relative amount of remaining stabilized surface is considered to be equivalent to the relative effective lifetime for the stabilizer. Based on the results of the field test, one year is expected to be the longest time a stabilizer would be effective at controlling erosion from this type of surface, and under these conditions. (A stabilizer showing 80% remaining after one year is assumed to be effective for only eight-tenths of a year.)

TABLE 1. Chemical Stabilizers Grouped by Relative Durability After Extended Weathering

Group	Stabilizer	Composition	Relative Durability
I	Wallpol 40-133	Vinyl acetate/acrylic	7 to 10 (good)
	SP-400	Latex emulsion	
	CPB-12	Acrylic emulsion with conditioners	
II	Sandstill II	Petroleum resins/surfactant	4 to 6 (fair)
	Soil Gard	Styrene butadiene	
	Dust Loc VMX-50	Acrylic latex	
	Dust Gard	$MgCl_2$ brine solution	
	Aerospray 70	Polyvinyl acetate	
	Orzan A	Ammonium lignin sulfonate	
	Coherex	Petroleum oils and resins/ surfactant	
	Marloc	Polyvinyl acetate	
	Soil Sement	Latex emulsion	
III	Hydro Mulch	Wood fiber mulch	0 to 3 (poor)
	Retain	Asphalt emulsion	
	Dust Binder C-266	Synthetic polymer emulsion	
	Polyco 2151	Vinyl acetate/acrylic	
	M-167	Latex-glycol emulsion/ surfactant	

COSTS OF LARGE-SCALE CHEMICAL STABILIZATION

The cost to chemically stabilize a tailings pile will vary greatly depending on the site location, size and condition of the tailings pile, and type of stabilizer selected. Table 2 shows the range of material costs for the field-tested stabilizers. These costs are based on 1984 estimated prices of the materials delivered to the Wyoming test site in quantities sufficient to treat a 40-ha (100-acre) tailings pile.

Large-scale stabilization costs shown in Table 2 are based on costs as estimated by American Nuclear for a similar stabilization project at their site in July 1982. This project consisted of a two-man crew and a tank truck fitted with a sprayer, which applied a chemical stabilizer to an inactive tailings pile showing signs of wind erosion. The crew was able to apply 1 to 2 tank loads during an 8-hour shift. The expected coverage for one tank load of the

TABLE 2. Estimated Application Costs of Chemical Stabilizers for a Large-Scale Tailings Stabilization Project

Chemical Stabilizer	1984 Material Costs, $/ha(a)	Large-Scale Stabilization Costs	
		$/ha(b)	$/ha/yr(c)
1 Aerospray 70	3280	3600	7200
2 SP-400	3170	3490	4360
3 Dust Lok VMX-50	2790	3110	6220
4 Wallpol 40-133	2690	3010	3762
5 Dust Gard	2260	2580	5160
6 CPB-12	1980	2300	3290
7 Marloc	1910	2230	5580
8 Dust Binder C-266	1880	2200	7330
9 Soil Sement	1730	2050	5130
10 Sandstill II	1630	1950	3250
11 M-167	1580	1900	19,000
12 Soil Gard	1350	1670	2780
13 Coherex	1250	1570	3930
14 Hydro Mulch	810	1130	3770
15 Retain	670	990	4950
16 Polyco 2151	480	800	2670
17 Orzan A	360	680	1700

(a) Stabilizer costs are based on delivered price to the field test location in central Wyoming, and on amount required to stabilize a 40-ha site. Delivered costs will vary with location.

(b) Includes expected labor and equipment charges of $320/ha based on American Nuclear's estimate for a similar large-scale project at their mill in 1982 using two operators and a 10,000-gal spray truck.

(c) Cost/ha/year is based on relative durability of the stabilizers as observed from the Wyoming field test.

stabilizer, when applied according to the manufacturer's directions, was approximately 1.67 ha (4.13 acres). The estimated costs for truck and crew was $60/hour, or a labor and equipment charge of $160 to $320/ha. The time and effort required to treat a given area would not vary significantly for any of the stabilizers, so a conservative estimate of $320/ha was used for all the materials. Application costs are a significant portion of the total for only the least expensive materials.

To assess the cost effectiveness of the stabilizers, the relative observed durabilities of the materials are plotted against the estimated large-scale application costs (Figure 3). The longer-lasting stabilizers tend to be the more expensive ones, with some exceptions. However, any stabilizers falling on a diagonal line drawn through the origin are for practical purposes equally cost effective. That is, a less expensive stabilizer can be applied more frequently to produce the same degree of erosion protection for essentially the same cost (compared to a more expensive stabilizer on the same diagonal line). For example, stabilizer 4 was given a durability rating of 8; its applied cost is $3010/ha and its effective lifetime was observed to be equivalent to eight-tenths of a year. Stabilizer 13 was given a rating of 4 with an applied cost of $1570/ha, and so could be applied twice as often for approximately the same

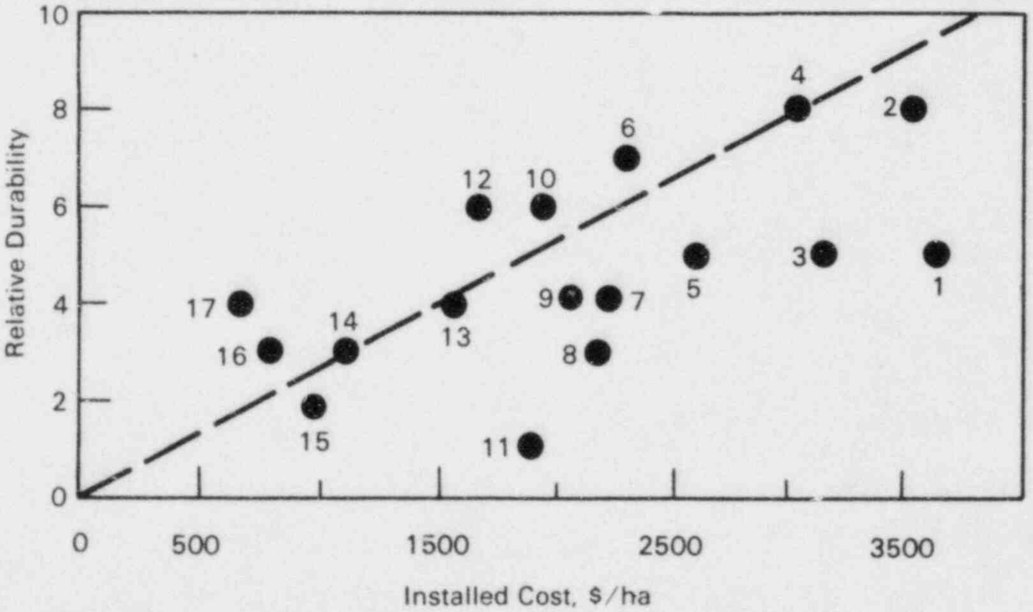


FIGURE 3. Cost Versus Relative Durability of Field-Tested Chemical Stabilizers. Numbers correspond to the numbered stabilizers in Table 2.

cost and degree of erosion protection. Those chemicals lying below the diagonal line would then be less cost effective than those lying above the diagonal. However, the final selection of a particular chemical stabilizer will depend on many site-specific requirements such as tailings pile construction and management, weather conditions, mill location, price and availability of stabilizers, and other such factors.

WIND EROSION CONTROL BY WIND VELOCITY REDUCTION

In early experiments, Bagnold (1954) observed that about 75% of the total movement of blowing sands occurred through saltation, the forward bounding movement of windblown particles too large to remain suspended in the air. (Saltation generally occurs with particles between 100 µm and 500 µm in diameter.) Size distribution analysis of tailings, particularly the more erodible beach sands, predicts that saltation will be the primary mechanism for tailings erosion (Elmore and Hartley 1984). Bagnold (1954), Belly (1964), and Gillette (1973) have shown the horizontal flux of particles from various soil types to be proportional to the cube of the wind speed. Therefore, cutting the wind speed in half should reduce tailings erosion to one-eighth the original amount. This is true if, by reducing the horizontal component of the wind velocity, the surface shear force of the wind is similarly reduced.

Wind speed can be reduced on large open areas using windscreens. Rows of trees or hedges have been used to protect structures and agricultural fields from high winds for many years (Van Eimern et al. 1964). Wind tunnel and field experiments have shown that windbreaks produce large areas of reduced wind velocity downwind of the break.

To date there has been relatively little reported experience with windscreens to reduce wind erosion of storage or tailings piles; windscreens have been tested for controlling fugitive dust from coal storage piles (Drehmel, Daniel and Carnes 1982). The use of windscreens to protect highways from blowing and drifting snow is an effective established practice, and many of the principles that govern the use of snow fences should also apply to the use of windscreens on tailings piles (Tabler 1975, 1980).

Figure 4 shows typical streamlines for flow about solid and porous windbreaks (Billman 1984). Recirculation regions are evident both upwind and downwind of the solid windbreak; they are regions of low velocity and high turbulence intensity (Figure 4a). A solid wall would thus result in a small sheltered area behind the barrier, due to the increased turbulence caused by

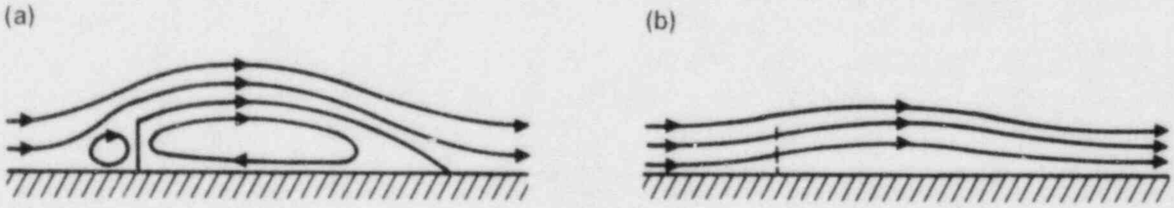


FIGURE 4. Streamlines of Air Flow About Windbreaks: (a) solid, (b) porous.

diverting the entire flow of air over the barrier. A porous barrier, on the other hand, absorbs part of the momentum of the wind and allows a portion of the flow to pass through at a lower velocity. This "bleed flow" smooths the wind flow across the sheltered area, decreasing the shear acting on the tailings surface. As porosity (ratio of open to total cross-sectional area) increases, the downwind recirculation region becomes smaller and moves downstream; the upwind recirculation region is eliminated. A region of reduced wind speed is evident in Figure 4b. Turbulence in the wind flow can also be created by surrounding terrain features and obstacles, and should be taken into account for proper siting of a windscreen.

Windscreens can be constructed to protect a tailings pile from erosion by lowering the wind velocities to the leeward of the screen below the threshold velocity for movement of the surface particles. The design and siting of a windscreen system are critical for its proper performance, and should consist of the optimal combination of several factors:

- windscreen height and length
- windscreen permeability (porosity)
- size and shape of openings in the screen
- location of the screen(s) on the tailings pile
- prevailing wind direction and maximum expected velocity
- surface particle characteristics (threshold velocity)
- surrounding terrain characteristics.

In general, the area behind some windscreens where the wind velocity is reduced to one-half the incident wind velocity extends 10 to 12 times the windscreen height (10 to 12 H) downstream of a porous windbreak. Thereafter, the velocity gradually increases until it again reaches the full upwind velocity. Greater magnitudes and larger areas of wind speed reduction occur with smoother upstream terrain and lower turbulence in the approach flow.

Virtually all research indicates that an aerodynamic porosity of 50% is close to the optimal value to produce the largest sheltered area. Because of this finding, most windscreen manufacturers attempt to create 50% porosity in their products. However, the actual measurement of porosity may vary among manufacturers. Optical porosity, which is often measured, may be considerably different from true aerodynamic porosity.

In addition to the reduction of wind velocity, another potentially important use of windscreens is the recapturing of windblown tailings on the downwind perimeter of the tailings pile. This system might serve as an effective backup for chemical stabilizers or windscreens, or when other measures are not practical. A downwind screen does not have to be very tall to capture saltating particles, which generally are lifted no higher than 1 to 2 m from the surface. Finer suspended particles can, however, be carried much higher once blown into the air.

Windscreens have the advantage of being essentially passive. They do not need to be powered or frequently renewed, and they do not contain chemicals that may adversely affect the mill processes or environment. The design of a windscreen system can also be quite flexible; it can range from low freestanding fences to portable modules to massive permanent installations, whichever is best suited to a particular application. This flexibility offers the mill's environmental engineers and operations personnel a wide range of control options.

WINDSCREEN FIELD TESTING

Due to the size of the commercially available windscreens, laboratory wind tunnel studies of these materials were not feasible. The porosity and dimensions of the windscreens and the roughness, shape, and dimensions of the tailings pile to be modeled are difficult to accurately scale down. Therefore, windscreen evaluations were conducted entirely at field-test sites. One test was established at the Wyoming site to evaluate the durability of the windscreens when subjected to actual weathering conditions. Test panels of eight commercially available windscreens (Table 3) were constructed for this test.

TABLE 3. Windscreens Evaluated at the Wyoming Test Site

Windscreen	Distributor	Description
Agrinet wind/ shade screen	Hydrolic Enterprises Casper, WY	Woven polyester
Athalon snow control fence	Athalon Products Denver, CO	PVC-coated stainless steel wire and fiberglass
DuPont Canada:	Flasher Handling Corp. Buffalo, NY	High-density polyethylene
L-300		50-mm mesh
L-36		3-mm mesh
CE-121		10-mm mesh
L-38		19-mm mesh
Julius Koch Dusttamer	KPN International Newtown, CT	Woven polyester
Wood-slat snow fence	Widely available	Vertical wood slats with horizontal wires

Another field test was established near PNL to study the relative effectiveness of three typical screen types: 1) vertical wood-slat (Canadian-style) snow fence, 2) woven polyester cloth with 50% porosity and small openings (Julius Koch Dusttamer), and 3) rigid extruded plastic mesh with 50% porosity and large openings (DuPont Canada L-300). Figure 5 shows the relative size of the openings in the Dusttamer and L-300 screens; each is said to have about the same aerodynamic porosity, 50%.

Durability Test

The windscreen durability test area at the Wyoming test site was located on a high flat bluff (Figure 6) that is exposed to the most extreme wind conditions in the area. The installed windscreens are shown in Figures 7a and 7b. The selected materials were chosen to be representative of the various types of commercially available windscreens, including the more common vertical wood-slat snow fence, extruded plastic screens with different opening sizes, and woven synthetic materials with different sizes and shapes of openings. The windscreen test panels were placed on the high bluff and oriented perpendicular to strong prevailing southwest winds. Appendix B includes photographs of the eight tested windscreens both at the time of construction and after nine months of exposure.

The test panels were each 1.2 m (4 ft) high and 15 m (50 ft) long. The windscreens were mounted on several types of posts including wood (Figure 8), standard steel T-type fence posts (Figure 9), and special aluminum posts made for the Dusttamer windscreen (Figure 10).

The results of the windscreen test indicate a considerable variation in durability of the tested materials (Table 4). Observations were made after exposure of the screens to nine months (September 1983 to June 1984) of severe weather conditions. The materials were ranked according to their observed relative durability. The most durable materials appeared to be the DuPont Canada materials; in particular the L-300. The least durable were the Julius Koch Dusttamer and the vertical wood-slat fence (see Appendix B). The poor performance of the Dusttamer, however, was a result of the special aluminum mounting posts failing and cutting the windscreen material, as shown in Figure 11. No other signs of degradation of the cloth were evident. The results of other test installations of this material indicate much better durability of the material itself. The vendor has since been testing other types of mounting posts to solve this problem.

The deteriorated condition of the wood-slat fence, on the other hand, was less surprising. The wires and wood slats were broken in several places along the length of the test panel, as shown in Appendix B (Figure B.8b). The experience of many people with this product indicate that, although initially less expensive than most other similar products, the vertical wood-slat fence

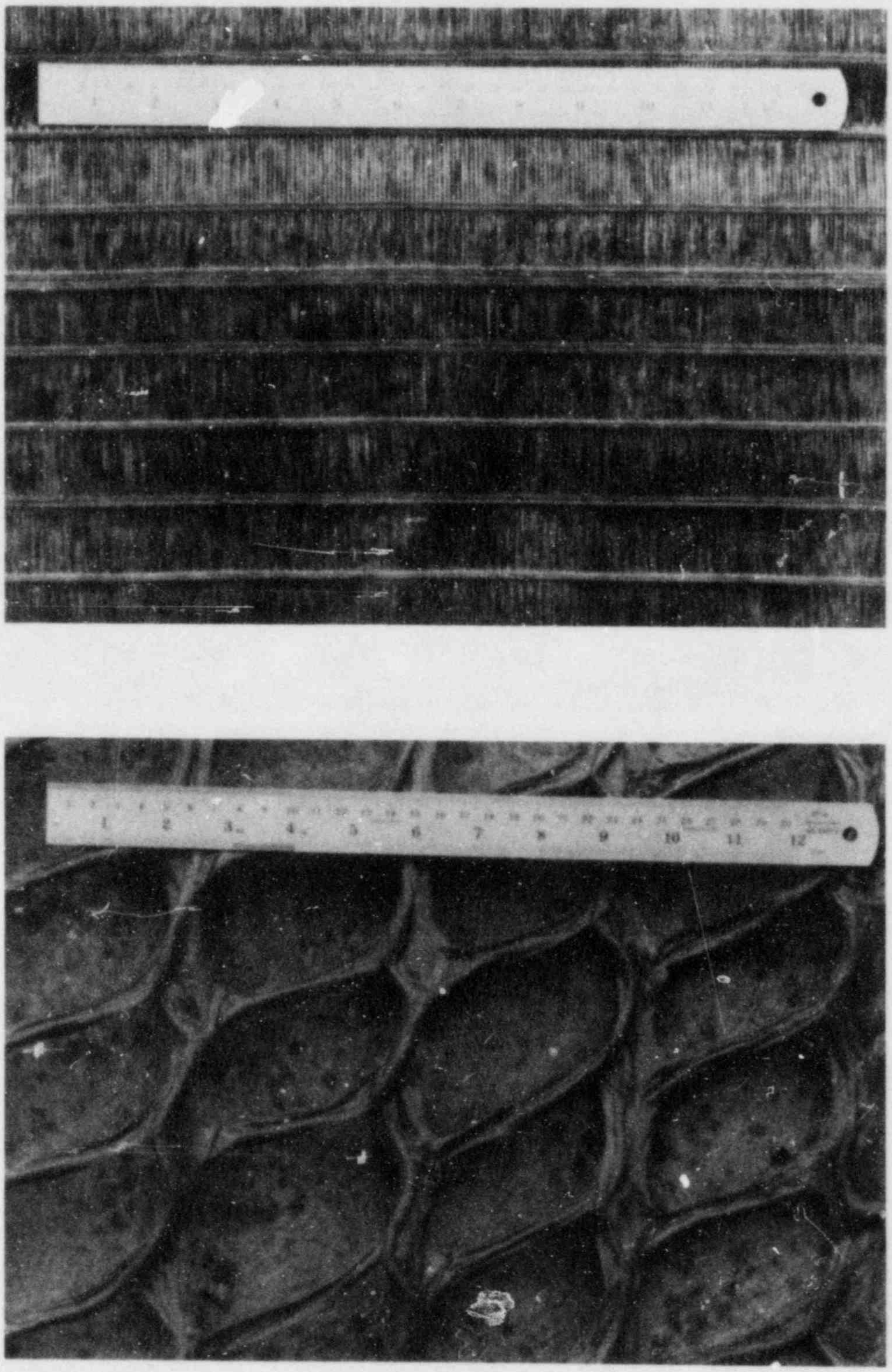


FIGURE 5. Closeup of the Dusttamer (top) and L-300 (bottom) Windscreens Showing Difference in Size of the Openings Between the Two Materials. Each is said to have close to 50% aerodynamic porosity.

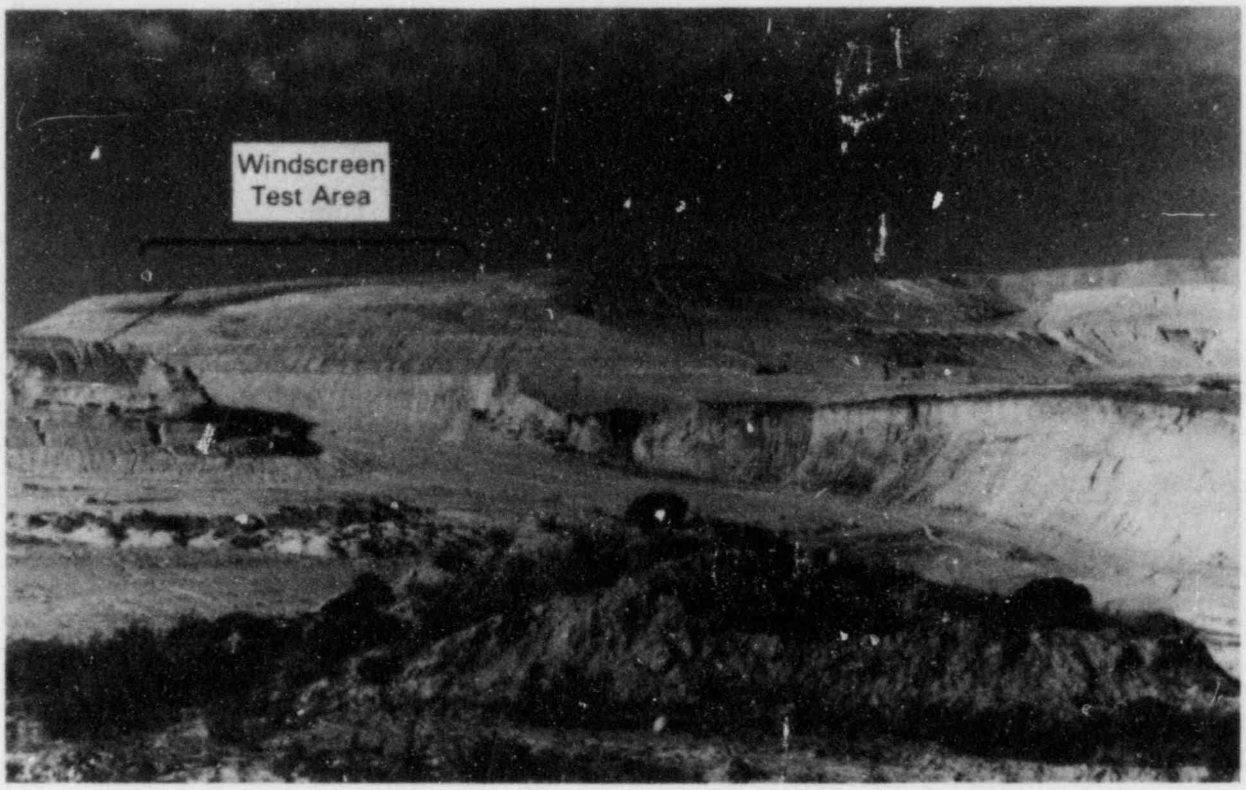
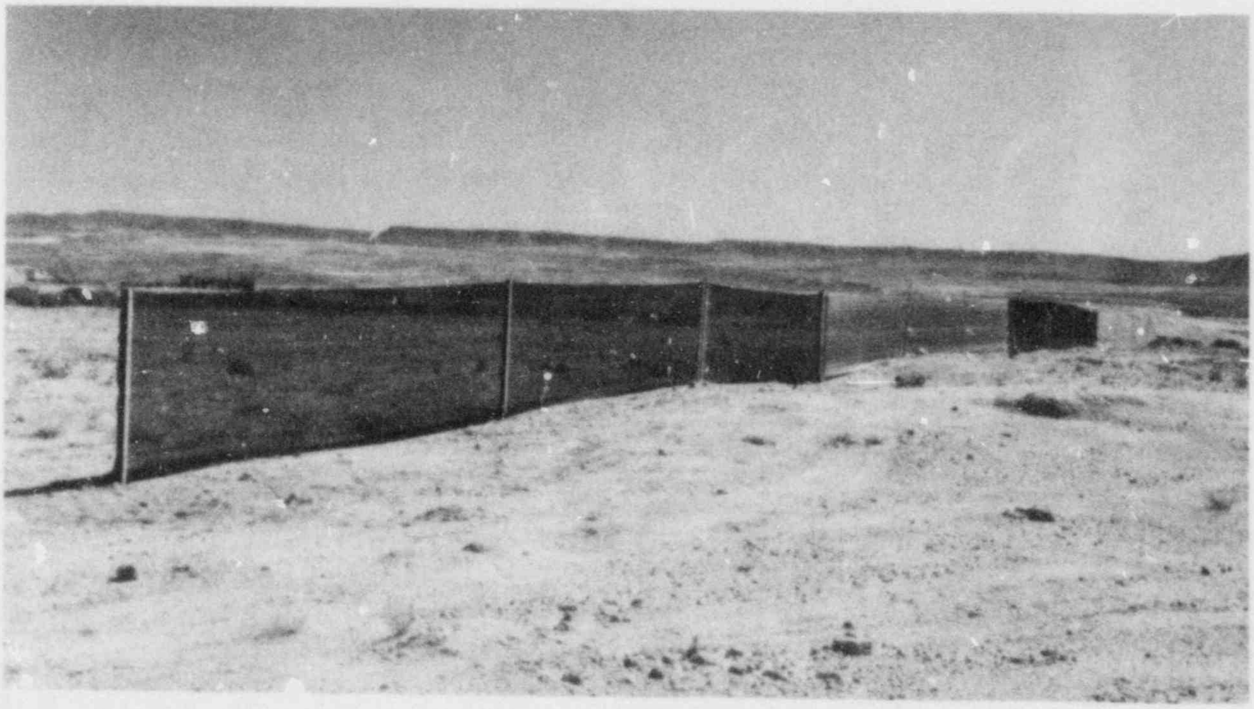


FIGURE 6. View of the High Bluff on Which the Windscreen Test Panels Were Erected at the Wyoming Test Site

(a)



(b)

FIGURE 7. (a) Installation of the DuPont Canada L-300 Windscreen Test Panel at the Wyoming Test Site; (b) Several Windscreen Test Panels Erected at the Wyoming Test Site

FIGURE 8. Wood Posts Tested as Supports for Selected Windscreen Test Panels

FIGURE 9. Steel Fence Posts Tested as Supports for Selected Windscreen Test Panels

FIGURE 10. Installation of the Julius Koch Dusttamer Windscreen on Special "Slide-Lock" Aluminum Posts. The hand-held device is used to properly tension the screen.

TABLE 4. Results of Windscreen Durability Test

Ranking[a]	Windscreen[b]	Observations
	DuPont Canada	
1	L-300	Some breaks from staples, otherwise good shape
2	L-36	Less stretch than L-38 and CE-121, no apparent deterioration
3	CE-121	Stretched a minor amount, but otherwise in good condition
4	L-38	Stretched but no other evidence of deterioration
5	Agrinet	Stretched considerably after installation, but no deterioration
6	Athalon	Broken wires and torn cloth from wind stress
7	Wood-slat	Wires and wood slats broken in places
8	Dusttamer	Aluminum posts broke from wind stress resulting in badly torn screen, but cloth itself seemed durable otherwise

---

(a) Ranking based only on durability (1 best, 8 worst). Cost, ease of installation, and other factors not considered.

(b) Windscreens installed 9-1-83. Observations were made during site visit 6-1-84 after nine months exposure to relatively constant winds 10 to 20 m/s.

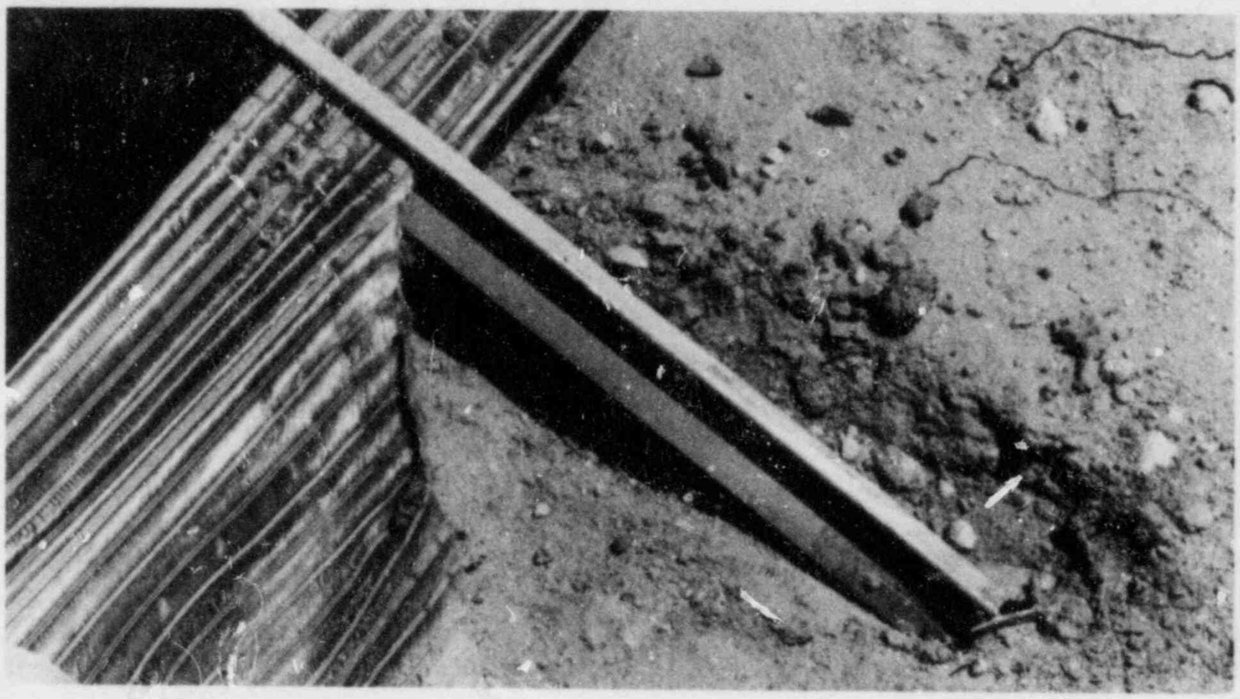


FIGURE 11. Closeup of the Fatigued Aluminum Post Used for the Julius Koch Dusttamer Windscreen

requires more frequent maintenance when subjected to harsh weather conditions. The other materials showed varying amounts of stretching and breaking, and all had suffered some abrasion from blowing sand. But none except the Dusttamer and wood-slat fence had severely deteriorated from high winds, UV exposure, freezing, or other weathering factors.

Performance Tests

A field test was initiated near PNL in November 1983 to evaluate the relative effectiveness or performance of three selected windscreens, and was monitored through July 1984. Wind velocity reductions over a sandy surface were measured behind each of the three screens with anemometers, and the extent of the leeward zone of reduced velocity was determined. Velocity reduction measurements were normalized with simultaneous measurements taken at the same heights on identical upwind and downwind towers (Figure 12).

The test site (Figure 13) was located in a flat open area to avoid any disturbances in the wind flow from obstacles such as trees or buildings. Wind data from a nearby weather station indicated that the predominant wind direction at this location was from the northwest. The test site was oriented so that the windscreens would lie perpendicular to the prevailing winds. An area approximately 100 m by 140 m (350 ft x 450 ft) was cleared and leveled. Three

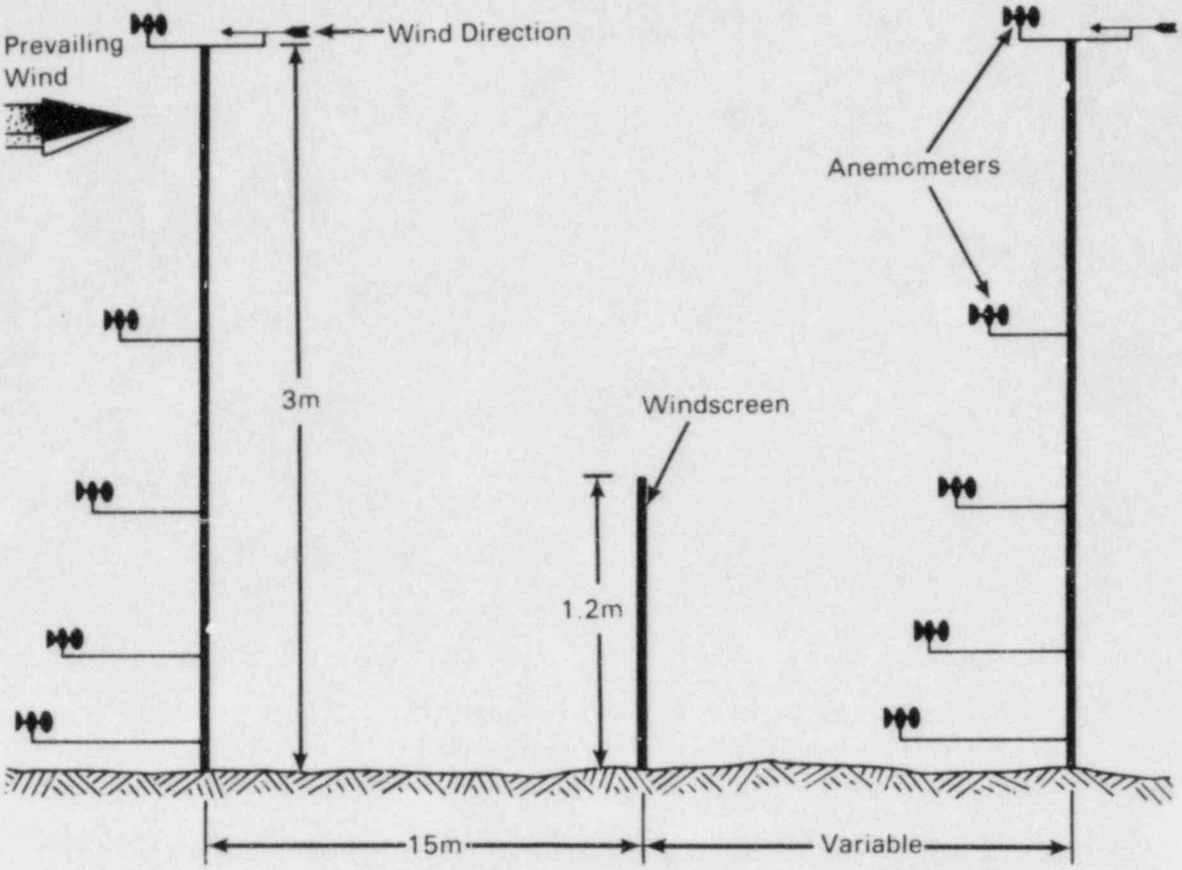


FIGURE 12. Relative Positions of the Anemometer Towers (upwind and downwind) and Windscreens at the PNL Field-Test Site (Drawing not to scale.)

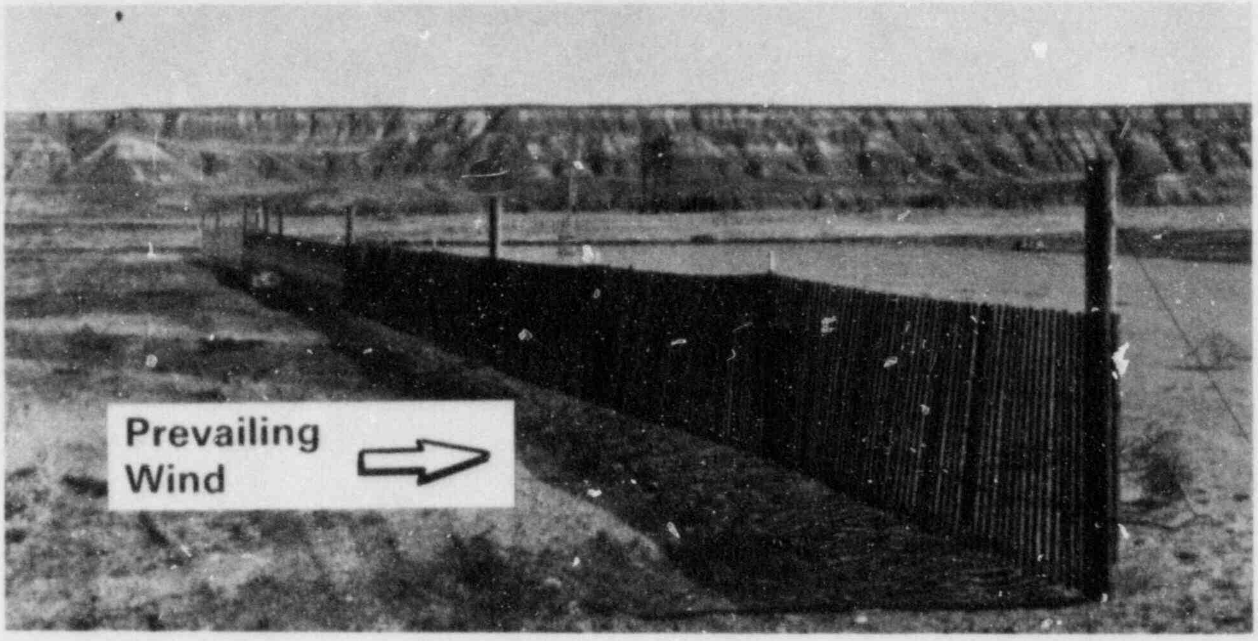


FIGURE 13. PNL Field-Test Site Showing the Three Windscreens Erected on a Flat, Unobstructed Area Perpendicular to the Prevailing Wind Direction

windscreens - Julius Koch Dusttamer, wood-slat snow fence, and DuPont Canada L-300 - were constructed along the upwind side of the test area. Figure 13 shows the PNL test site with the screens constructed perpendicular to the prevailing wind direction. (Note the portable anemometer tower on the downwind side of the screen. The stationary upwind tower is located left of the edge of the photograph.) The screen sections were each 30 m (100 ft) long. An area 30 m by 120 m (100 ft x 400 ft) behind the windscreen panels was covered with 15 cm (6 in.) of fine sand to simulate tailings. The sand-covered area was installed to detect differences in erosion protection by the three windscreens compared to an unprotected control area on the side of the test plot. (Particle flux measurements were to be made on this sandy area, but winds occurring at the test site were not strong enough during the period of the field test to create measurable fluxes.) Figure 14 shows the layout for the windscreen test site.

The relative size of the zone of reduced wind velocity was considered a measure of the windscreens' effectiveness at reducing wind erosion. Results of normalized velocity reduction measurements are shown in Figure 15. The Julius Koch Dusttamer was the most effective, having the largest protected zone. It continued to show some wind reduction at distances up to 35 times the height of the screen (35 H) downwind of the screen. The vertical wood-slat snow fence and the DuPont Canada L-300 material had protected zones of approximately 20 to

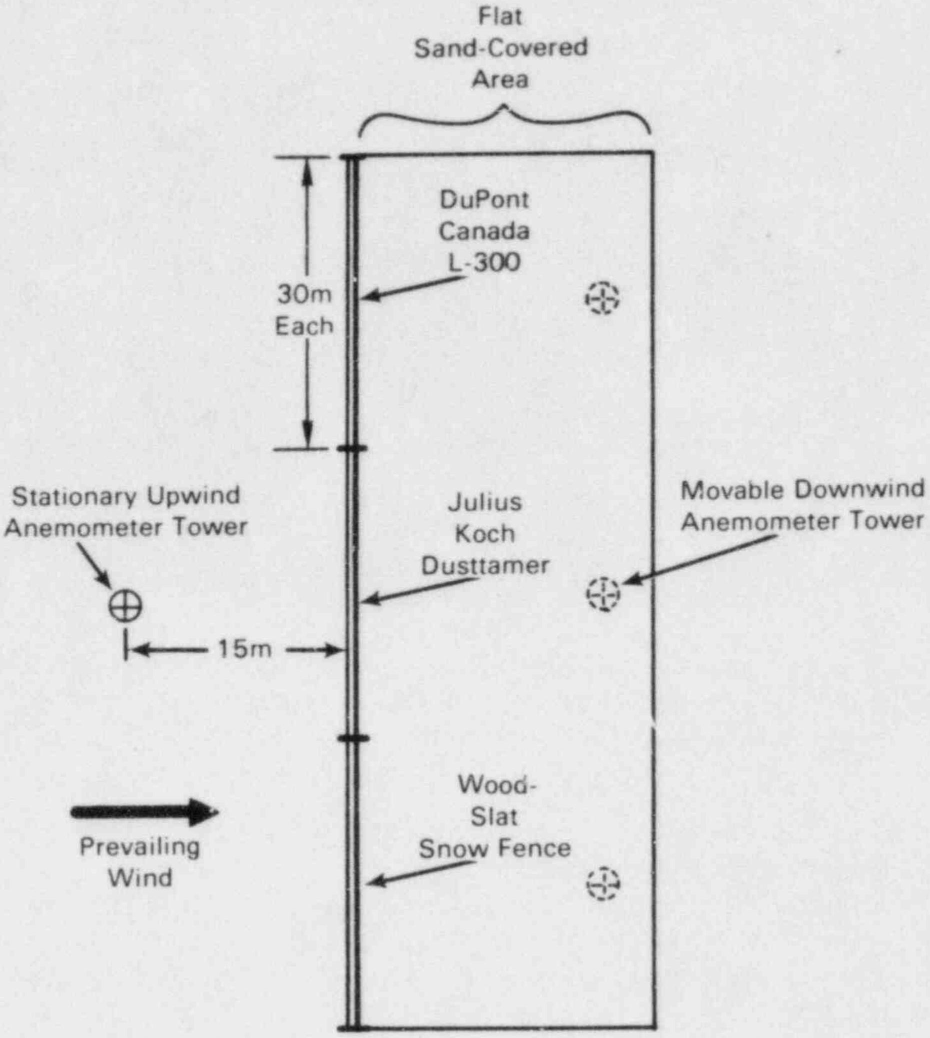


FIGURE 14. Layout of the PNL Windscreen Performance Test Site (Drawing not to scale.)

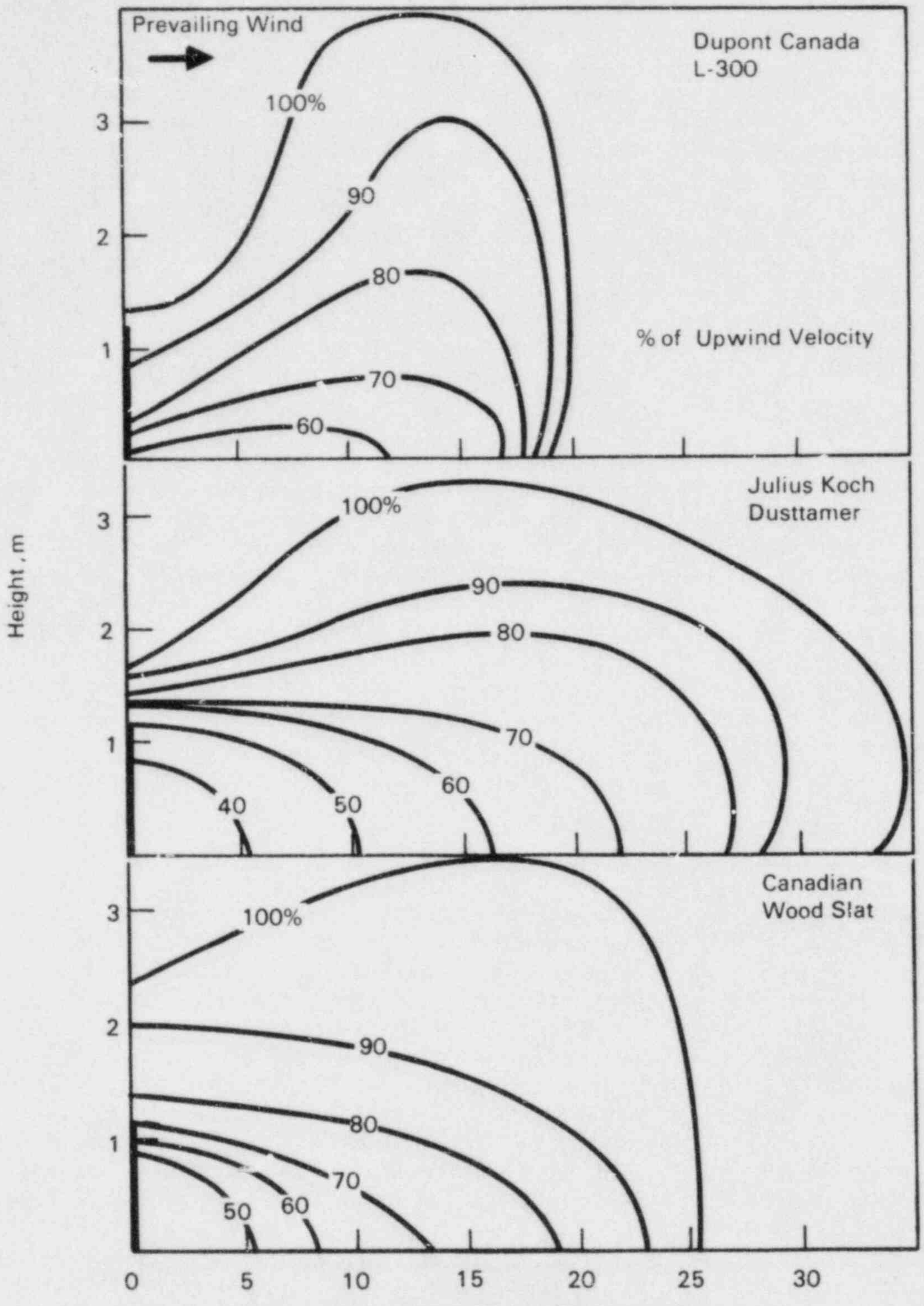


FIGURE 15. Wind Velocity Reductions Above a Smooth Sandy Surface at the PNL Field-Test Site Downwind of Three Types of Windscreens. Curves shown are presented as a percentage of the incident upwind velocity.

25 H each. These two materials have been designed primarily to capture suspended particles, especially blowing snow, rather than to maximize wind velocity reduction. The larger size of openings in these screens helps to prevent them from becoming blinded with snow, which would reduce their efficiency. This illustrates the effect of opening size on the performance of a windscreen independent of the screen's porosity. Differences in opening sizes among screens with similar porosity were shown in Figure 5. In terms of particle reduction, the DuPont material might perform better than the wood-slat fence, since the height of its protected zone is greater, enabling it to help settle out particles that are carried higher in the air. In general, windscreens with smaller openings may be a better choice from an aerodynamic standpoint for wind reduction, while the screens with larger openings could be better used to capture blowing particles at the site boundaries.

To construct a system of windscreens that will effectively protect an area from most potential wind erosion events, a reasonable estimate of the maximum expected velocities and directions of winds is needed. Suppose for instance that a 50% reduction in highest expected wind velocity would lower surface wind speeds below the threshold velocity for movement of the surface particles. In such a case a series of parallel screens, perpendicular to the wind and separated by the distance shown by the intersection of the 50% isotach and the surface, would be required. In addition, however, a good design must allow for increased turbulence created by local terrain, which can decrease the efficiency of a windscreen. An example illustrating the design of a windscreen installation is provided in the "Case Studies" section.

LARGE-SCALE WINDSCREEN SYSTEM COSTS

The cost to construct a windscreen system for wind erosion protection is dependent on many site-specific requirements that are complicated by the probability of weather events and the effects of local terrain features on turbulence in wind flow patterns. However, some estimates can be made using the results of the field tests. The material costs for the eight tested windscreens (1.2 m high) ranged from \$2.60 to \$6.30/linear meter, as shown in Table 5. Based on the field-test experience and on data from suppliers, a two-man crew with appropriate equipment should be able to install about 60 to 75 m of screen per hour. As with chemical stabilization, the labor costs should not vary significantly among the different products. Using the \$60/hour estimate for manpower and equipment calculated for chemical stabilizer application, the installation costs for the tested windscreens are estimated to be about \$0.80 to \$1.00/m.

From the results of the field tests, the cost to provide wind erosion protection for a tailings pile with a windscreen system will vary depending on the type of windscreen chosen, due to differences in the effectiveness, durability, and initial cost of each screen. Variable wind patterns would require more extensive windscreen installations, if winds strong enough to cause tailings erosion occurred from several directions. In general, a windscreen system is expected to cost more initially than some chemical stabilizers. However, windscreens should last considerably longer than chemical stabilizers (perhaps 3 to

TABLE 5. Material Costs for Field-Tested Windscreens

Windscreen	Component Costs (1984) Screen, \$/m[(a)]	 Posts, \$/m[(b)]	Total System, \$/m
Agrinet	4.40	0.30	4.70
Athalon	11.50	0.30	11.80
DuPont Canada			
L-300	4.35	0.30	4.65
L-36	5.05	0.30	5.35
CE-121	8.25	0.30	8.55
L-38	6.20	0.30	6.50
Dusttamer	6.30	0.60	6.90
Wood-slat fence	2.60	0.30	2.90

(a) Cost for a 1.22-m (4-ft) high screen.

(b) Posts used were wood and steel types except for Dusttamer aluminum posts. Wood and steel were approximately $3.00 each. The spacing between posts was 10 m.

5 years or longer if properly maintained). If so, windscreens may be more cost effective than chemical stabilizers over the longer term, again depending on many site-specific factors. A more detailed cost analysis of windscreen installations at a hypothetical tailings pile is provided in the following section.

HYPOTHETICAL CASE STUDIES

This section provides examples that compare the cost of application of chemical stabilizers with the cost of installing a windscreen system on a hypothetical tailings pile to protect the surface from wind erosion. The examples are necessarily simplified for this purpose, and the choice of either method for a particular application would require detailed information of many site-specific variables that are beyond the context of this study. These examples do, however, illustrate some of the basic considerations involved in this type of analysis.

For the hypothetical tailings pile in this evaluation, the following assumptions were made:

- The size of the tailings pile is 40.5 ha (100 acres).
- The shape of the pile is square with a flat top 636 x 636 m.
- The current operational status of the tailings pile is recently inactive, there is no ponded water, and the tailings are sufficiently consolidated to support required stabilization equipment.
- The location of the mill site is comparable to the Wyoming field-test site for which delivered prices of the materials and weather conditions are known.
- The climate of the example site is:
  - semiarid, seasonal
  - peak wind velocity is 22 m/s from one prevailing direction
  - variable winds are not high enough to cause erosion.
- The chemical stabilizers and windscreens are available at the same prices as when tested at the Wyoming site.

CASE 1: CHEMICAL STABILIZATION

The cost to initially stabilize a tailings pile, as previously shown in Table 2, ranges from \$680 to \$3600/ha for the field-tested stabilizers. However, the yearly cost to maintain an erosion-resistant crust on the tailings, based on the expected effective lifetimes, ranges from \$1700/ha/yr to \$19,000/ha/yr, as shown in Table 3. Therefore, the annual costs to stabilize a 40-ha tailings pile under conditions similar to those of the field test could range from a low of $68,000/yr to a high of $760,000/yr. Areas of high wind shear, such as at the crest of dikes, would require heavier or more frequent applications, which would increase the overall cost.

CASE 2: WINDSCREEN INSTALLATION

The proper use of windscreens for effective wind erosion control, as previously discussed, requires more detailed information on wind, site topography, and windscreen performance data than is needed for chemical stabilization. However, some of the assumptions made about the hypothetical site will simplify the design for purposes of this illustration.

The Julius Koch Dusttamer windscreen was selected first for this analysis. Previous studies, including the PNL field test, show this type of screen to provide one of the largest sheltered zones behind the windscreen (Figure 15). The cost of an initial installation of the windscreen was estimated based on the performance test data. Following the Dusttamer, similar analyses with the DuPont Canada L-300 and the wood-slat snow fence were performed to compare the expected installation costs of each type of windscreen. The observed durability for each screen was then factored into the analysis. Thus, for an erosion protection program lasting 5 years for the hypothetical tailings pile, an estimated maintenance cost and replacement cost are included. The analyses resulted in a cost per year for each screen, similar to the analysis for chemical stabilizers.

The assumed peak wind speeds were given as 22 m/s (50 mph). In general, the threshold velocity for this type of particulate tailings material would be about 11 m/s (25 mph), measured at a height of about 3 m above the ground. Therefore, to prevent windblown tailings the minimal design for a windscreen system would be to construct parallel screens across the pile perpendicular to the prevailing wind direction at separations that would provide the necessary 50% velocity reduction.

As seen in Figure 15, the 50% isotach for the Dusttamer windscreen (by which the resultant wind velocity is reduced to half the incoming velocity) extends to about 10 times the fence height (10 H). Assume that the edge of the tailings pile would not create increased turbulence in the wind flow. (In reality a raised edge would probably result in accelerated wind flow and increased turbulence along the crest of the dike.) For this design, then, the first fence row would be placed along the crest of the upwind dike. The next parallel row would be placed at a distance of 10 H from the first screen. The wind at that point would be reduced to 11 m/s. Succeeding rows would only have to be set up at intervals of approximately 35 H, or at the 100% isotach; since at that point the wind approaching each screen is now only half the original upwind velocity. This method of spacing for the screens is illustrated for the Dusttamer windscreen in Figure 16. Other screens would have similar parallel rows but with different spacings, as shown in Figure 15.

For a 1.2-m-high Dusttamer windscreen the installation would require 15 parallel rows of windscreens across the tailings pile for protection from the expected winds, or a total of 9540 m of screen. At $7.90/m the total installed cost for the 40-ha site would be $75,400, or $1860/ha (Table 6).

The DuPont Canada L-300 windscreen (1.2 m high) has its 50% isotach at about 5 H and the 100% isotach at 20 H (Figure 15). An installation using this type of screen would require 27 parallel rows, for a total of 17,170 m of screen. At $6.15/m the installed cost would be $105,600 or $2610/ha.

Performance test results for the vertical wood-slat snow fence show the 50% isotach at 6 H and the 100% isotach at 26 H (Figure 15). Protecting the

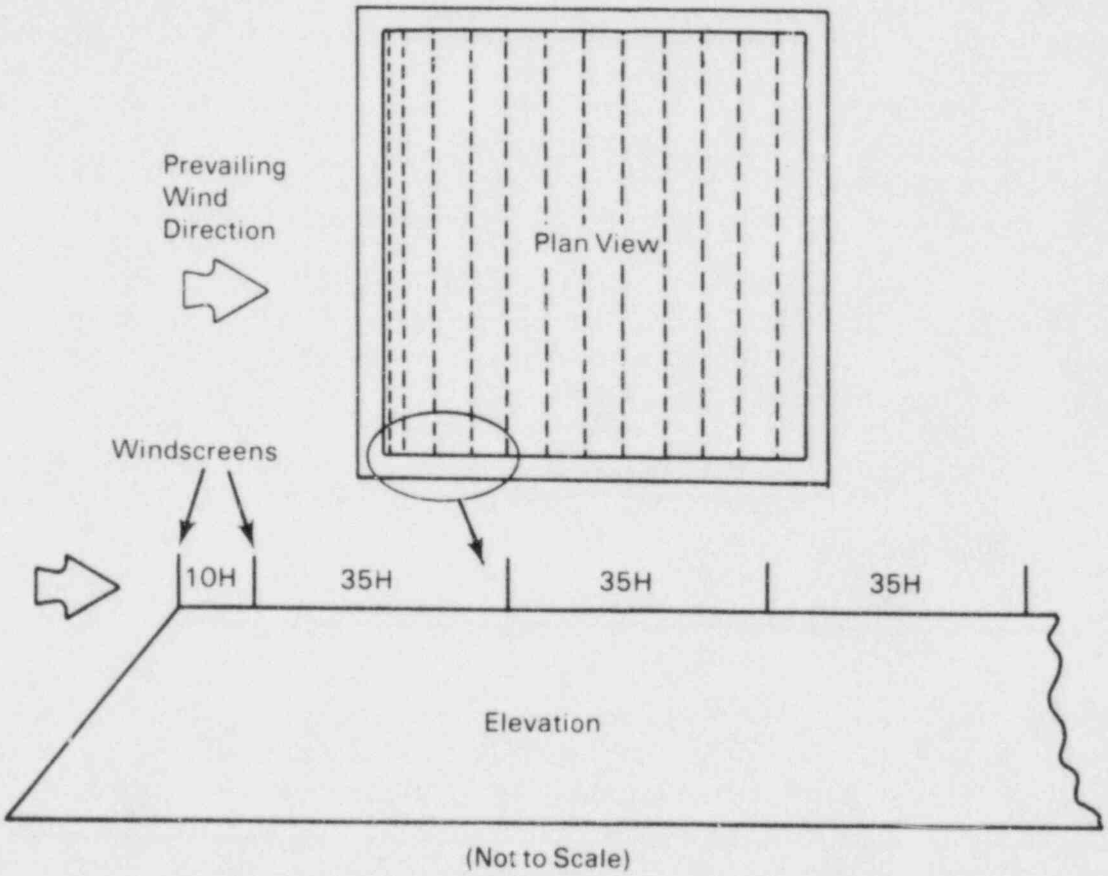


FIGURE 16. Windscreen Layout on a Hypothetical Tailings Pile. The spacings shown are for the Dusttamer windscreen.

hypothetical tailings pile with the wood-slat snow fence would require 21 parallel rows or 13,360 m of fence. At an installed cost of $4.40/m the total cost of this system would be $58,800 or $1450/ha.

This portion of the cost analysis indicates that the least costly screen would be the wood-slat snow fence. However, the relative durability of each screen has not yet been considered. Results of the durability test in Wyoming show that the wood-slat fence would require significantly more maintenance than the other two. And, because the poor field performance of the Dusttamer was apparently due to problems with the posts and not the screen, the Dusttamer is expected to last as long or longer than the DuPont Canada L-300. The Dusttamer and the L-300, if properly installed, would last for 5 years with minimal maintenance. The wood-slat snow fence would require more maintenance, and is expected to last only 3 years, based on observations made from the durability test. The maintenance cost is assumed for this example to be 5% of the installed cost for the Dusttamer and the L-300, and 20% for the wood-slat snow fence.

The total costs of these windscreen systems based on the installed cost and maintenance cost for the 40.5-ha tailings pile are:

- Julius Koch Dusttamer - $94,480 or $467/ha/yr
- DuPont Canada L-300 - $139,940 or $690/ha/yr
- wood-slat snow fence - $156,784 or $774/ha/yr.

Details and results of this cost analysis are presented in Table 6.

The cost for a windscreen system using a taller 1.8-m windscreen may be somewhat lower since the installation costs of fewer rows might be lower. (It is assumed that a 1.8-m screen would require about the same time and effort to construct as a 1.2-m screen of the same length.) Screens much taller than 1.8 m would become increasingly expensive due to mounting requirements, and would be impractical unless other circumstances, such as the need for large open areas of the tailings pile for additional slurry deposition, would justify the taller windscreens.

DISCUSSION

Although the initial cost of a windscreen system may be greater than that of some chemical stabilizers, the long-term (3 to 5 years) cost would probably be less, even including maintenance costs. With proper maintenance most windscreen systems should last a minimum of three to five years. The estimated annual cost for windscreen systems for the hypothetical tailings pile range from $16,000 to $30,000 per year. These estimated costs are substantially lower than the expected annual cost to chemically stabilize the 40-ha site, which ranges from $68,000 to $760,000. As shown in Figure 17, the estimated

TABLE 6. Cost Analysis for Windscreen Installations on a Hypothetical Tailings Pile for a Five-Year Wind Erosion Control Program

	Screen Type		
	Julius Koch Dusttamer	DuPont Canada L-300	Wood-Slat Snow Fence
Screen height	1.2 m	1.2 m	1.2 m
50% Isotach	10 H	5 H	6 H
100% Isotach	35 H	20 H	26 H
Screen spacing(a)			
2nd row at	12 m	6 m	7 m
Other rows at	42 m	24 m	31 m
Total screen	15 rows	27 rows	21 rows
	9,540 m	17,170 m	13,360 m
Life expectancy	5 yr	5 yr	3 yr
Estimated Costs, 1984 dollars			
Screen	$6.30/m	$4.35/lin. m	$2.60/lin. m
Posts	$0.60/m(b)	$0.30/m(c)	$0.30/m(c)
Labor	$1.00/m	$1.50/m	$1.50/m
Total cost	$7.90/lin. m	$6.15/lin. m	$4.40/lin. m
	or $75,400	or $105,600	or $58,800
General maintenance costs over life of system	$0.40/m/yr(d) or $19,080	$0.40/m/yr(d) or $34,340	$0.88/m/yr(e) or $35,270
Total	$467/ha/yr	$691/ha/yr	$774/ha/yr
	$94,480 (5 yr)	$139,940 (5 yr)	$156,784 (5 yr)

(a) First row of windscreens at windward edge of tailings pile.
(b) Based on a 10-m spacing between posts and a cost of $6.00/post.
(c) Based on a 10-m spacing and a cost of $3.00/post.
(d) Based on 5% of the installed cost per year.
(e) Based on 20% of the installed cost per year.

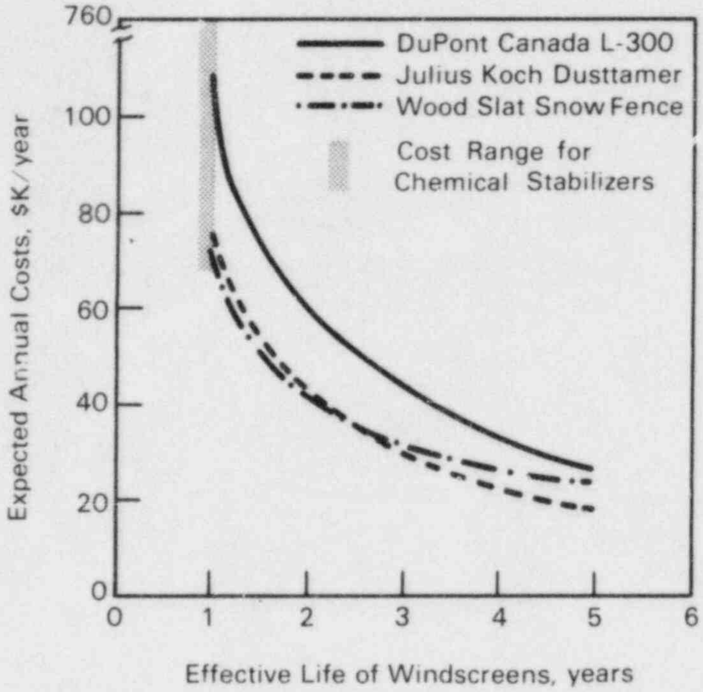


FIGURE 17. Total Cost per Year Versus the Expected Life of Windscreen Systems for the Hypothetical 40-ha Tailings Pile. The vertical bar at year one is the range of costs for tested chemical stabilizers.

annual cost for windscreens would still be lower than for the chemical stabilizers if their effective life were at least more than one year. Other factors can also make the choice of a windscreen system more attractive than chemical stabilization. For instance, some windscreen systems may be considered capital investments for many companies, which then may qualify for investment tax credits. Also, new tax laws may allow depreciation of the system costs over a period of a few years. Chemical dust suppressants do not afford the same tax incentives. The major drawback to windscreens is the complexity and increased costs of installation for a site where strong winds occur from more than one direction. For such a site, surface stabilization may be the only practical alternative.

These comparisons of chemical stabilizers and windscreens for wind erosion protection of tailings piles are highly simplified. The assumptions made for these examples are, however, not unrealistic, but certainly much more information would have to be considered to make a proper selection of the most cost effective method for a specific site. This analysis does serve to illustrate that the use of a windscreen system (a relatively new technology for wind erosion control) may be more cost effective than the more conventional method of chemical stabilization. Under certain circumstances, careful analysis for a particular site may indicate that some combination of chemicals and windscreens may provide the optimal method of erosion control.

REFERENCES

Bagnold, R. A. 1954. The Physics of Blown Sand and Desert Dunes. Methuen and Co., London, England.

Belly, P. 1964. Sand Movement by Wind. Defense Documentation Center for Scientific and Technical Information.

Billman, B. J. 1984. "Windbreak Effectiveness for the Control of Fugitive Dust Emissions from Storage Piles--A Wind Tunnel Study." Presented at the Fifth Symposium on the Transfer and Utilization of Particulate Control Technology, Kansas City, Missouri.

Dean, K. C., and R. Havens. 1973. "Comparative Costs and Methods for Stabilization of Tailings." In Tailings Disposal Today, Proceedings of the International Tailings Symposium, Miller Freeman Publications, San Francisco, California.

Drehmel, D. C., B. E. Daniel, and D. Carnes. 1982. "Relative Effectiveness of Chemical Additives and Windscreens for Fugitive Dust Control." Environmental Progress 1(1):16-20.

Elmore, M. R. and J. N. Hartley. 1983. Field Testing of Fugitive Dust Control Techniques at a Uranium Mill Tailings Pile - 1982 Field Test, Gas Hills, Wyoming. NUREG/CR-3510, PNL-4798, Pacific Northwest Laboratory, Richland, Washington.

Elmore, M. R., and J. N. Hartley. 1984. Laboratory Testing of Chemical Stabilizers for Control of Fugitive Dust Emissions from Uranium Mill Tailings Piles. NUREG/CR-3697, PNL-5025, Pacific Northwest Laboratory, Richland, Washington.

Gillette, D. A. 1973. "On the Production of Soil Wind Erosion Aerosols Having the Potential for Long-Range Transport." Special Issue of Journal de Researches Atmospheriques, the Nice Symposium of the Chemistry of Sea-Air Particulate Exchange Processes, Nice, France.

Johnson, M. S., and A. D. Bradshaw. 1977. "Prevention of Heavy Metal Pollution from Mine Wastes by Vegetative Stabilization." The Institution of Mining and Metallurgy Transactions, London, England.

Leroy, J. C. 1973. "How to Establish and Maintain Growth on Tailings in Canada--Cold Winters and Short Growing Seasons." In Tailings Disposal Today, Proceedings of the International Tailings Symposium, Miller Freeman Publications, San Francisco, California.

Li, C. T., M. R. Elmore, and J. N. Hartley. 1983. A Review of Fugitive Dust Control for Uranium Mill Tailings. NUREG/CR-2856, PNL-4360, Pacific Northwest Laboratory, Richland, Washington.

Schwendiman, L. C., et al. 1980. *A Field Modeling Study of Windblown Particles from a Uranium Mill Tailings Pile.* NUREG/CR-1407, PNL-3345, Pacific Northwest Laboratory, Richland, Washington.

Tabler, R. D. 1975. "Predicting Profiles of Snowdrifts in Topographic Catchments." In *Proceedings of the Western Conference* 43:87-97.

Tabler, R. D. 1980. "Self-Similarity of Wind Profiles in Blowing Snow Allows Outdoor Modeling." *Journal of Glaciology* 26:94.

Van Eimern, J., et al. 1964. "Windbreaks and Shelterbelts." *World Meteorological Organization Technical Note* No. 59.

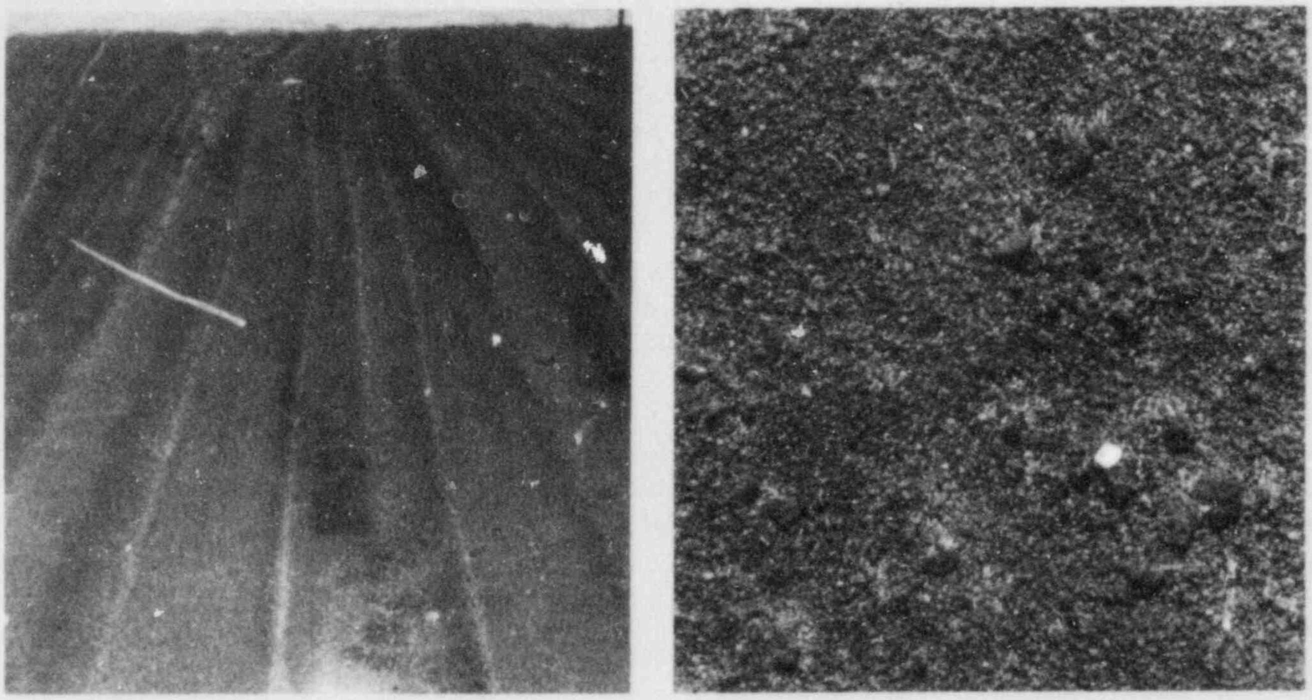
APPENDIX A

TEST PLOTS FOR CHEMICAL STABILIZERS

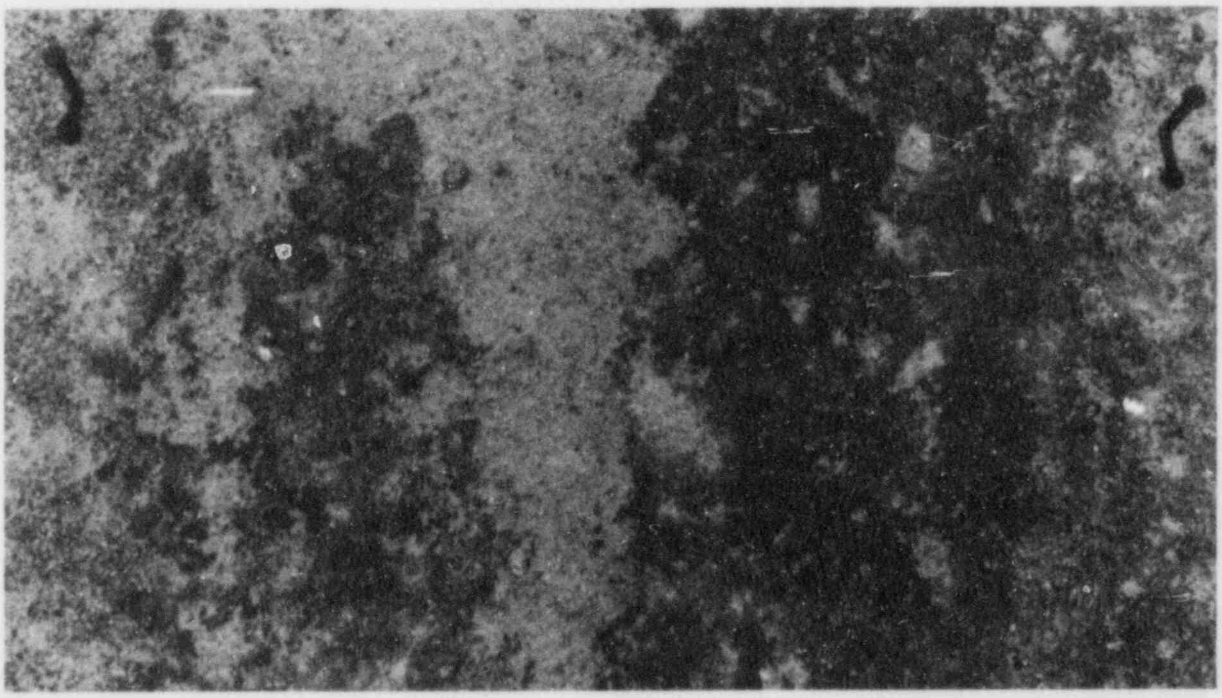
APPENDIX A

TEST PLOTS FOR CHEMICAL STABILIZERS

This appendix shows the test plots of the chemical stabilizers applied and tested during the 1983 field test at the Wyoming site. The top photograph shows the surface of the test plot soon after application of the stabilizers. The bottom photograph shows the condition of the stabilized surface after nine months of exposure. Both of the new products, Retain and Soil Sement, weathered extensively compared to the Wallpol 40-133, which was applied to provide a reference for the stabilizers evaluated during the previous year's test.



(a)



(b)

FIGURE A.1. Surface of Test Plot Treated with Retain: (a) soon after application; (b) after nine months of exposure.

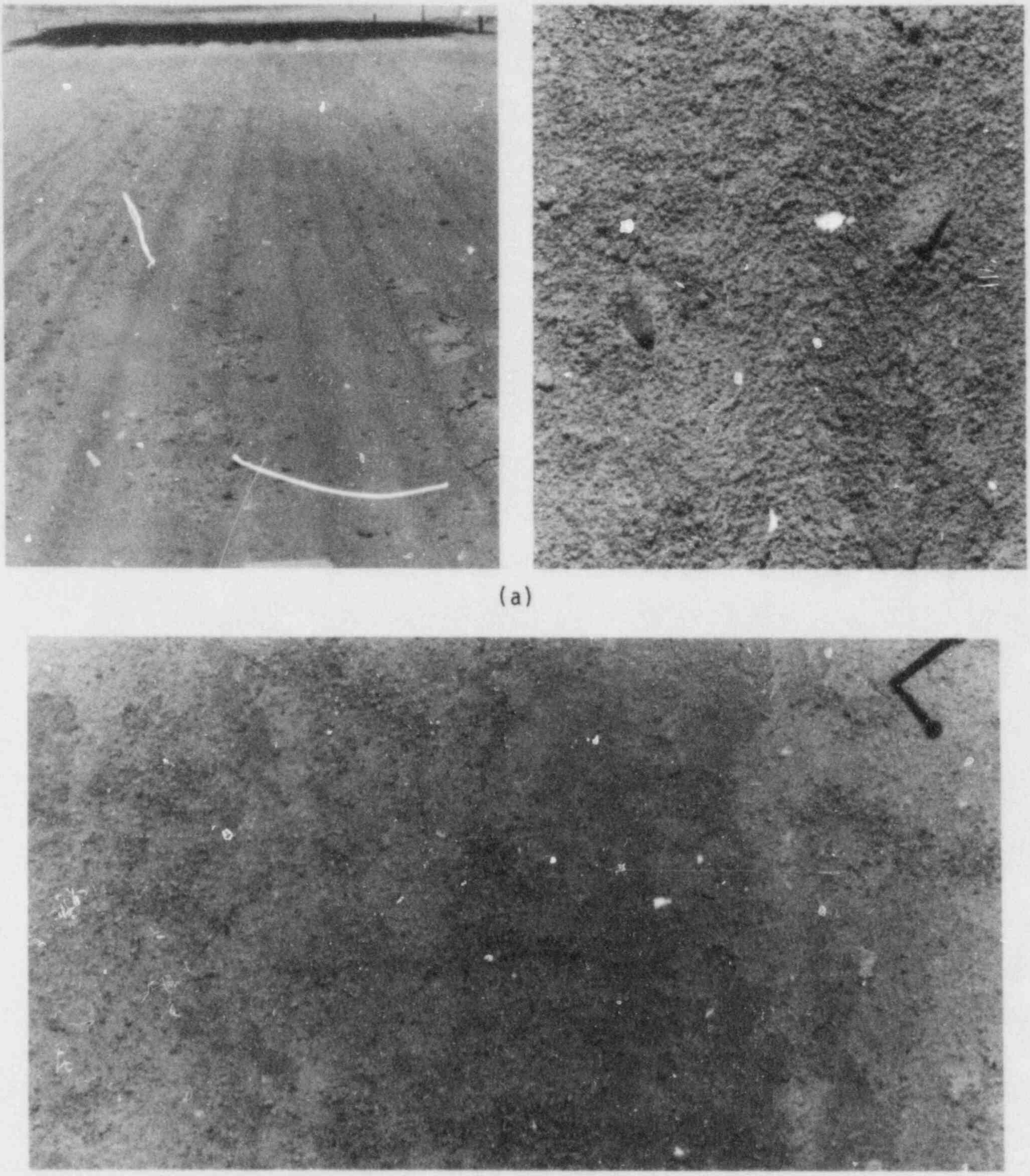
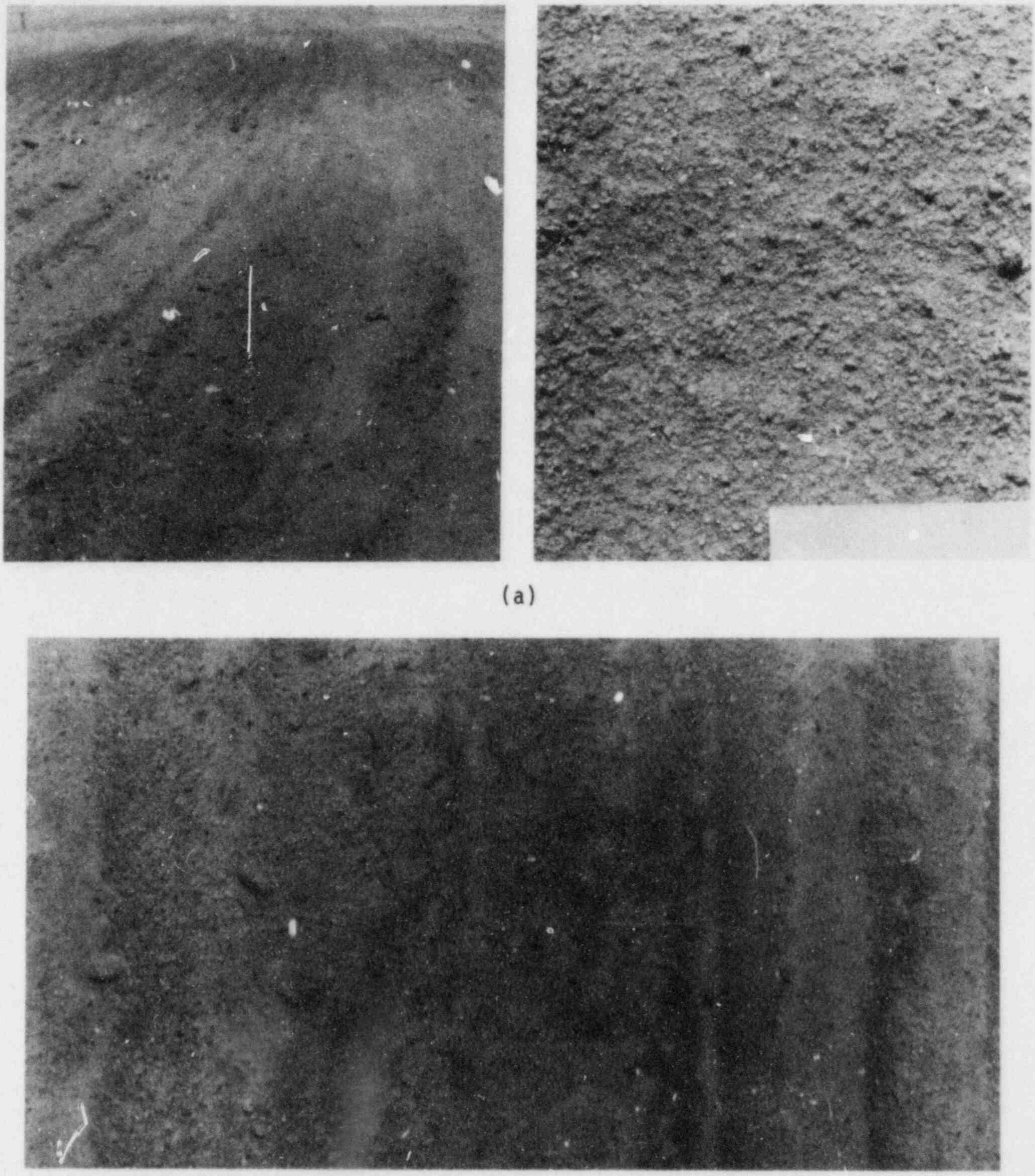


FIGURE A.2. Surface of Test Plot Treated with Soil Sement: (a) soon after application; (b) after nine months of exposure.



(a)

(b)

FIGURE A.3. Surface of Test Plot Treated with Wallpol 40-133: (a) soon after application; (b) after nine months of exposure. There was very little degradation compared with the other two products.

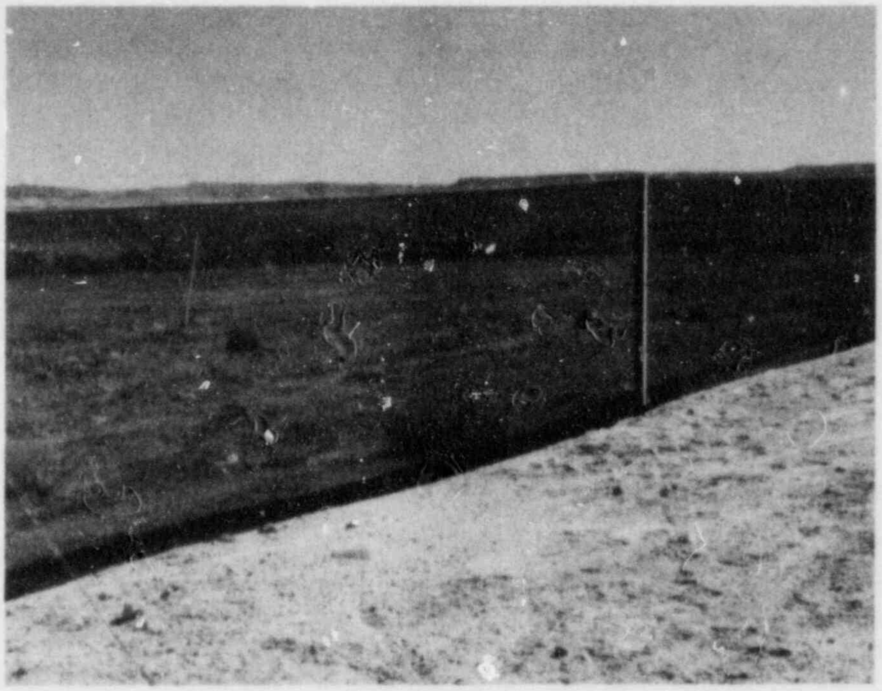
APPENDIX B

TEST PLOTS FOR WINDSCREENS

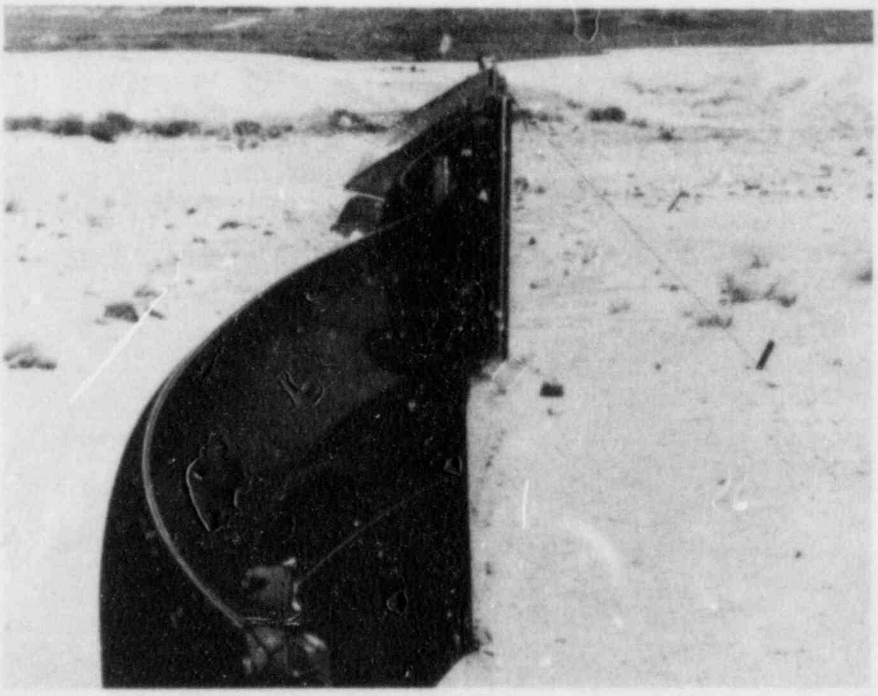
APPENDIX B

TEST PLOTS FOR WINDSCREENS

This appendix includes photographs of the eight windscreen test panels installed at the Wyoming field-test site. The top photograph on each page was taken at the time the test panels were constructed. The bottom photographs were taken nine months later, illustrating the relative durability of each material. Durability of the tested screens ranged from good (no obvious degradation) to poor (significant degree of tearing or breaking).

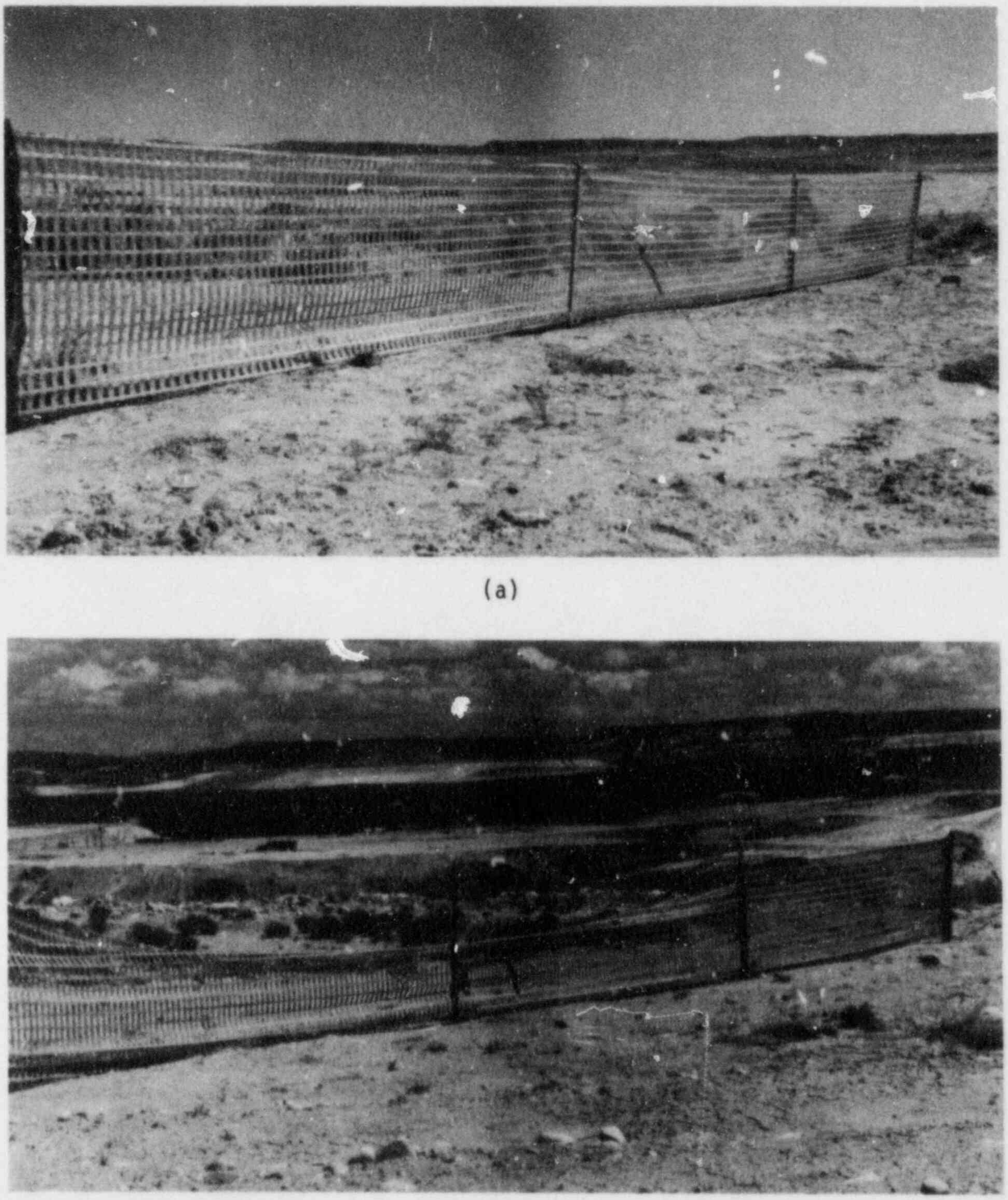


(a)



(b)

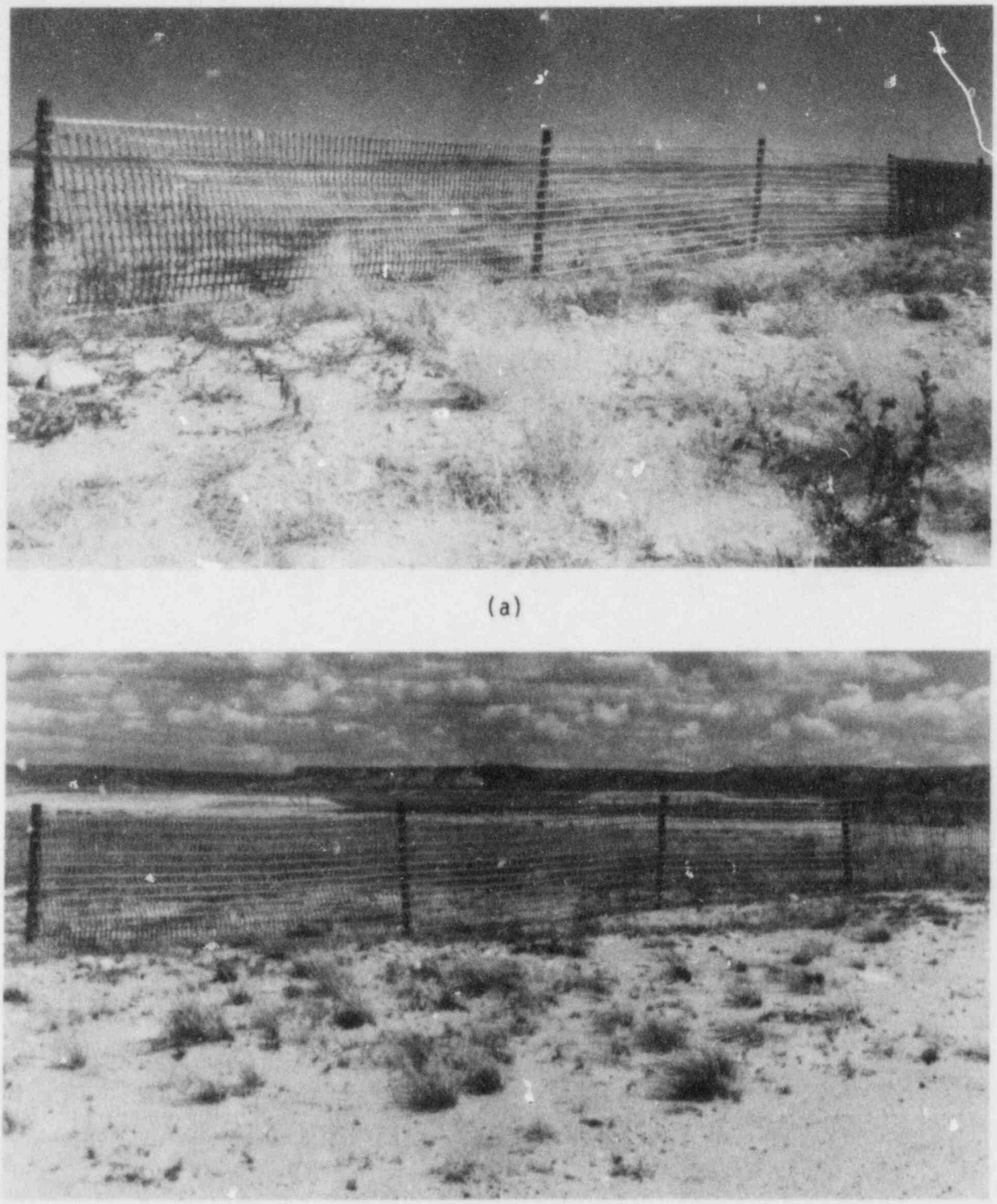
FIGURE B.1. Agrinet Wind/Shade Screen (a) as installed; (b) after nine months of weathering. The screen showed no significant degradation but stretched more than the other tested materials.



(a)

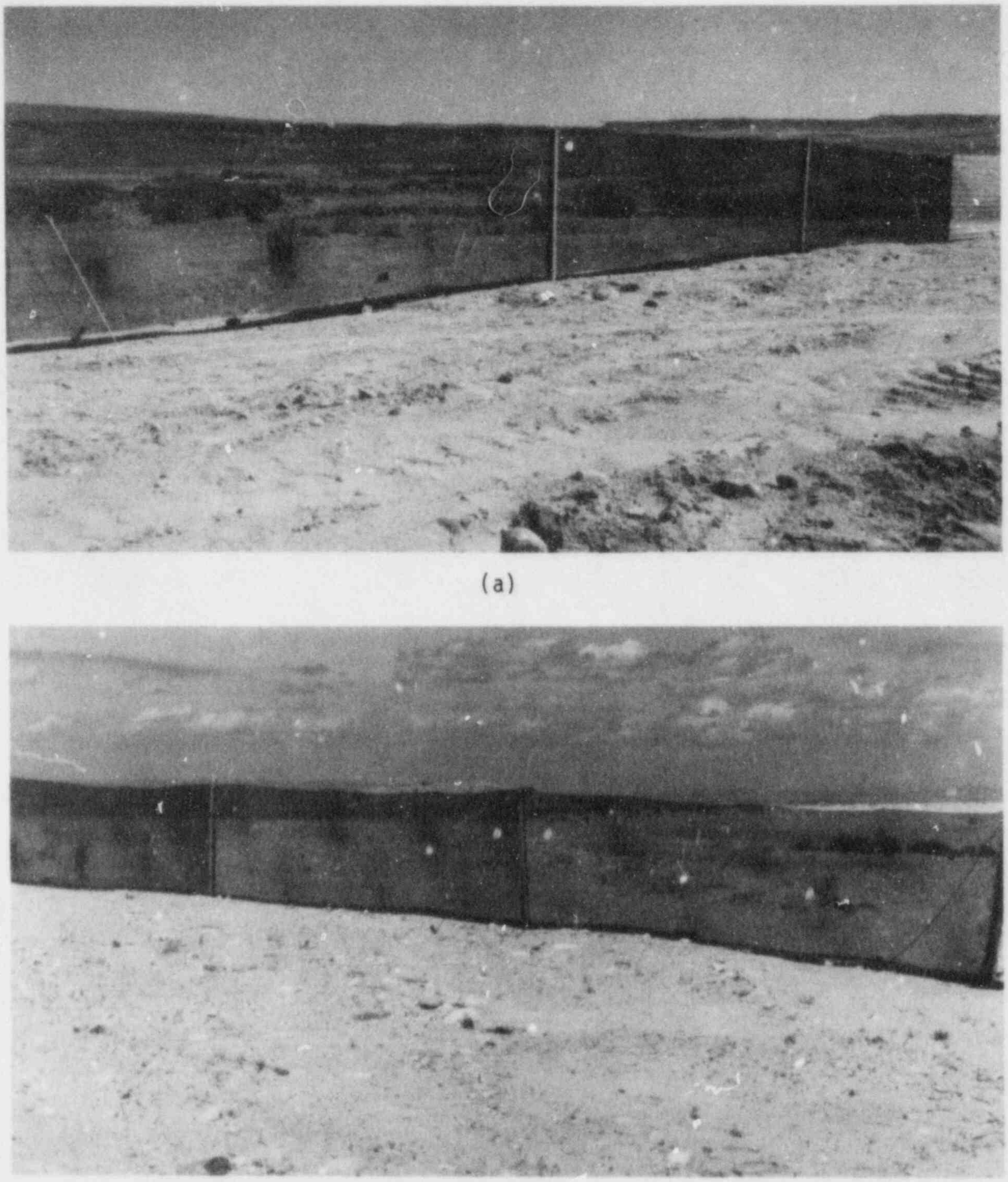
(b)

FIGURE B.2. Athalon Snow Fence (a) as installed; (b) after nine months of weathering. The screen tore at several of the high stress points where it was attached to the fence posts.


(a)

(b)

FIGURE B.3. DuPont Canada L-300 Windscreen/Snow Fence (a) as installed; (b) after nine months of weathering. This screen showed the best durability of the tested materials.

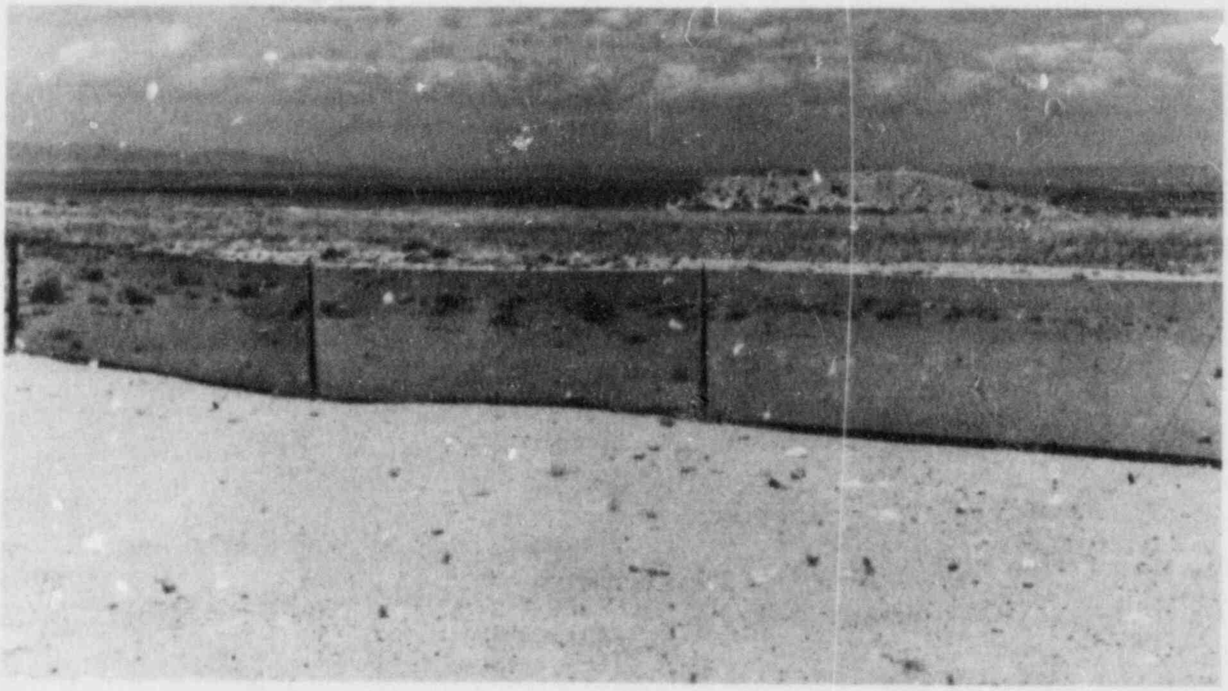


(a)

(b)

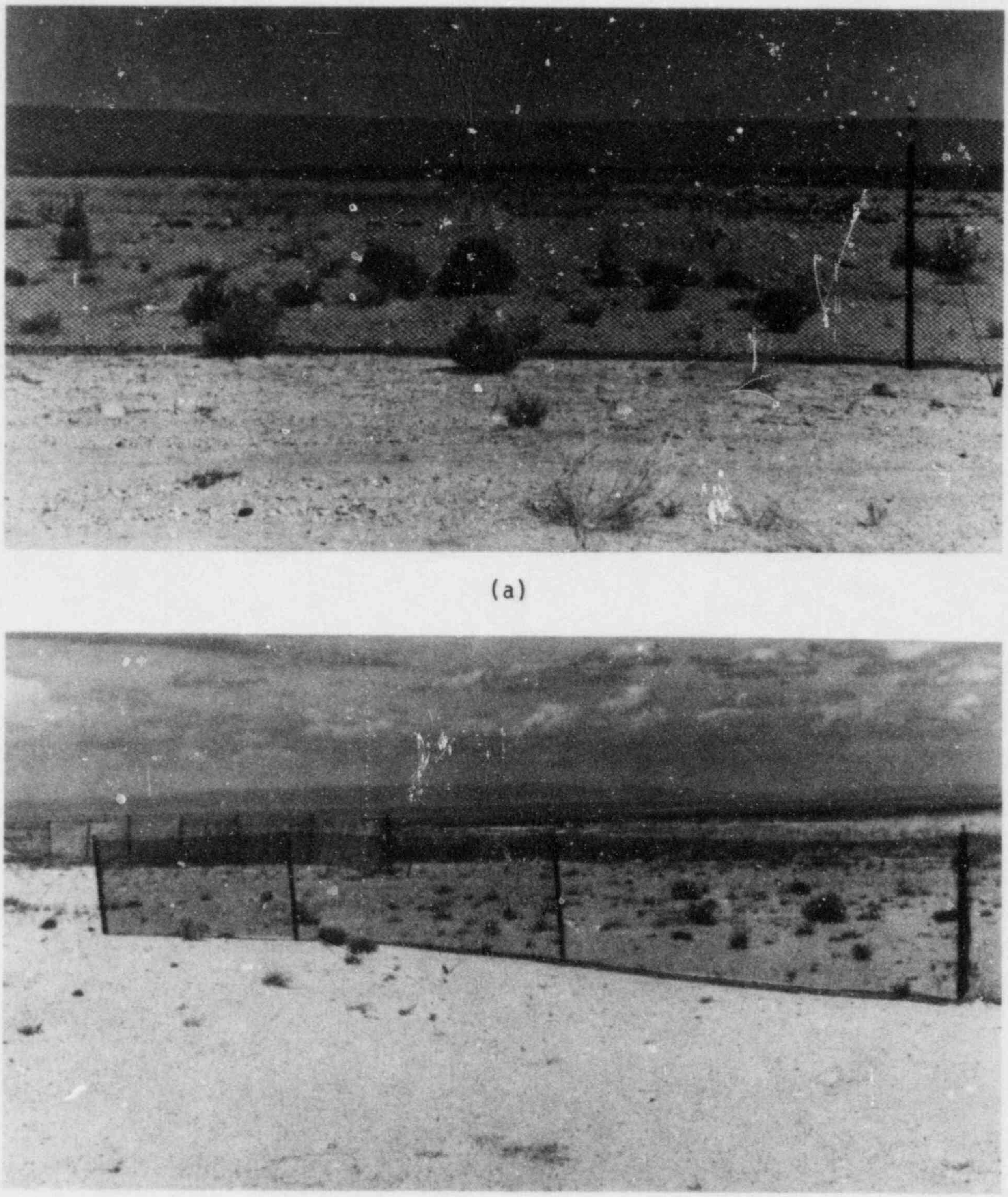
FIGURE B.4. DuPont Canada L-36 Windscreen (a) as installed; (b) after nine months of weathering. The material showed good durability, but with slightly more stretching than other DuPont screens.

(a)



(b)

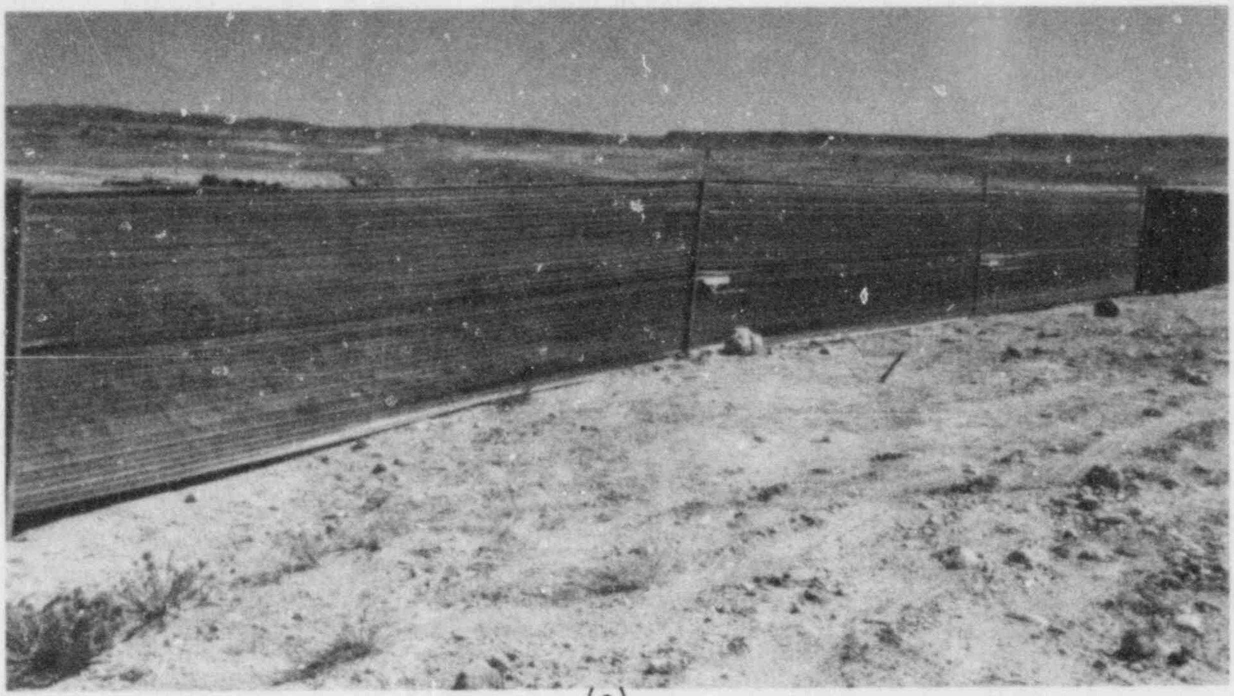
FIGURE B.5. DuPont Canada CE-121 Windscreen (a) as installed; (b) after nine months of weathering. This material had stretched a minor amount, but showed no other signs of degradation.



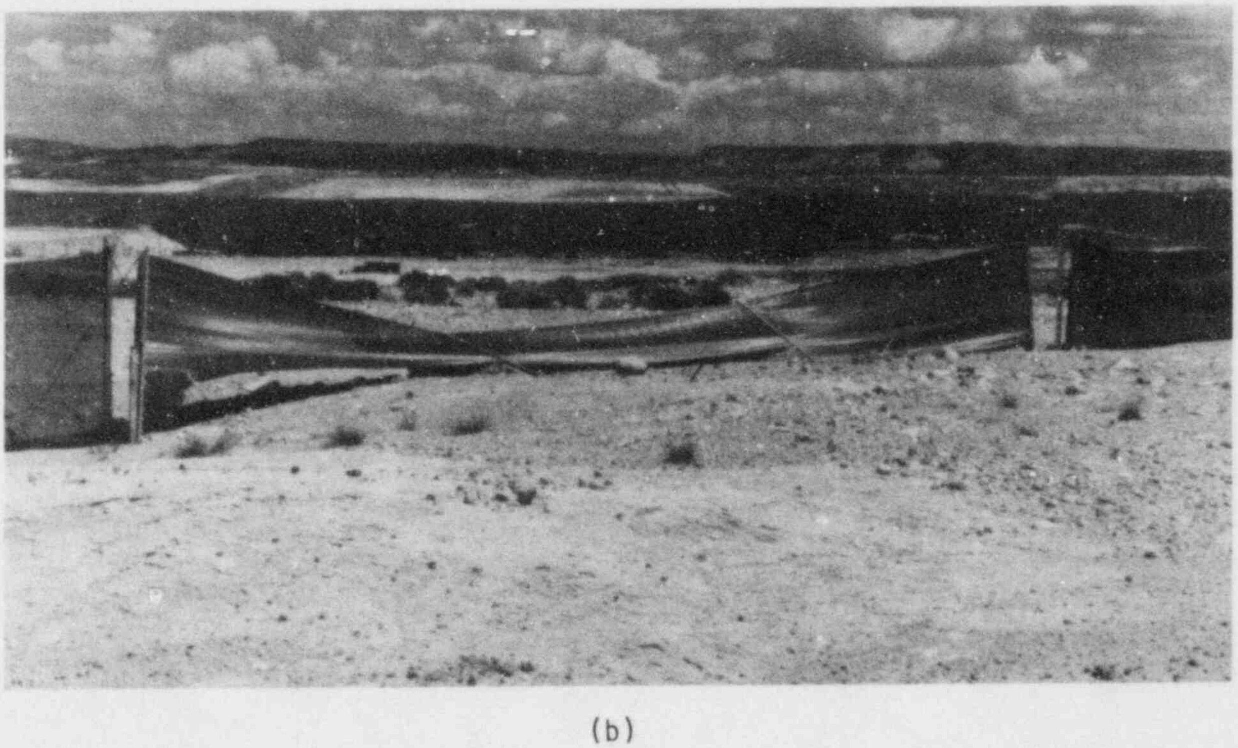
(a)

(b)

FIGURE B.6. DuPont Canada L-38 Windscreen (a) as installed; (b) after nine months of weathering. The material showed very little stretching or other degradation after the exposure period.



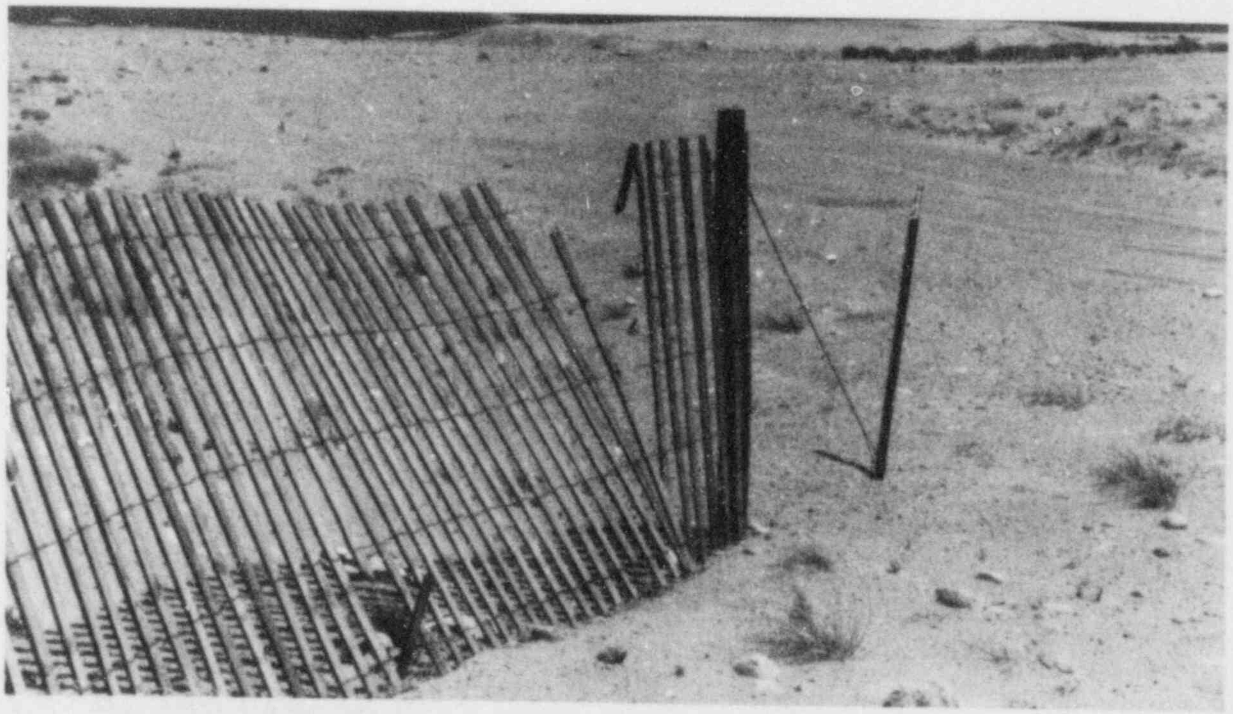
(a)



(b)

FIGURE B.7. Julius Koch Dusttamer Windscreen (a) as installed; (b) after nine months of weathering. Collapse of the test panel was due to failure of special aluminum posts, not the windscreen material.

(a)



(b)

FIGURE B.8. Wood-Slat Snow Fence (a) as installed; (b) after nine months of weathering. Note both the broken wood slats and wires.

NUREG/CR-4089
PNL-5340
RU

DISTRIBUTION

No. of
Copies

OFFSITE

U.S. Nuclear Regulatory
Commission
Division of Technical
Information
and Document Control
7920 Norfolk Avenue
Bethesda, MD 20014

E. F. Conti
Office of Nuclear Regulatory
Research
U.S. Nuclear Regulatory
Commission
Mail Stop 1130-SS
Washington, DC 20555

G. Gnugnoli
Office of Nuclear Material
Safety and Safeguards
U.S. Nuclear Regulatory
Commission
Mail Stop 1130-SS
Washington, DC 20555

5 F. Swanberg, Jr.
Office of Nuclear Regulatory
Research
U.S. Nuclear Regulatory
Commission
Mail Stop 1130-SS
Washington, DC 20555

D. Lewis
Jacobs Engineering Group, Inc.
5301 Central Ave. NE
Suite 1700
Albuquerque, NM 87108

No. of
Copies

M. Matthews
Uranium Mill Tailings Remedial
Action Project
5301 Central Ave. NE
Suite 1700
Albuquerque, NM 87108

R. D. Tabler
Rocky Mtn. Range and Forest
Experiment Station
222 So. 22nd Street
Laramie, WY 82070

E. J. Cos
American Nuclear Corp.
Gas Hills Project
P.O. Box 1520
Riverton, WY 82501

R. Lawrence
KPN International, Inc.
19 Pebble Road
Newtown, CT 06470

FOREIGN

D. R. Davy
Chief, Environmental Science
Division
Australian Atomic Energy
Commission
Lucas Heights Research
Laboratory,
Private Mail Bag
Sutherland, NSW, Australia 2232

V. C. Haw
Director, National Uranium
Tailings Program
555 Booth Street
Ottawa, Canada K1A0G1

No. of
Copies

ONSITE

50 Pacific Northwest Laboratory

T. D. Chikalla
M. R. Elmore (20)
M. G. Foley
G. W. Gee
R. K. Hadlock
J. N. Hartley (15)
A. C. Leslie
P. C. Walkup
W. H. Walters
P. L. Whiting
Publishing Coordination (2)
Technical Information (5)

NRC FORM 335
(11-81)

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

1. REPORT NUMBER (Assigned by DDC)
NUREG/CR-4089
PNL-5340

4. TITLE AND SUBTITLE (Add Volume No., if appropriate)
Evaluation of Field-Tested Fugitive Dust Control Techniques for Uranium Mill Tailings Piles

2. (Leave blank)

3. RECIPIENT'S ACCESSION NO.

7. AUTHOR(S)
M. R. Elmore, J. N. Hartley

5. DATE REPORT COMPLETED
MONTH December | YEAR 1984

DATE REPORT ISSUED
MONTH January | YEAR 1985

9. PERFORMING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)
Pacific Northwest Laboratory
P. O. Box 999
Richland, Washington 99352

6. (Leave blank)

8. (Leave blank)

12. SPONSORING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)
Division of Radiation Programs and Earth Sciences
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555

10. PROJECT/TASK/WORK UNIT NO.
TD 1288

11. FIN NO.
B2370

13. TYPE OF REPORT
Final

PERIOD COVERED (Inclusive dates)
September 1983--June 1984

15. SUPPLEMENTARY NOTES

14. (Leave blank)

16. ABSTRACT (200 words or less)

Seventeen chemical stabilizers, rated as the most promising of those tested in earlier laboratory studies, were applied to test plots on a uranium mill tailings pile at the American Nuclear Corporation-Gas Hills Project mill site in central Wyoming. The durability of these materials when exposed to actual site conditions was evaluated over time. In addition, eight commercially available windscreens were field tested. Test panels of the eight materials were constructed at the Wyoming site to compare their relative resistance to weathering. A second test was conducted near Pacific Northwest Laboratory to evaluate the effectiveness of the windscreens at reducing wind velocity. Results of the field tests on the chemical stabilizers and windscreens are presented in this report, along with effectiveness-versus-cost information. Direct comparison of these two dust control methods is difficult due to the dependence of each on site-specific factors. However, simplified model case studies were developed to assess the cost of chemical stabilization versus windscreen systems for a hypothetical, inactive tailings pile.

17. KEY WORDS AND DOCUMENT ANALYSIS
uranium mill tailings
fugitive dust
chemical stabilization
windscreen

17a. DESCRIPTORS

17b. IDENTIFIERS/OPEN-ENDED TERMS

18. AVAILABILITY STATEMENT
Unlimited

19. SECURITY CLASS (This report)
Unclassified

20. SECURITY CLASS (This page)
Unclassified

21. NO. OF PAGES

22. PRICE
$

NRC FORM 335 (11-81)

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300

NUREG/CR-4089

EVALUATION OF FIELD-TESTED FUGITIVE DUST CONTROL TECHNIQUES
FOR URANIUM MILL TAILINGS PILES

JANUARY 1985

120555078877 1 1AN1RU
US NRC
ADM-DIV OF TIDC
POLICY & PUB MGT BR-PDR NUREG
W-501
WASHINGTON DC 20555