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Project Summary

Evaluation of At-Sea Disposal of FGC Wastes

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This two-volume report is the third in a series of reports on a continuing EPA research program on the feasibility of the disposal of flue gas cleaning (FGC) wastes in the ocean. Volume 1 gives results of laboratory-scale chemical and biological experiments (by Arthur D. Little, Inc. and the New England Aquarium's Edgerton Research Laboratory) with untreated (unstabilized FGC wastes designed to provide basic data on environmental impact potential. Volume 2 gives results of further chemical and biological tests with a forced-oxidation (sulfate-rich) FGC waste and with stabilized FGC wastes.

Results of tests performed to date, as well as related assessment efforts, indicate that the conventional (concentrated-dump) at-sea disposal of unstabilized FGC wastes with soil-like properties on the Continental Shelf appears to be environmentally undesirable, unless contradicted by further work. Test results also indicate that at-sea dispersed disposal of sulfate-rich (and, possibly, sulfite-rich) soil-like FGC wastes is sufficiently promising to merit further research. Likewise, results of this and other programs indicate that conventional or concentrated disposal of brick-like stabilized FGC wastes is also promising.

This Project Summary was developed by EPA's Air and Energy Engineering Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Background

This is the third in a series of reports on a research program, sponsored by the U.S. Environmental Protection Agency, on the feasibility of the disposal of Flue Gas Cleaning (FGC) wastes from coal-fired power plants both in mines and at sea. The first two reports presented findings concerning both in-mine and at-sea disposal. The first report consisted of issue identification for future research, based on a review of available information. The second report included results of original physical and chemical testing as well as additional assessment of available literature. This report, in two volumes, describes subsequent investigations of at-sea disposal by Arthur D. Little, Inc. (ADL) and the Edgerton Research Laboratory of the New England Aquarium (NEA).

The first report identified four environmental impact categories of concern in the potential at-sea disposal of FGC wastes from coal-fired power plants: benthic sedimentation, suspended waste in the water column, sulfite-related toxicity and oxygen depletion, and trace contaminants.

The second report focused on physical and chemical investigations of unstabilized FGC wastes in seawater. Testing and assessment efforts emphasized three subject areas: the physical fate of unstabilized FGC wastes in the water column (i.e., the hypothetical "column" of water between the ocean surface and the ocean bottom), the physical fate of unstabilized FGC wastes on the ocean bottom, and the chemical fate of unstabilized FGC wastes in seawater.

Overall conclusions of the first two reports emphasized the need for case-by-case analyses of prospective at-sea disposal of FGC wastes, along with the following more specific conclusions:

- The conventional disposal of unstabilized FGC wastes with soil-like physical properties on the Continental Shelf appeared to be environmentally unacceptable, without further contradictory evidence.

- Problems of at-sea disposal of sulfite-rich FGC wastes, particularly those related to oxygen depletion, appeared to be much greater than the problems associated with other FGC wastes.
- Disposal options which appeared promising and worthy of further research included:
  - dispersed disposal of unstabilized sulfate-rich and stabilized brick-like FGC wastes on the Continental Shelf;
  - concentrated disposal of brick-like FGC wastes; and
  - disposal of unstabilized sulfate-rich FGC wastes in the deep ocean.

Part 1 Purpose and Scope

This third phase of the program was designed to fulfill several research needs identified in the earlier assessments. Part 1 experiments were designed to study:

1. acute toxicity of unstabilized FGC wastes to marine water column organisms;
2. chronic toxicity and substrate suitability of unstabilized FGC wastes of marine benthic organisms; and
3. leaching behavior and bioaccumulation of trace contaminants from FGC wastes in seawater.

One series of tests consisted of measurements of the acute toxicity of unstabilized FGC wastes to marine zooplankton and finfish, with the wastes maintained in suspension of the water column. The second series of tests was conducted in two parts. First, leaching tests were conducted to determine the amounts of selected metallic trace contaminants that could leach from the wastes under different mixing conditions. Then, 6-week exposure tests were performed in flow-through seawater systems with partial FGC waste substrates and marine benthic plants, invertebrates, and finfish. Organisms and the water column were monitored for the trace metals for the duration of the tests. The wastes tested are shown in Table 1.

Part 1 Results

Suspended Sediment Impacts

The results of toxicity testing with suspended wastes and water-column organisms indicated that there are unlikely to be significant differences between the water column impacts of descending, sulfate-rich FGC wastes and impacts presently experienced in disposal of dredged materials. Specifically, test results were obtained for marine/estuarine species with documented high sensitivity to suspended sediment impacts; i.e., the zooplankton *Acartia tonsa* and the filter-feeding fish *Menidia menidia.* The toxicity values upon exposure of these species to suspended sulfate-rich, soil-like FGC wastes were in the same range as those obtained by other investigators upon exposure of the same species to suspensions of various natural soils under comparable test conditions.

However, exposure of the same species to agitated suspensions of *sulfite-rich,* unstabilized FGC wastes produced dramatic oxygen depletion and organism mortality. The latter results suggest that conventional release of descending masses of unstabilized, sulfite-rich FGC wastes could lead to toxic phenomena in the ocean water column, depending on the degree of attraction to or voluntary avoidance of the descending masses by disposal site organisms. Dispersed, rather than conventional, disposal of these wastes, or disposal following stabilization, are possible means of mitigating this impact potential.

Sulfite-Related Oxygen Depletion on the Ocean Bottom

Results of month-long exposure tests with benthic marine organisms reinforced earlier concerns over the potential adverse effects of sulfite-related oxygen depletion. In circumstances where unstabilized, sulfite-rich FGC wastes comprised 25 percent or more of the test tank substrate, finfish agitated the wastes sufficiently to lead to oxygen depletion and organism mortality. However, in circumstances where the wastes comprised smaller areas of the tank substrate, voluntary avoidance and an absence of oxygen depletion and organism mortality prevailed throughout the tests.

These results suggest that dispersed disposal combined with voluntary avoidance *may* provide means of mitigating the oxygen-depletion impact potential of unstabilized, sulfite-rich FGC wastes, but field-scale observations would be needed to evaluate this possibility.

Trace Contaminant Impacts

The results of the exposure tests concerning leaching, toxicity, and bioaccumulation of trace metals varied for the several chemicals and wastes investigated. As shown in Table 2, the exposure conditions associated with one unstabilized, sulfate-rich waste resulted in extensive mortality of experimental invertebrates (clams and snails), but had no comparable effect on finfish (flounder). There was no apparent explanation for the observed toxicity of this one sulfate-rich waste: the measured levels of trace metals in the water column were within the non-toxic range observed by other researchers working with other comparable metal mixtures and the same marine organisms. Possible explanations included the presence of high levels of an unmeasured chemical (e.g., copper) or the contamination of the waste sample in some other manner not detectable by traditional bulk or trace metal analysis.

There was an absence of toxicity and significant bioaccumulation associated with the leaching of nickel and zinc in tests with FGC wastes relatively rich in these constituents (compared with the full range of data on the FGC wastes). This result suggested that the levels of nickel and zinc, two trace contaminants identified as potential problems in the earlier work, would be likely to preclude at-sea disposal of FGC wastes.

Results of cadmium and selenium indicated continuing release and bioaccumulation of these chemicals when tested with some of the experimental FGC wastes in seawater. These results indicated that further testing of FGC wastes relatively rich in

Table 1. *FGD Waste Samples Used In Laboratory Testing*

Process Source	*Sample Code*	*Waste Type*	*Waste Form*	*Acute Toxicity*	*Thirty-Day Exposure*
Dual Alkali	*DA1*	*Sulfite-Rich (without ash)*	*Filter Cake*	—	*X*
Direct Lime	*L1*	*Sulfite-Rich (with ash)*	*Filter Cake*	—	*X*
Direct Lime	*L2*	*Sulfite-Rich (without ash)*	*Filter Cake*	*X*	—
Direct Limestone	*LS2*	*Sulfite-Rich (without ash)*	*Thickener Underflow*[a]	*X*	—
Direct Limestone (forced oxidation)	*LS3*	*Sulfate-Rich (with ash)*	*Filter Cake*	—	*X*
Acid Scrubbing	*G1*	*Sulfate-Rich (without ash)*	*Centrifuge Cake*	*X*	—

[a]*Settled*

these metals would be required to evaluate fully their long-term impact potential.

Part 1 Conclusions

Overall conclusions regarding the need for case-by-case disposal evaluations and the technical feasibility of control options were still considered valid. Other specific conclusions were:

- The concentrated disposal at sea of unstabilized FGC waste with soil-like physical properties still appears to be environmentally unacceptable, *unless contradicted by further work.*
- The problems of disposal of sulfite-rich FGC wastes still appear considerable, but dispersal appears to be a potentially useful control option.
- The potential release of some trace contaminants remains a valid concern that could preclude at-sea disposal of FGC wastes. This concern does not appear to extend to nickel and zinc.
- Dispersed disposal at sea of all forms of FGC wastes and concentrated disposal at sea of stabilized brick-like FGC wastes appear promising.
- Conventional disposal of unstabilized sulfate-rich FGC wastes in the deep ocean may be promising, but needs to be reconsidered after further testing to determine if the toxicity of one such waste in this program was an isolated phenomenon.

Part 1 Recommendations

The more important research needs identified from these investigations were:

- further bioassay data on sulfate-rich FGC wastes;
- further leaching and bioassay data on selected FGC waste trace contaminants;
- limited field-scale tests to investigate avoidance responses and trace contaminant update;
- parallel data for stabilized FGC wastes; and
- continued investigations of any full-scale field situations where FGC wastes have entered or been placed in marine environments.

Part 2 Purpose and Scope

Three of the research needs identified in the Part 1 study were addressed in Part 2:

1. Development of further bioassay data on the type of unstabilized sulfate-rich FGC waste that had been associated with high levels of organism mortality in previous testing;
2. Development of further leaching and bioassay data on selected FGC waste trace metals in seawater; and
3. Development of chemical and bioassay data parallel to that from earlier studies, this time for a representative selection of stabilized FGC wastes.

During the timeframe of the investigations reported in this series, investigations of at-sea disposal of stabilized FGC wastes continued at the State University of New York (S.U.N.Y.) at Stony Brook, under the sponsorship of various agencies. The S.U.N.Y. work involves a series of laboratory and limited field-scale studies of the physical and chemical characteristics and ecological impact potential of artificial reefs made of *brick-like,* sulfite-rich FGC wastes stabilized by a modified version of the Conversion Systems Inc. (CSI) process. This work, collectively, is referred to as the Coal-Waste Artificial Reef Program (C-WARP).

The investigators for this study maintained cognizance of the S.U.N.Y. work, and attempted to design their experiments so as to complement, rather than duplicate, that work. In particular, Part 2 focused on the study of *soil-like* (rather than brick-like) stabilized FGC wastes, and sulfate-rich (forced-oxidation) wastes, neither of which were studied by S.U.N.Y.

Table 2. *Animal Mortality Record Long-Term Exposure Test*

Date	*Number*	*Organism*	*Tank No.*	*Waste*
July 3	*2*	*Pseudopleurenectes*	*1*	*Control*
	1	*Littorina*	*8*	*Control*
July 5	*1*	*Mya*	*6*	*LS3*[a]
	1	*Littorina*	*6*	*LS3*
July 6	*4*	*Mya*	*6*	*LS3*
July 7	*1*	*Mya*	*6*	*LS3*
	2	*Littorina*	*6*	*LS3*
July 8	*1*	*Mya*	*6*	*LS3*
July 11	*1*	*Littorina*	*5*	*DA1*
July 12	*1*	*Littorina*	*5*	*DA1*
	3	*Littorina*	*6*	*LS3*
July 20	*2*	*Littorina*	*6*	*LS3*
	1	*Littorina*	*8*	*Control*
July 21	*1*	*Mya*	*6*	*LS3*
	1	*Mya*	*overflow tank*	*LS3*
July 24	*1*	*Littorina*	*6*	*LS3*
	1	*Littorina*	*8*	*Control*
July 25	*2*	*Mya*	*overflow tank*	*LS3*
July 26	*1*	*Mya*	*overflow tank*	*LS3*
	1	*Littorina*	*5*	*DA1*
July 27	*1*	*Mya*	*overflow tank*	*LS3*
	1	*Littorina*	*5*	*DA1*
August 7	*1*	*Mya*	*overflow tank*	*LS3*

[a]See Table 1 for Waste Sample Code.

Part 2 Results

Benthic Sedimentation Impacts

The results of the Part 2 thirty-day exposure tests with both unstabilized and stabilized, soil-like FGC wastes included observations of voluntary use (in some cases preferential) of these wastes as substrates by facultative, benthic marine organisms which would otherwise inhabit various or fine-grained natural substrates (i.e., clams and worms). No examples of waste avoidance by these organisms were observed. These observations tend to indicate that the *physical characteristics* of soil-like FGC wastes are compatible with use by facultative marine organisms at dumpsites set in other fine-grained sediments. However, there are still no data to contradict the expectation that fine-grained, soil-like FGC wastes would prove unsuitable substrate for indigenous organisms if concentrated on areas of the ocean bottom that would otherwise be covered by coarse sand and/or reef substrates.

Sulfite-Related Oxygen Depletion

The investigation of oxygen depletion by sulfite-rich stabilized wastes in Part 2 indicated that such depletion would occur with these wastes, but to a lesser degree and at a slower rate than previously measured for unstabilized, sulfite-rich wastes. Higher slurry concentrations of stabilized versus unstabilized wastes were required to produce oxygen depletion, and the time required to deplete the available oxygen increased by factors of about two to five, even at the higher slurry concentrations. No oxygen depletion below 5.8 ppm was experienced in any of the 30-day exposure tests with sulfite-rich stabilized wastes. However, the wastes were not subjected to the same degree of bio-turbation in the Part 2 tests that had prevailed and proved problematic in Part 1.

Trace Contaminant Impacts

The results of the leaching and biological exposure testing in Part 2 tended to confirm (for additional stabilized and unstabilized FGC wastes) the Part 1 findings with respect to nickel and zinc, and to indicate leaching behavior and implications similar to those for nickel and zinc with respect to copper. For all three of these metals, the incremental changes in ambient seawater concentrations were below the levels reported to cause adverse ecological effects in the marine environment and, in some cases, resulted in net *decrease* over background levels.

There were no apparent waste-related test organism mortalities in the Part 2 tests. These results, particularly for the two wastes that were physically and chemically comparable, the toxic sample of sulfate-rich unstabilized wastes used in Part 1, tend to reinforce the hypothesis that the toxicity of that Part 1 sample was a relatively unique phenomenon.

Results for other trace metals, notably arsenic, cadmium, chromium, and selenium, were inconclusive. There was an absence of these elements over the 30-day exposure period in the Part 2 tests. However, the concentrations of these elements were continuing to rise in one or more test species at the conclusion of the tests.

Stabilization appeared to reduce the availability of cadmium for seawater leaching, but appeared to have little or no effect on the availability of other elements, including chromium and selenium.

Part 2 Conclusions

Principal conclusions of this part of the study were:

- The overall conclusions of the earlier assessment are still considered valid; i.e., there remains a need for case-by-case analyses of prospective at-sea disposal of FGC wastes and the viability of available control options.
- The at-sea disposal of stabilized, sulfite-rich FGC waste appears to be environmentally preferable from the standpoint of sulfite-related oxygen depletion. Mitigation by dispersed disposal may be feasible and necessary, but requires field-scale investigation.
- The previously observed incidence of contamination-related acute or sub-chronic toxicity associated with one sample of a sulfate-rich, unstabilized FGC waste appears to have been highly waste-specific. Such toxicity should not be expected for a broad spectrum of sulfate-rich FGC wastes, and can be evaluated case-by-case with required, standard at-sea disposal bioassays.
- The limited potential for near-term release and accumulation of copper, nickel, and zinc from either unstabilized or stabilized FGC wastes appears unlikely to constrain at-sea disposal of these wastes.
- The data suggest that leaching of arsenic, cadmium, chromium, and selenium appears to be within environmentally acceptable limits for relatively short-term exposures, but leave open some questions about the impacts of prolonged exposure.
- FGC waste stabilization by addition of lime and fly ash appears to be a potentially effective means of mitigating impacts associated with the release of some trace metals (e.g., cadmium) but not others (e.g., selenium, chromium).
- Disposal options which continue to appear promising include:
  - —dispersed disposal of all forms of FGC wastes on the Continental Shelf or in the deep ocean;
  - —conventional or concentrated disposal of stabilized FGC wastes on the Continental Shelf or in the deep ocean; and
  - —conventional or concentrated disposal of unstabilized, sulfate-rich FGC wastes in the deep ocean.

Part 2 Recommendations

The following research needs were identified based on Part 2:

- Limited field-scale tests with sulfite- and metal-rich FGC wastes would be of value in investigating the importance of:
  1. organism avoidance responses as potentially mitigative of sulfite-related toxicity of sulfite-rich FGC wastes; and
  2. longer-term chronic uptake and toxicity of arsenic, cadmium, chromium, and selenium leached from FGC wastes under more representative conditions for leaching and water exchange.
- Investigation of any field situations where FGC wastes have entered or been placed in marine environments would contribute to current knowledge of the subject.

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The complete report consists of two volumes, entitled "Evaluation of At-Sea Disposal of FGC Wastes:"
"Volume 1. Biological Testing and Studies with Untreated Wastes," (Order No.PB 85-156 180/AS; Cost: $16.00)
"Volume 2. Biological Testing and Studies with Stabilized Wastes," (Order No. PB 85-156 198/AS; Cost: $11.50)
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