United States Environmental Protection Agency
Research and Development

Environmental Research Laboratory Gulf Breeze FL 32561

EPA-600/S4-84-055 Sept. 1984

EPA

Project Summary

Results of the Drilling Fluids Research Program Sponsored by the Gulf Breeze Environmental Research Laboratory, 1976 - 1983, and Their Application to Hazard Assessment

Thomas W. Duke and Patrick R. Parrish

This report summarizes a cooperative research program supported by the U.S. Environmental Protection Agency (EPA) from 1976-1984 to evaluate the impact of drilling fluids on the marine environment. EPA issues permits for the discharge of drilling fluids on the U.S. Outer Continental Shelf (OCS) under the National Pollutant Discharge Elimination System (NPDES). Information gained from this research program and fully reported in a final report can be used by EPA personnel and others involved in the NPDES permitting process.

The report is divided into four sections: (1) a brief discussion of the uses and characteristics of drilling fluids; (2) a presentation of the results of the research program, including a review of pertinent publications resulting from the program, data derived from chemical and biological studies of used drilling fluid samples from the Gulf of Mexico and from laboratory studies with generic drilling fluids, a discussion of environmental concentrations, and a synthesis of fate and effects data obtained through the Adaptive Environmental Assessment (AEA) process; (3) recent reviews and reports; and (4) conclusions.

This Project Summary was developed by EPA's Environmental Research Laboratory, Gulf Breeze, FL, to announce key findings of the research project that are fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Drilling fluids (also called muds) are essential to rotary drilling processes used in exploratory and production wells on the OCS. These fluids are pumped through the drill pipe and drill bit and returned to the surface, bringing sand, rocks, and drill cuttings. The fluids perform several important functions, including cooling, lubrication, reduction of corrosion, and maintenance of hydrostatic pressure. Drilling fluids contain a heterogenous mixture of chemicals and other ingredients. Their exact formulation depends upon the substrate through which the drilling is taking place, depth of the well, and particular functions of the fluid required at a specific time.

Release of drilling fluids from drilling platforms into the marine environment is of concern because of their potential adverse impacts on organisms and alteration of substrates and other aspects of the environment. Through the research described herein, EPA has attempted to provide scientific information on the fates and effects of drilling fluids in the marine environment.

Methods

Research efforts for this project were accomplished mainly through EPA Cooperative Agreements with academic institutions and contracts with private laboratories. The principal investigators at participating institutions were encouraged to publish their results in peer-reviewed journals or peer-reviewed EPA reports available through the National Technical Information Service (NTIS). Investigators used a variety of drilling fluids and various techniques in their experiments; detailed information can be found in the respective published papers referenced herein.

Results

Some examples of results obtained include the impact of drilling fluids on various species of marine organisms. Corals were studied by several investigators (Dodge, 1982; Szmant-Froelich et al., 1982; Szmant-Froelich, 1983; Kendall et al., 1983; and Parker et al., 1984). Exposure of *Montastrea annularis* to 100 parts per million (ppm) of used drilling fluid significantly reduced calcification and respiration rates, gross photosynthesis, nitrate uptake rate, and feeding response, but exposure to 1 and 10 ppm of the same fluid did not. However, *Montastrea annularis* exposed to 1 ppm, 10 ppm, or 100 ppm of used drilling fluid showed significant effects in three biochemical measures—diacylphospholipids, plasmalogen phospholipids and free amino acids. *Acropora cervicornis* responded to exposures of 25 ppm, 50 ppm, and 100 ppm with significant decreases in calcification rate and soluble tissue protein content in growing tips.

Conklin et al. (1983) and Doughtie et al. (1983) tested the effects of samples of used drilling fluids on molting grass shrimp (*Palaemonetes pugio*). Concentrations from 360 ppm to 14,500 ppm caused 50 percent mortality in the test within 96 hours (96-h LC50). There was a high correlation between the presence of diesel oil-like hydrocarbons in the drilling fluid samples and toxicity, but a low correlation between chromium content and toxicity.

Derby and Atema (1981) and Capuzzo and Derby (1982) conducted research on the effects of used drilling fluids on American lobsters (*Homarus americanus*). Exposures of lobster legs to 10 ppm and 100 ppm for 3 to 5 minutes caused diminished response to food odors by 29% and 44%, respectively. The 96-h LC50's for five drilling fluids were from 74 ppm to 500 ppm, and sublethal exposures resulted in alterations of normal physiological functions, such as growth and respiration rates.

Other experiments were conducted with invertebrates by Schatten et al. (in press) and Crawford and Gates (1983) who studied sea urchins and sand dollars. *Lytechinus variegatus* and *Arbacia punctulata* exposed to ≥1 millimolar barium sulfate (233 ppm) exhibited reduced fertilization processes, and 10 millimolar exposure halted all fertilization and development. The development of *Echinarachnium parma* embryos was not adversely affectd by ≤100 ppm drilling fluid, but 1 and 10 parts per thousand (ppt) adversely affected fertilization and subsequent embryo development.

Crawford and Gates (1981) also investigated the effects of used drilling fluids on development of a fish, *Fundulus heteroclitus*. Embryos placed in concentrations from 1 ppm to 10 ppt showed no significant adverse effects during early development but, by the seventh day of exposure, various sublethal effects were observed. The no-observable-effect concentration was 10 ppm.

The adverse effect of used drilling muds containing diesel oil-like hydrocarbons on several species of marine organisms was illustrated recently in a research project coordinated by EPA's Environmental Research Laboratory at Gulf Breeze, Florida (ERL/GB). Eleven mud samples, collected from operating wells at various geographical locations and depths in the Gulf of Mexico by the Petroleum Equipment Suppliers Association, were split into subsamples. Duplicate samples were sent to the American Petroleum Institute and retained at ERL/GB where tests were conducted to evaluate the effects of the liquid, suspended particulate, and solid phases of each drilling fluid and the whole fluid on mysids (*Mysidopsis bahia*). In addition, Conklin and Rao (University of West Florida) evaluated the effects of the fluids on grass shrimp (*Palaemonetes intermedius*); the New England Aquarium (NEA) staff, hard clams (*Mercenaria mercenaria*); Powell (Texas A&M University), corals (*Acropora cervicornis*); and Crawford (Trinity College), the mummichog (*Fundulus heteroclitus*), sand dollars (*Echinarachnius parma*), and sea urchins (*Strongylocentrotus purpuratus*, *Lytechinus pictus*, and *L. variegatus*).

Chemical analyses of the 11 drilling fluids were performed by Science Applications, Inc. (SAI) and by NEA. The SAI group analyzed the fluids for barium, aluminum, cadmium, chromium, copper, and iron as well as for aromatic and aliphatic fractions. The NEA staff analyzed the fluids for barium, cadmium, chromium, copper, manganese, lead, and zinc. The two oxidation states of chromium, Cr^{+3} and Cr^{+6}, were studied. Also, the NEA group determined concentrations of "diesel" in each of the drilling fluid samples.

In summary, the toxicity of these 11 used muds to mysids, grass shrimp, hard clams, and coral was greater (lower LC50's) than previously reported for used muds, with the exception of those from Mobile Bay, Alabama. The LC50's ranged from 25 ppm to ≥1,500 ppm. Also, some embryological research with mummichog and several species of echinoderms indicated that some of the muds significantly inhibited embryological development; one required a 10^5 dilution to reach a "safe" concentration. An inspection of the data reveals, with the exception of corals, a relationship between the "diesel" oil content and toxicity of the muds. A Spearman Rank Order Correlation Analysis (Steel and Torrie, 1980) yielded significant (α=0.05) correlation coefficients between -0.74 and -0.96. Subsequent results obtained by testing the toxicity of drilling muds before and after addition of API #2 fuel oil also confirmed that addition of diesel increased the toxicity of the muds tested.

The Adaptive Environmental Assessment Method was used to synthesize data on the impact of drilling fluids on the marine environment and to prepare dynamic simulation models to describe the impact. The models were constructed and refined by participants at two workshops who agreed at the onset that the models could serve as a tool for evaluating the impact of drilling fluids on the environment, but that they were inappropriate as the sole basis for environmental evaluations. The parameters used in the models, outputs from various scenarios, and discussions of applicability of the outputs are discussed in the final project report and by Auble et al. (1982).

Conclusions and Recommendations

Results of research activities from this and other projects show that drilling fluids are toxic to marine organisms at certain concentrations and exposure regimes. Further, drilling fluids can adversely affect animals—especially benthos—through physical contact, by burying, or by altering substrate composition. Drilling fluids also can exert effects by disrupting essential physiological functions of organisms.

Much less information is available on the environmental concentrations of drilling fluids that result from discharges into the marine environment than is available on toxic effects. However, available data and models suggest that when discharges are made from platforms located in open, well-mixed, and relatively deep (>20 meters [m]) marine environments under the ranges of operating and environmental conditions discussed in the Adaptive Environmental Assessment workshops, most detectable acute effects will be limited to an area within several hundred meters of the point of discharge. Based on laboratory-derived effects data, there will be sufficient dilution of the drilling fluids in the water column (10^6 dilution within approximately 1,000 m of the point of discharge) to minimize acute effects on water column organisms similar to those tested to date. Benthic organisms within about 300 m of the discharge will be potentially subject to adverse effects caused by burial and chemical toxicity; they may also be susceptible to direct effects or substrate changes for greater distances. Possible exceptions to these generalizations could occur when discharges are near sensitive biological areas, such as coral reefs, or in poorly flushed environments.

Laboratory toxicity tests indicated that #2 fuel oil of known composition, "diesel-like" hydrocarbons in used drilling fluids from the Gulf of Mexico, and mineral oil were correlated with toxicity — the higher the hydrocarbon content, the greater the toxicity. Tests showed that when API #2 fuel oil (diesel) was added to one of the used fluids with a low "diesel" content, the treatment increased the toxicity of the fluid to grass shrimp. Similar results were obtained when mineral oil was added to laboratory-prepared generic drilling fluids; the toxicity of fluid to mysids increased as the concentration of mineral oil increased. Experiments conducted with grass shrimp indicated that when equal amounts of API #2 fuel oil and mineral oil were added to a hydrocarbon-free reference drilling fluid prepared by the National Bureau of Standard for use in the ERL/GB research program, the fuel oil-treated preparation was about three times more toxic than the reference fluid with mineral oil added. Additional tests are needed to compare the toxicity of these two additives to other organisms as are tests to determine their no-observed-effect concentrations on various species and communities. It would also be useful to establish a data base on the long-term toxicity of other drilling fluid additives, including biocides.

More data on sublethal and chronic effects should be developed to assess the potential long-term toxicity of drilling fluids to benthic communities. Such studies should generate information on the bioaccumulation of specific drilling fluid components. Additional evaluations of the toxicity of Cr^{+3} and Cr^{+6}, and the effects and bioavailability of other drilling fluid components such as barite are also needed. Additional research also is needed to quantitatively address the limits of applicability of the assumptions and inputs of the fate models developed in the AEA workshops in order to validate the models. Special emphasis should be placed on the evaluation of models of discharges from multiple development rigs because these are the sites of the most intensive drilling fluid discharges.

The Adaptive Environmental Assessment process appears to be a sound approach in developing models to explain the fate and effects of drilling fluids discharged in the marine environment. Development of the AEA models has accentuated certain gaps in our knowledge and has emphasized the importance of considering the potential magnitude of the effects of natural episodic events and the dynamics of marine ecosystems. The rigor and general applicability of these models in special cases where discharges are close to shore in areas of high productivity, or where discharges are proximal to unique habitats, is not well established. Along with a general effort to validate the predictive capability of the models, a special effort is needed to determine how well these models address special cases and other contingencies. The need is particularly acute where permit activities involve nearshore coastal or estuarine environments.

In summary, it is possible through existing data and empirical and numerical models to estimate the impact of drilling fluids on specific areas of the marine environment, based on predicted environmental concentrations and effects (determined mainly in the laboratory) at those concentrations. However, the data base for the models should be expanded by (a) monitoring existing and proposed discharges for specific information, and (b) conducting long-term tests at environmentally realistic concentrations to determine community and system effects and chronic effects on organisms representative of areas of biological concern. At present, there is not sufficient evidence that acute toxicity tests, even under optimal conditions, reveal subtle, adverse effects that could occur at the ecosystem level of biological complexity as the result of drilling fluid discharges.

Literature Cited

Auble, G.T., A.K. Andrews, R.A. Ellison, D.B. Hamilton, R.A. Johnson, J.E. Roelle, and D.R. Marmorek. 1982. Results of an adaptive environmental assessment modeling workshop concerning potential impacts of drilling muds and cuttings on the marine environment. EPA-600/9-82-019, Environmental Research Laboratory, Gulf Breeze, FL. 64 pp.

Cappuzzo, J.M. and J.G. Smith Derby. 1982. Drilling fluid effects to developmental stages of the American Lobster. EPA-600/4-82-039, Environmental Research Laboratory, Gulf Breeze, FL. 52 pp.

Conklin, P.J., D. Drysdale, D.G. Doughtie, K.R. Rao, J.P. Kakareka, T.R. Gilbert, and R.F. Shokes. 1983. Comparative toxicity of drilling muds: Role of chromium and petroleum hydrocarbons. Marine Environmental Research 10(2):105-125.

Crawford, R.B. and J.D. Gates. 1981. Effects of a drilling fluid on the development of a teleost and an echinoderm. Bulletin of Environmental Contamination and Toxicology 26:207-212.

Derby, C.D. and J. Atema. 1981. Influence of drilling muds on the primary chemosensory neurons in walking legs of the lobster, *Homarus americanus*. Canadian Journal of Fisheries and Aquatic Sciences 38(3):268-274.

Dodge, R.E. 1982. Effects of drilling mud on the reef-building coral *Monstastrea annularis*. Marine Biology 71(2):141-147.

Doughtie, D.G., P.J. Conklin, and K.R. Rao. 1983. Cuticular lesions induced in grass shrimp exposed to hexavalent chromium. Journal of Invertebrate Pathology 42(2):249-258.

Kendall, J.J., Jr., E.N. Powell, S.J. Connor and T.J. Bright. 1983. The effects of drilling fluids (muds) and turbidity on the growth and metabolic state of the coral *Acropora cervicornis*, with comments on methods of normalization for coral data. Bulletin of Marine Science 33(2):336-352.

Parker, J.H., J.S. Nickels, R.F. Martz, M.J. Gehron, N.L. Richards, and D.C. White. 1984. Effect of oil and gas well-drilling fluids on the physiological status and microbial infection of the reef building coral *Montastrea annularis*. Archives of Environmental Contamination and Toxicology 13(1):113-118.

Schatten, G., D. Simerly, and H. Schatten. In press. The effects of barium sulfate on sea urchin fertilization and early development. In: Wastes in the Sea, Vol. 3. John Wiley and Sons, Inc., New York.

Steel, R.G. and J.H. Torrie. 1980. Principles and Procedures of Statistics, 2nd Ed. McGraw-Hill, New York. 633 pp.

Szmant-Froelich, A., V. Johnson, T. Hoehn, J. Battey, G.J. Smith, E. Fleischmann, J. Porter, and D. Dallmeyer. 1982. Physiological effects of oil-drilling muds on the Caribbean coral *Monastrea annularis*. In: Reef and Man: Proceedings of the Fourth International Coral Reef Symposium, Manila. E.D. Gomez et al., Editors. Pp. 163-168.

Szmant-Froelich A. 1983. Physiological effects of drilling muds on reef corals. EPA-600/3-83-013, Environmental Research Laboratory, Gulf Breeze, FL. 54 pp.

*The EPA authors **Thomas W. Duke** and **Patrick R. Parrish** are with the Environmental Research Laboratory, Gulf Breeze, FL 32561.*

The complete report, entitled "Results of the Drilling Fluids Research Program Sponsored by the Gulf Breeze Environmental Research Laboratory, 1976-1983, and Their Application to Hazard Assessment," (Order No. PB 84-223 072; Cost: $17.50, subject to change) will be available only from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650

The EPA authors can be contacted at:

Environmental Research Laboratory
U.S. Environmental Protection Agency
Sabine Island
Gulf Breeze, FL 32561

☆ U.S. GOVERNMENT PRINTING OFFICE; 1984 — 759-015/7786

United States
Environmental Protection
Agency

Center for Environmental Research
Information
Cincinnati OH 45268