Standard Guide for Ecological Considerations for the Use of Bioremediation in Oil Spill Response—Sand and Gravel Beaches[1]

This standard is issued under the fixed designation F 1481; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide covers considerations and recommendations for the use of biodegradation enhancing (bioremediation) agents to assist in minimizing the impact of oil spills on sand and gravel beaches. Aesthetic and socioeconomic factors are not considered, although these and other factors are often important in spill response.

1.2 This is a general guide only, which assumes that the oil is biodegradable and that the bioremediation agent selected can be used safely (in terms of ecological impact and human health) and effectively when applied correctly and used in compliance with relevant government regulations. Oil considered for bioremediation includes crude oils and certain refined petroleum products.

1.3 This guide addresses the application of bioremediation agents alone or in conjunction with other technologies.

1.4 This guide applies to freshwater, estuarine, and marine beach environments.

1.5 In making bioremediation-use decisions, appropriate government authorities must be consulted as required by law.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* In addition, it is the responsibility of the user to ensure that such activity takes place under the control and direction of a qualified person with full knowledge of any potential or appropriate safety and health protocols.

2. Terminology

2.1 *Definitions:*

2.1.1 *aerobes*—organisms that require air or free oxygen for growth.

2.1.2 *anaerobes*—organisms that grow in the absence of air or oxygen, and do not use molecular oxygen in respiration.

2.1.3 *bioaugmentation*—addition of microorganisms (predominantly bacteria) to amplify the biodegradation rate of target pollutants.

2.1.4 *biodegradation*—chemical alteration and breakdown of a substance to usually smaller products caused by microorganisms or their enzymes.

2.1.5 *bioremediation agents*—inorganic and organic compounds and microorganisms that enhance biological degradation processes, predominantly microorganismal.

2.1.6 *biostimulation*—addition of limiting nutrients to enhance the rate of biodegradation of target pollutants by indigenous species (predominantly bacteria).

2.1.7 *ecosystem*—organisms and the surrounding environment combined in a community that is self-supporting.

2.1.8 *identification*—process of designating an unknown organism by comparing it with known organisms.

2.1.9 *indigenous*—native to a given habitat or environment.

2.1.10 *marine*—relating to the ocean.

2.1.11 *methemoglobinemia*—acquired blood disorder leading to oxygen deprivation, stupor, and death from exposure to nitrates in drinking water.

2.1.12 *nutrient*—a substance that supports organismal growth.

2.1.13 *refined petroleum products*—products derived by way of various treatment processes from crude oil, a highly complex mixture of paraffinic, cycloparaffinic, and aromatic hydrocarbons that contain a low percentage of sulphur and trace amounts of nitrogen and oxygen compounds. Hydrocarbon products made from the refining of crude oils are specified in Section 5 of the Annual Book of ASTM Standards.[2]

2.1.14 *species*—a taxonomic category characterized by individuals of the same genus that are mutually similar and are able to interbreed.

2.1.15 *toxicity*—the property of a material, or combination of materials, to adversely affect organisms.

3. Significance and Use

3.1 The purpose of this guide is to provide remediation managers and spill response teams with guidance on an alternate means (called bioremediation) of safely and effectively cleaning up oil spills on beaches that takes advantage of natural microbial degradation processes.

[1] This guide is under the jurisdiction of ASTM Committee F–20 on Hazardous Substances and Oil Spill Responseand is the direct responsibility of Subcommittee F20.24on Bioremediation and Safety Audit.

Current edition approved May 15, 1994. Published July 1994. Originally published as F 1481 – 93. Last previous edition F 1481 – 93.

[2] *Annual Book of ASTM Standards*, Vols 05.01, 05.02, 05.03, 05.04, and 05.05.

3.2 This guide can be used in conjunction with other ASTM guides addressing oil spill response operations.

4. General Considerations for Making Bioremediation-Use Decisions

4.1 Bioremediation has been used primarily as a longer-term beach treatment tool as opposed to a first response tool.

4.2 Bioremediating a site on an oiled beach usually involves minimal physical disruption of the site **(1)**.[3]

4.3 Bioremediation may work faster than natural biodegradation and appears to have few adverse affects when used correctly **(1)**. Therefore, it may be useful in helping to remove some of the toxic components of petroleum (for example, low to medium molecular weight aromatic hydrocarbons) from a spill site more quickly (weeks to months) than they might otherwise be removed (years). Bioremediation will be somewhat less effective (month to years) in removing the high molecular weight components (for example, polynuclear aromatic hydrocarbons) from stranded oil.

4.4 Biodegradation rates are significantly reduced in anaerobic beach environments.

4.5 Bioremediation performance is particularly dependent upon the efficiency of the petroleum hydrocarbon degrading bacteria indigenous to an area or added as in bioaugmentation in degrading oil; the availability of rate-limiting nutrients; and the susceptibility of the target crude oil or refined product to microbial degradation.

4.6 Bioremediation must be carried out under the guidance of qualified personnel that understand both the chemical as well as the safety and health aspects of site activities.

4.7 Bioremediation may show improvement over natural weathering in lightly oiled beaches. Heavily oiled beaches require greater cleanup time than lightly oiled beaches, and are more amenable to bioremediation after removal of the gross contamination.

5. Sand and Gravel Beach Environments

5.1 Characteristics of beach environments can affect the transport and fate of oil, which will affect the use of bioremediation agents.

5.2 Sand beaches vary widely in their grain size, width, slope, origin, exposure to waves, and sediment transport patterns. Sand beaches can be divided into two basic types: fine grained and coarse grained. The compact sediments of fine-grained sand beaches (grain sizes range between 0.0625 and 0.25 mm) prevent deep (less than 10 cm) penetration of oil. Asphalt pavement formation is likely in sheltered areas where oil accumulation is heavy. The grain size of sediments on coarse-grained sand beaches ranges between 0.25 and 2 mm. The more porous sediments allow penetration of oil up to 25 cm. Oil layers can be buried much deeper into the beach face by clean sand by repeated episodes of deposition over time. While fine-grained sand beaches support low to moderate infaunal densities, coarse-grained sand beaches do not generally support a rich biological community **(2)**.

[3] The boldface numbers in parentheses refer to references at the end of this practice.

5.3 Gravel refers to a wide range of grain sizes and is further divided into classes as follows: granule (2–4 mm); pebble (4–64 mm); cobble (64–256 mm); and boulder (256 mm and larger). Boulder beaches can support dense epifaunal communities. In terms of the fate of spilled oil, gravel beaches have high porosity and permeability that allow deep penetration from the surface. These beaches also have a high potential for oil burial through buildup. Asphalt pavement formation is likely in sheltered areas where accumulation is heavy **(2)**.

6. Background

6.1 Approaches to bioremediation for oil spill response include biostimulation, the addition of limiting nutrients to stimulate indigenous microorganisms, and bioaugmentation, the addition of contaminant-degrading microorganisms. As a precaution, it should be noted that nutrient components may be toxic or harmful to plants, animals and humans, and that non-indigenous species may at least temporarily alter the indigenous microbial ecological balances. Water effluent nitrate nitrogen levels in drinking water must be avoided to diminish risks of anemias such as methemoglobinemia. Similarly, excessive ammonium nitrogen levels should be avoided because they can adversely affect fish and invertebrates, the latter of more concern since many are immobile and could not avoid the treated area. Therefore, nitrogen and other nutrient levels must be monitored. Instructions to ensure safety and effective product use should be established by the manufacturer for each product, and specific instructions followed by the product user. No adverse environmental effects have been associated with field applications of nutrients or bioaugmentation products.

6.2 Biostimulation has been shown to be effective in enhancing biodegradation of oil on beaches. Biostimulation employs the addition of appropriate nutrients (for example, nitrogen, phosphorous, micro-nutrients, oxygen, and so forth) which may have been limiting. This approach may lead to increases in the rate of degradation if microbial degraders of the target contaminant are present in the beach material or purging waters. In some cases there may not be an indigenous contaminant-degrading population to stimulate. This may be the case in pristine environments where there has not been adequate time for the degraders to evolve. Biostimulation is time demanding, as an initial lag period is required for natural selection of degraders. As a precaution, it should be noted that stimulation of pathogenic organisms may also occur. Microorganisms as well as contaminants should be monitored throughout the process.

6.3 Bioaugmentation should prove useful in enhancing biodegradation of oil on beaches. Bioaugmentation generally employs large-scale, on-site production and addition of contaminant-degrading microorganisms usually chosen from stock cultures, predominantly bacterial species. This approach rapidly increases microbe concentrations to levels associated with maximal biodegradation rates. These applications should be characterized with respect to their safety and contaminant degradation activities in various matrix types, temperatures, pH, and inorganic and organic micro- and macroenvironments. Microbes selected must be non-pathogenic and must metabolize the contaminant(s), rendering them harmless. Activities of the amended bacteria need to be well understood and their growth controllable. Microorganisms as well as contaminants should be monitored throughout the process. Assessment of performance of nonnative microorganisms should be determined since they may be less adaptable to environmental changes than indigenous organisms.

6.3.1 Genetically engineered microorganisms, although under development and apparently safe and effective in the laboratory setting, have not yet been authorized for environmental release **(3)**.

6.4 For spills involving crude oil and Nos. 4–6 fuel oils, significant reductions may not occur for several weeks. Distillates (for example, jet fuel, diesel fuel, No. 2 fuel oil) and residual require at least two weeks for significant reductions. Asphalt pavement formations are not amenable to bioremediation treatment.

6.5 Environmental concerns related to bioremediation use include the possibility that the addition of fertilizers could cause eutrophication leading to algal blooms and oxygen depletion; that components of some fertilizers could be toxic to sensitive species or harmful to human health; and that the introduction of nonnative microorganisms could compete with some indigenous species, upsetting ecological balances **(1)**.

6.6 To date, no significant environmental or health problems have been associated with the field applications of bioremediation technologies to marine oil spills **(1)**.

6.6.1 Transient acute toxicity effects, limited to areas immediately adjacent to fertilized beaches, were observed during one of the initial experimental field applications of nutrients following the Exxon Valdez oil spill **(4)**. However, toxicity tests using mysids showed no acute effects in extensive testing conducted during subsequent operational bioremediation treatments **(4)**.

6.6.2 Ammonia levels remained below toxic concentrations following nutrient applications on a fuel oil contaminated beach on Prall's Island, New Jersey, in 1990 **(4)**.

6.6.3 Microorganisms introduced to augment degradation of North Slope crude oil did not result in any significantly greater invertebrate mortality than fertilization alone of crude oil **(5)**.

6.7 A field monitoring program is usually appropriate to establish the efficacy and safety of bioremediation treatment. The following parameters could be included in the monitoring program: visual observations (for example, indigenous species mortality, behavioral effects, appearance changes, and oil distribution), temperature (air and water), salinity, dissolved oxygen, sea state, wind velocity, efficacy samples (water, sediment, and/or beach material), and toxicity samples (water, sediment, and/or beach materials). Water and sediment/beach material samples should be analyzed for oil hydrocarbons, ammonia- and nitrate nitrogens, phosphate, and toxicity (4-day acute or 7-day chronic) **(6)**.

6.7.1 The monitoring of contaminant levels or alterations in contaminant constituents, as well as of biological parameters, would be used to assess any correlations of biological activity and contaminant reduction. Biological activity can be determined by growing site organisms on petri plates. This allows assessment of viable organisms and, if grown using specific organic compounds, can determine their contaminant degradation specificity.

6.7.2 Metabolic products of biological activities can be monitored through sediment, water, and air sampling.

7. Recommendations

7.1 Bioremediation should be considered as one of the potential treatment methods available to site remediation managers once gross quantities of contamination have been removed.

7.2 Bioremediation should only be performed with appropriate technically-qualified personnel, following health and safety protocols for such activity.

7.3 There are time requirements for bioremediation associated with the amount of type of contaminant, and conditions in which the bioremediation agents are applied.

7.4 The selection of appropriate bioremediation agents should form an integral part of most facilities' contingency plans. Before selection is carried out and duly recorded, however, it should be reviewed in terms of efficacy, toxicity, and other potential human and ecological impacts.

7.5 In order to measure success a rigorous monitoring program should be established to determine the natural levels of the contaminant, ammonia- and nitrate nitrogens, phosphate and any associated toxicity in the surrounding areas; contamination levels; and to track the contamination plume. The basic design and elements of the monitoring program should be based on the requirements of methods that will be used to measure efficacy and safety, and the goal of assuring statistical validity of results.

8. Keywords

8.1 beaches; bioremediation; gravel beaches; oil spill response; sand beaches

REFERENCES

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(**4**) Hoff, R., *A Summary of Bioremediation Applications Observed at Marine Oil Spills*, National Oceanic and Atmospheric Administration, Report HMRB 91-2, 1991, p. 30.

(**5**) Atlas, R. M., and Busdosh, M., *Microbial Degradation of Petroleum in the Arctic*, Proceedings of the 3rd International Biodegradation Symposium, Kingston, RI, August 1975, p. 85.

(**6**) Environmental Protection Agency, Region 6 Bioremediation Spill Response Plan, Superintendent of Documents, U.S. Government Printing Office, Washington, DC, 20402, 1992, p. 38 and appendices.