ARTICLE — VOL. 4

Oil-Contaminated Soil and Groundwater Remediation with the Multi-Microbial Consortium Agent Oppenheimer Formula™

Bioaugmentation that tackles oil — a "composite contaminant" — through the teamwork of diverse microbes

BioRangers

• Overview

"Oil" — A Composite Contaminant

"Oil contamination of soil and groundwater" refers to contamination by petroleum products consisting mainly of petroleum hydrocarbons (mineral oils). Petroleum is a "composite (mixture)" of hydrocarbons spanning a wide range — from C1 to C50 or more in carbon number, and from room temperature to over 700°C in boiling point. Because it is intricately separated and blended during the refining process, the composition differs by product — gasoline, kerosene, diesel, heavy oil, lubricating oil and so on — and its chemical formula is said to be "impossible to specify." Effective remediation begins with knowing the "oil."

Target **Oil-contaminated soil and groundwater**	Agent used **Oppenheimer Formula™**
Method **Bioaugmentation**	Final breakdown products **Water and carbon dioxide**

• Concept

Countering "Composite Contamination" with "Composite Microbes"

There are many methods for remediating (treating) oil — thermal treatment, chemical treatment, mobile recovery, excavation removal, solidification and containment, and more — but almost all of them, apart from bioremediation, require secondary waste treatment, consume large amounts of energy to build and operate plants, or turn soil and groundwater strongly acidic or strongly alkaline, imposing high cost and environmental burdens. Bioremediation, by contrast, harnesses microbial activity itself, so it requires little energy input; because it ultimately breaks oil down into water and carbon dioxide, it produces no secondary waste, making it a low-burden method.

Main remediation (treatment) methods for oil contamination
Thermal treatment (heating, incineration ⋯)
Chemical treatment (hydrogen peroxide ⋯)
Lime, ultraviolet light, ozone ⋯
Mobile recovery (washing, gas extraction, pumping ⋯)
Excavation removal (replacement)
Solidification and containment
Bioremediation

Conventional biostimulation (activating indigenous microbes) involves many uncertain factors — whether the relevant microbes are present, in what quantity, and how effective they are — and a single microbe struggles to address "composite contamination." This technology is a bioaugmentation that applies "Oppenheimer Formula," which contains a high concentration of diverse oil-degrading microbes, to the site. Through the interaction (teamwork) of microbial consortia gathered from natural environments around the world, it enables the breakdown of oil — a composite substance — and the handling of diverse contaminants and environments. The idea is: meet "composite contamination" with "composite microbes."

• Track record

The Agent's Track Record and Public Adoption

"Oppenheimer Formula" is an oil-degrading multi-microbial consortium agent developed by Dr. Carl H. Oppenheimer (professor emeritus at the University of Texas), an authority in marine microbiology. It was first used worldwide as a marine oil-spill countermeasure during the crude-oil spill from the 1990 tanker explosion (the Mega Borg) in the Gulf of Mexico, and it is registered as a microbial agent in the U.S. Environmental Protection Agency (EPA) National Contingency Plan (NCP) Product Schedule.

In Japan, its use began experimentally with support from Hyogo Prefecture during the 1997 heavy-oil spill from the tanker Nakhodka, and it was subsequently adopted in numerous public research-and-development grants — the Ministry of the Environment's "Survey on the Development and Dissemination of General-Purpose Groundwater Remediation Equipment" (2001), the Ministry of Economy, Trade and Industry's Rapid-Response Regional Revitalization Consortium R&D; Program (2002), and the Ministry of the Environment's Environmental Technology Verification Model Project (verification number 020-0305 / 2003), among others. In 2006 it was also registered in the Ministry of Land, Infrastructure, Transport and Tourism's NETIS as "Oil Remediation Technology Using a Multi-Microbial Consortium Agent" (registration number KT-060059).

Overseas use record **Over 25 years**	Domestic remediation record **Over 500 projects in 20 years**
Main targets **BTEX-type fuel-oil contamination at petroleum-related facilities**	EPA registration **NCP Product Schedule**

Remediation Case Studies — Class-A Heavy Oil and Machine Oil

Case ① (Class-A heavy oil): A Class-A heavy-oil leak from the fuel piping of a general factory came to light when an oil sheen was spotted on the pond of an adjacent park. The volume of contaminated soil was about 20,000m³, and a condition of the work was that the trees within the park not be felled. The greater part was treated by in-situ remediation (injecting a mixed solution of the multi-microbial consortium agent, nutrients, and an essential-element aqueous solution, combined with bioventing to promote gas exchange), while the excavatable portion was treated by landfarming (blending, mixing and curing the solution into the soil).

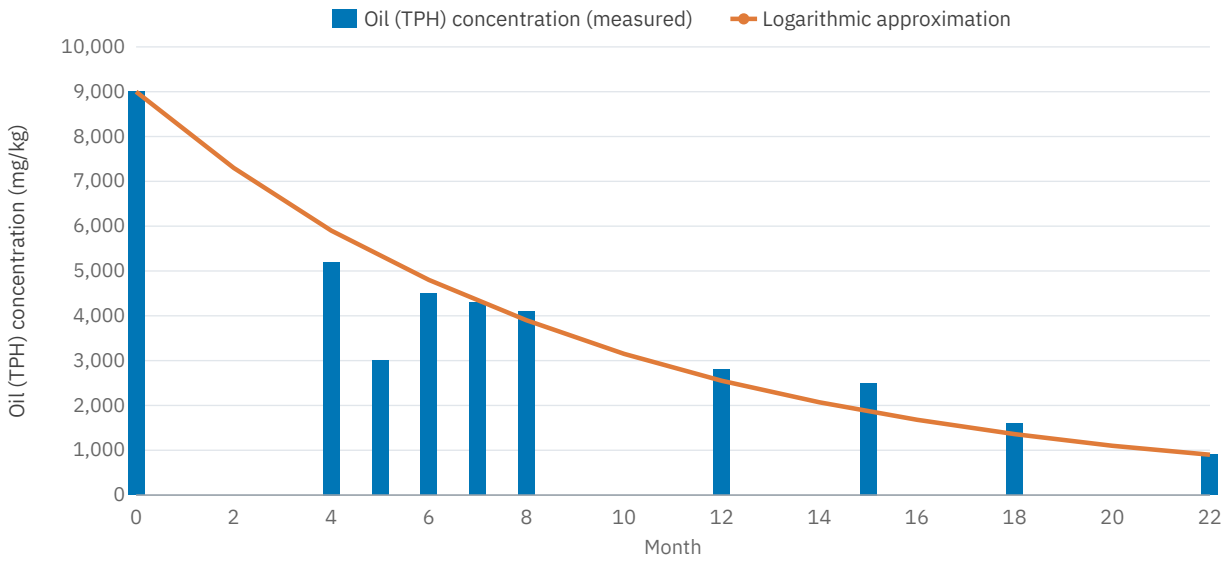

Figure 1: Trend in oil (TPH) concentration (in-situ remediation). Bars are measured values; the curve is a logarithmic approximation.

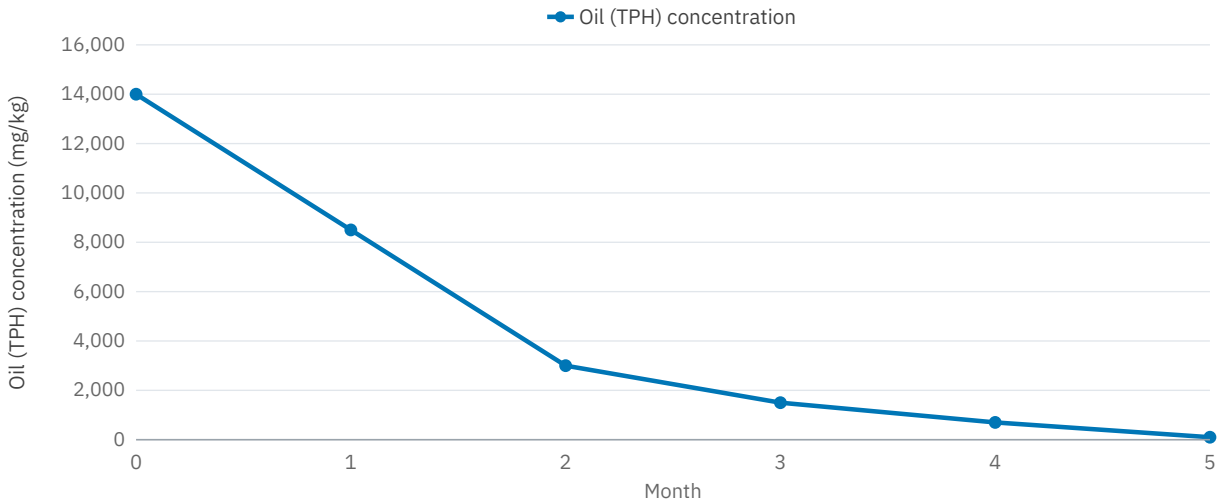

Figure 2: Trend in oil (TPH) concentration (landfarming, Class-A heavy oil)

Case ② (machine oil): Machine-oil contamination at the site of a former general factory, with an initial oil concentration averaging about 20,000mg/kg. Landfarming was adopted; although mixing was impossible during the winter due to snow cover, remediation progressed smoothly and the target value of 1,000mg/kg was reached in about 8 months (December to August of the following year).

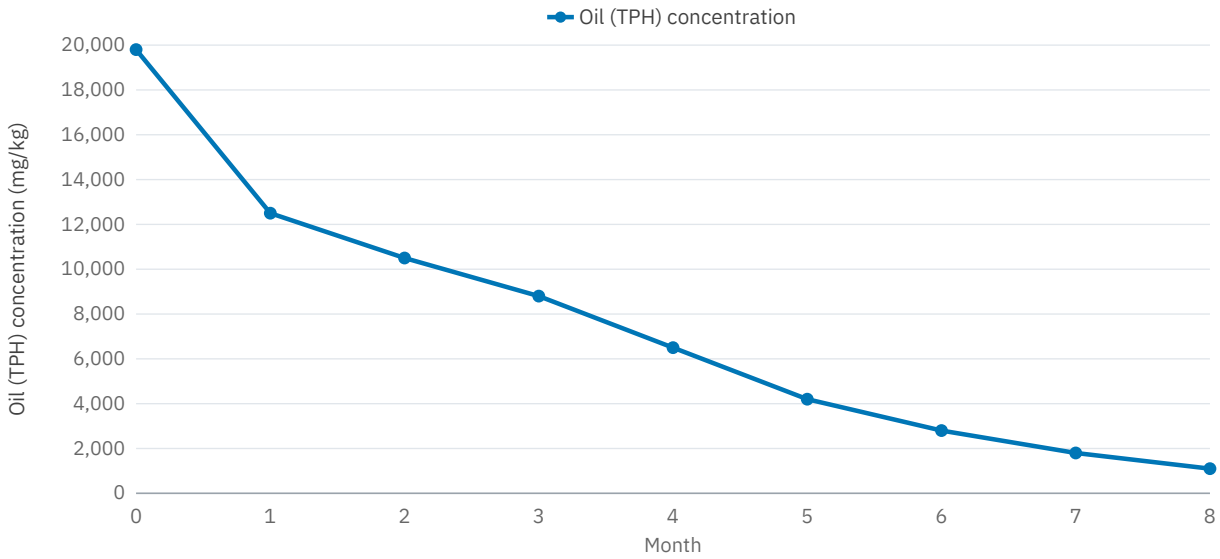

Figure 3: Trend in oil (TPH) concentration (landfarming, machine oil)

• Recalcitrant & safety

Breakdown of Recalcitrant Substances and Safety

We have demonstrated, from the laboratory level to the field level, the breakdown of substances generally regarded as recalcitrant — heavy oils (containing resins, asphaltenes and the like), lubricating oils, and polycyclic aromatic hydrocarbons (PAHs). In a comparison of PAH breakdown across various microbial agents (Figure 4), Oppenheimer Formula I / TCE Formula showed higher degradation performance than competitors' agents.

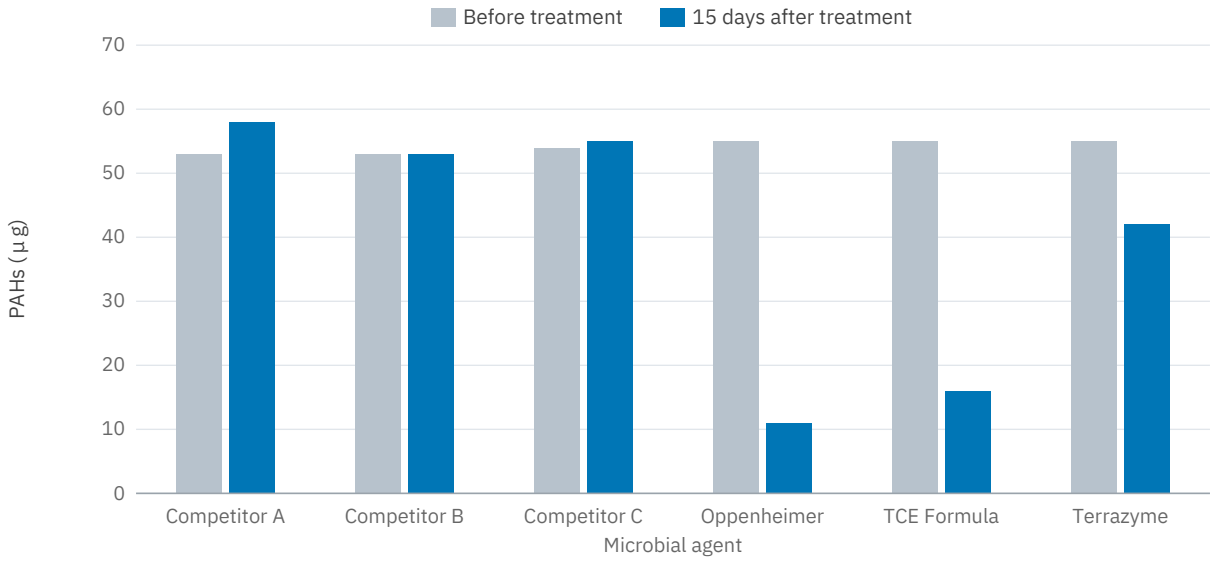

Figure 4: Comparison of polycyclic aromatic hydrocarbon (PAHs) breakdown across various microbial agents

This agent is a microbial consortium gathered from natural environments around the world, and contains no genetically modified microbes. During quality control we confirm that it contains no pathogenic microbes, and we have conducted ecosystem safety tests — including toxicity tests on aquatic organisms and mutagenicity tests — in Japan and abroad, all of which confirmed it to be safe. Beyond oil-contamination remediation, it is used in a wide range of applications, including wastewater treatment for factories and kitchens, and agricultural and aquaculture uses.

Safety test item	Result	Testing institution (excerpt)
Presence of pathogenic bacteria (microarray analysis)	None	Gifu University Graduate School of Medicine
Presence of pathogenic bacteria (fatty-acid analysis, etc.)	None	Texas Department of State Health Services / Accu Lab, USA
Presence of E. coli	None	Yagai Kagaku Co., Ltd.

Safety test item	Result	Testing institution (excerpt)
Toxin-production test	None	MICROTOX TEST™ (Grace Dearborn, Canada)
Freshwater/saltwater fish impact test (silversides, etc.)	None	U.S. EPA Environmental Research Laboratory, et al.
Invertebrate impact test (mysids, water fleas, sea urchins, etc.)	None	U.S. EPA / University of Texas Marine Science Institute, et al.
Algae impact test (diatom Skeletonema costatum)	None	Environment Agency Oil Bioremediation Study Survey
Mutagenicity test	Negative	Saga University / Chemicals Evaluation and Research Institute
umu test	Negative	National Institute of Advanced Industrial Science and Technology / Chemicals Evaluation and Research Institute
Medaka growth test	Negative	Prefectural University of Kumamoto