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Project Summary

An Evaluation of the Disposal of Flue Gas Cleaning Wastes in Coal Mines and at Sea: Refined Assessment

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This report gives a refined assessment of the feasibility of disposing of flue gas cleaning (FGC) wastes in coal mines and at sea. Its focus is on specific impact areas identified in an earlier assessment (EPA-600/7-77-051, NTIS No. PB269270). These areas were further investigated through laboratory studies as well as an additional review of published information. For FGC waste disposal in coal mines, the issues addressed are: (1) physical stability of FGC waste deposited in surface mines; (2) effects of freezing on waste dewatering/drainage; (3) fugitive emissions from handling and disposal; (4) leaching of Total Oxidizable Sulfur (TOS) from sulfite-rich wastes; (5) release of gases from waste deposits; and (6) corrosion potential for concrete bulkheads used for containment in underground mines. For disposal of FGC wastes at sea, the impact issues studied were: (1) the physical fate in the water column during descent from conventional barge disposal; (2) benthic transport and sedimentation of dumped FGC wastes; and (3) depletion of oxygen due to dissolution of TOS from sulfite-rich wastes. These issues represent potential environmental impacts which may require evaluation for specific disposal conditions. In general, existing control measures can mitigate such impacts; e.g., modification of waste properties and waste placement methods.

Engineering cost estimates were prepared for several methods of disposal of blended FGD waste and fly ash in surface coal mines, the most promising mine disposal options. Annual first-year costs in 1980 dollars for pit bottom disposal ranged from $2.50-$4.50 per metric dry ton for onsite disposal (mine 4 miles from power plant) to $10-$19 for offsite disposal via rail haul (100 to 200 miles one-way). These costs include stackout and handling at the waste processing area through final placement.

This Project Summary was developed by EPA's Industrial Environmental 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).

Introduction

This is the second report on a research program sponsored by the U.S. EPA's Industrial Environmental Research Laboratory at Research Triangle Park (IERL-RTP). The program consists of investigations by Arthur D. Little, Inc. (ADL), the New England Aquarium (NEA), and the University of North Dakota (UND), of the feasibility of disposing of Flue Gas Cleaning (FGC) wastes in mines and at sea. The FGC wastes studied were those from non-recovery Flue Gas Desulfurization (FGD) systems and mixtures of FGD wastes and coal ash.

The first report (EPA-600/7-77-051, NTIS No. PB269270) gave results of a preliminary ADL assessment of the environmental, technical, regulatory, and economic aspects of projected mine and at-sea disposal operations. The purpose of the initial assessment was to evaluate the overall viability and acceptability of disposal and to determine the most promising disposal options.

This report refines the preliminary assessment, based on additional evaluation of selected impact issues identified in the initial effort as requiring further study. The purpose of the refinement, therefore, was to acquire additional information necessary to have a more complete understanding of the fate and effects of FGC wastes in coal mine and ocean environments, and a more accurate estimate of the cost of selected disposal options.

Purpose and Objectives

The purpose of this refined assessment was to acquire additional information: (1) to provide a more complete understanding of the fate and effects of FGC wastes in mine and ocean environments; and (2) to allow more accurate estimates of the costs of promising disposal options. Specific objectives were to:

- Perform limited laboratory testing to provide better insight into the behavior of FGC wastes relating to impact issues for which significant data gaps exist.
- Refine the initial assessment to the extent possible based on the laboratory test results supplemented by other relevant data and information.
- Prepare engineering estimates of the capital investment and operating costs for representative disposal options believed to be technically feasible and potentially environmentally acceptable.

While consideration of all aspects of the initial assessment were generally within the scope of this effort, attention was focused on specific physical and chemical impact issues raised in the initial assessment.

Assessment of Disposal In Coal Mines

Impact Issues Studied

The initial assessment indicated that surface coal mines (Figure 1) were the most promising sites for in-mine disposal of FGC wastes. It was also reported that, while methods for handling and placement of such wastes are available, certain chemical and physical properties of the wastes might have adverse impacts on the environment and/or the operation of the mine being utilized for disposal. Six key chemical and physical impact issues identified in that initial study were subjected to more detailed evaluation in this effort, using information and data obtained from the following sources (an "x" indicates a source):

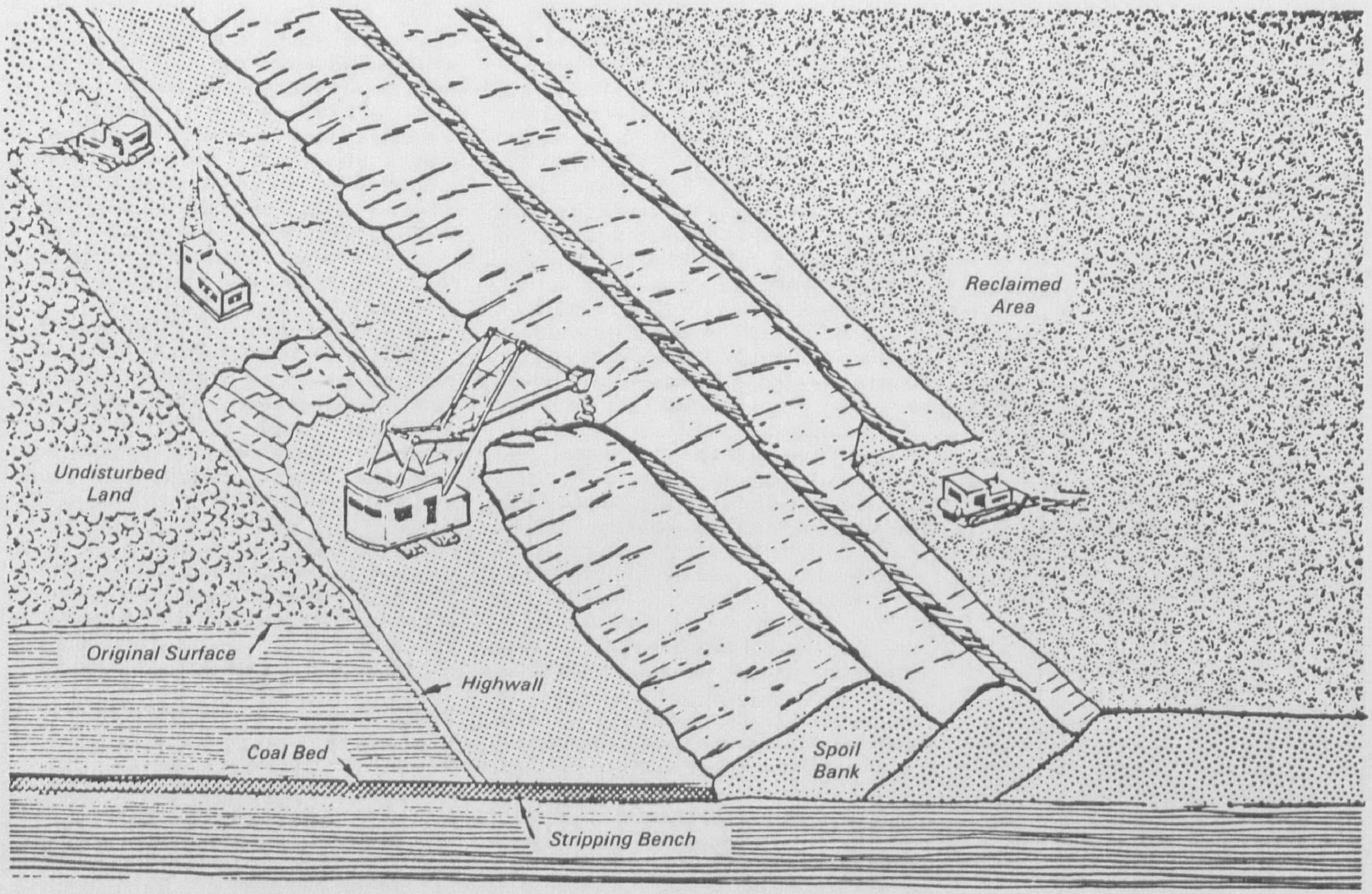

Figure 1. Area strip mining with concurrent reclamation.

Issues	Information Sources		
	ADL Testing	Independent Testing	Related Information
Physical			
Stability in Surface Mines		x	x
Freezing Effects	x	x	x
Fugitive Emissions		x	x
Chemical			
Dissolution of Total Oxidizable Sulfur (TOS)	x	x	
Offgassing (SO_2/H_2S)	x (SO_2 only)	x (H_2S only)	
Concrete Corrosion			x

The testing performed and the related assessment focused on unstabilized waste because of the lack of definitive data on its behavior. Where possible and appropriate, extrapolation to the potential fate and effects of stabilized wastes has been made.

Conclusions

Overall conclusions of the initial assessment are still considered valid. The disposal of FGC wastes in coal mines is feasible from a technical standpoint: practical options are available in terms of waste processing, placement, and site management to control most potential adverse environmental impacts. However, the viability and environmental impacts of each disposal situation must be evaluated, based on the specific hydrogeology of the site, waste characteristics, and placement method.

Specific conclusions regarding the issues and impacts addressed in this refined assessment include the following.

Stability

Requirements for physical stability of waste deposits in surface mine disposal operations depend on the type of disposal operations, the mine characteristics, and the methods of mining employed. In general, it would be expected that most wastes at solid levels near optimum moisture content would have physical and engineering properties adequate to ensure acceptable stability (e.g., resistance to flow under its own weight due to disturbances from mining activities). In the case of sulfite-rich wastes, this would also necessitate admixture of filtered (or centrifuged) waste with some amount of fly ash. Where the FGD waste solids cannot be adequately dewatered and insufficient fly ash is available for stabilization, admixture of both fly ash and lime may be required. However, simply adding lime may not ensure short-term stability (prior to curing) if the waste is too wet. In such cases, stockpiling the waste may be required to allow time for curing to begin (which also increases solids content) prior to disposal. Other control measures available, depending on the type of disposal, to minimize stability problems include: production of gypsum rather than sulfite-rich material; mixing of waste with soil/overburden; control of placement to minimize rewetting (and saturation); and creation of containment walls of overburden either during or after disposal (e.g., by placing the waste in discrete areas or on one side of the pit).

Freeze/Thaw Effects

Freezing of wastes may alter their chemical and physical properties, which can affect handleability and ultimate strength developed. Laboratory testing of untreated waste samples indicated no significant effect of freeze/thaw on drainage of water from the waste. The degree and effect of freezing on handleability can be minimized by dewatering (and admixture with ash) to achieve near-optimum moisture content. For areas with extreme temperatures, heated trucks may be required (e.g., piping exhaust through truck walls) to ensure handleability.

Freezing would normally be expected to slow curing rates of stabilized wastes. If it occurs prior to the onset of curing, freezing may severely reduce the ultimate strength achieved. If it occurs after initiation of curing, there may be little or no effect on hardening. To increase curing rates and ultimate strength under winter conditions, longer stockpiling of the waste (4-7 days) may be desirable to allow curing to begin before disposal.

Fugitive Emissions

Although possible, emission of dust from FGC wastes in mine disposal operations is unlikely due to the relatively high moisture content of the wastes; fugitive dust emissions from stockpiles can be easily controlled. Drying of the waste pile surface will usually result in crustation; however, if dust emissions result, they can be minimized by wetting the surface in much the same way that dirt road surfaces are wetted.

Total Oxidizable Sulfur (TOS) Dissolution

Dissolution of calcium sulfite from sulfite-rich FGD wastes can result in TOS levels in leachates ranging from tens to hundreds of ppm depending on groundwater ionic strength, acidity, and hardness. This can result in levels of chemical oxygen demand (COD) sufficient to deplete dissolved oxygen in groundwater and affect local receiving waters. Where sulfite-rich waste deposits might adversely impact aerobic ground and surface waters, the solubility of TOS should be a consideration in the impact of waste leachate. Often, the concentration of TOS, which represents an immediate oxygen demand, may not result in significant reductions in dissolved oxygen due to low leachate rates.

Offgassing Potential

There is potential for offgassing CO_2, SO_2, H_2S, and (possibly) other gases from waste deposits in mines, particularly in underground mines. The release of SO_2 and H_2S is of greatest concern.

SO_2 offgassing can result from contact of neutral or slightly basic, sulfite-rich wastes with highly acidic mine waters (pH $<\sim 3.0$), especially during initial disposal when the quantity of waste is relatively small compared to the amount of acid. Longer term evolution fo SO_2 is generally not only less likely to occur, but also more difficult to predict. The potential for short-term evolution can be minimized by: (1) avoiding placement of sulfite-rich wastes in mine areas containing highly acidic drainage; (2) pumping out and treating water prior to placement; (3) preneutralizing water with limestone; or (4) increasing the alkalinity of the waste by admixture of lime or limestone. Long-term SO_2 offgassing can also be reduced by minimizing infiltration and/or acidification of groundwater in the mine by: (1) maximum filling of voids; (2) use of bulkheads; or (3) reduction of waste permeability by use of stabilization. If the waste is stabilized by admixture of fly ash and lime prior to disposal, additional lime may be required to also negate the effects of the acid water on the curing of the waste.

Release of H_2S from FGD wastes has been noted in some instances. Laboratory testing has also indicated the potential for H_2S release. It could occur from either sulfate- or sulfite-rich materials due to the activity of sulfate-reducing bacteria. Some of the same measures used to control SO_2 offgassing may also be appropriate for H_2S offgassing. These include: proper selection of disposal sites and disposal methods; waste stabilization prior to disposal; and, in the case of underground disposal, maximum filling of voids and use of bulkheads to reduce contact with water.

Bulkhead Corrosion

Use of bulkheads as containment walls may be required in some areas of underground mine disposal operations. If constructed of concrete, they may be susceptible to chemical attack by FGC waste liquors. Deterioration would be expected to be most severe for acidic wastes, especially those containing high levels of dissolved solids (e.g., sodium, magnesium, chloride and sulfate). There was very little information on cement and concrete behavior in the presence of liquors similar to those that might result from closed-loop operation of FGC systems. Parametric corrosion testing needs to be performed to assess the effects of FGC wastes and to develop a data base sufficient for specifying adequate cement/concrete mixes. Such testing needs to cover realistic and extreme ranges of scrubber liquors and leachate composition. Of particular importance would be pH and concentrations of chloride, sulfate, fluoride, sulfite, sodium, and magnesium.

Measures which can minimize the potential for deterioration of concrete bulkheads include: coating of imbedded steel in reinforced structure; reduction in leachate generation by maximum filling of voids and/or waste stabilization, and increasing the alkalinity of the waste to avoid developing acidic conditions.

Additional Research and Information Needs

Identified research needs include: (1) field-scale demonstration of promising surface mine and/or underground mine disposal; and (2) monitoring of full-scale ongoing operations to establish practical disposal methods and to evaluate actual environmental impact potential (both detrimental and beneficial). One such program designed to satisfy both needs is currently underway at the Baukol-Noonan lignite surface mine near Center, ND. This program has been funded by the U.S. EPA and Department of Energy (DOE); results will be published.

Additional testing of waste properties and impact potential under controlled conditions is also desirable to enable better predictions of disposal requirements and waste behavior. Important among these are:

- Additional triaxial compression and dynamic load tests on a variety of wastes (including dry sorbent wastes) and moisture levels. This will better indicate the degree of dewatering and/or fly ash addition required for disposal of untreated wastes and the effects of variability on handling and stability of the wastes.
- Leaching column tests using mine waters and overburden materials to assess potential pollutant mobility in mining environments as well as potential for improvement of mine drainage. This is best performed in concert with demonstration testing or as a part of full-scale monitoring. A limited amount of such testing had been performed by Michael Baker, Jr., Inc., Twin City Testing, and the University of North Dakota (as part of the program at Center, ND).
- Tests to evaluate the effects of FGC waste liquors and leachates on cement and concrete.

Assessment of Disposal at Sea

Impact Issues Studied

Laboratory tests and related assessments of the disposal of FGC wastes focused on three areas:

- Physical fate of wastes in the water column.
- Physical fate of wastes on the ocean bottom.
- Chemical fate of untreated FGC wastes in seawater (i.e., TOS dissolution and oxygen depletion).

Conclusions

The two overall conclusions of the initial assessment are still considered valid. These conclusions pointed out the need for case-by-case analysis of disposal and affirmed the technical feasibility of available control options. Other specific initial conclusions have been reinforced by this assessment, with some modifications, as indicated below:

- Unless further work contradicts observed and anticipated benthic sedimentation impacts including mud flows, the disposal of untreated or treated FGC wastes with soil-like physical properties by bottom-dump barge (Figure 2) or outfall on the continental shelf should be considered environmentally undesirable. As noted below, continued research relating to this option is needed.
- Problems of disposal of sulfite-rich FGC wastes, both on and off the continental shelf, appear to be much greater than those associated with other FGC materials. There appear to be special grounds for concern over the potential for oxygen depletion in the vicinity of sulfite-rich

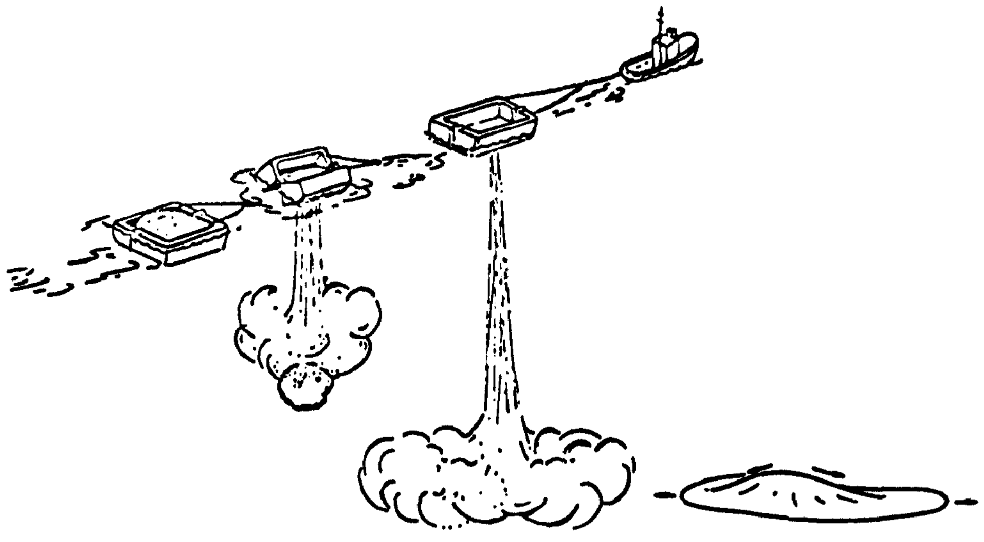

Figure 2. *Transport processes—hinged-bottom-dump barge.*

waste masses. However, direct sulfite toxicity may be a relatively minor issue because of the significant rate of the oxidation reaction.

- Disposal options which still appear promising and are recommended for further research include:
  - dispersed disposal of untreated sulfate-rich FGC waste on the continental shelf;
  - concentrated disposal of treated brick-like FGC waste on the continental shelf;
  - dispersed disposal of treated brick-like FGC waste on the continental shelf;
  - dispersed disposal of untreated sulfate-rich FGC wastes in the deep ocean; and
  - concentrated disposal of all forms of sulfate-rich FGC wastes in the deep ocean.

Additional Research and Information Needs

The following research needs are believed most important:

- Empirical bioassay data on the acute and/or chronic effects of sulfite-rich FGC wastes on representative marine organisms.
- Empirical bioassay data on the long-term availability and accumulation of FGC waste-related metallic trace contaminants.
- Empirical bioassay data on the suitability of soil-like FGC materials as benthic substrates in quiescent waters.
- The development of empirical data and verified theoretical models to predict field-scale FGC waste behavior during descent through marine water columns.
- Continual investigation of field situations where FGC wastes have entered marine environments.

Economic Considerations for Mine Disposal

Cases Studied

Six cases were developed to cover potential combinations of waste type, transportation mode, and in-mine placement for technically promising mine disposal options. For each case, engineering costs were estimated for the loading (at the plant), transport, unloading, and placement of the wastes in the mines. Both capital and operating costs were estimated. No estimates were made of certain other elements of the actual overall disposal costs, including costs associated with handling and/or processing (thickening, filtration, etc.) operations required prior to transport of the waste to ultimate disposal. The latter costs were not considered unique to mine disposal operations: they would also be incurred equally for such alternatives as disposal in managed landfills.

Results

The estimated per-ton costs for pit-bottom disposal in the six mine disposal cases were as follows:

	$/Ton (Mid-1980 $)	
	Wet	Dry
E-1 Lime scrubbing with stabilization, on-site mine disposal, Eastern coal.	2.85	4.40
E-2 Limestone scrubbing with fly ash, forced oxidation, on-site mine disposal, Eastern coal.	2.25	2.75
E-3 Lime scrubbing with stabilization, offsite mine disposal, Eastern coal.	8.00	12.25
E-4 Limestone scrubbing with fly ash, forced oxidation, off-site mine disposal, Eastern coal.	8.50	10.30
W-1 Limestone scrubbing with fly ash, on-site mine disposal, Western coal.	2.65	3.55
W-2 Limestone scrubbing with fly ash, off-site mine disposal, Western coal.	13.95	18.65

Comparison With Other Disposal Costs

A comparison of mine disposal costs to transport and placement costs for disposal of similar FGC wastes in managed landfills showed that the estimates for the hypothetical onsite mine disposal cases were about 75-80% of the typical comparable costs for disposal in managed landfills. Cost savings include the fact that mine disposal would not have the added reclamation cost of a managed fill. However, the estimates for the offsite mine disposal cases were 4-5 times higher than comparable costs for disposal in managed fills. This may be a result of the assumption of rail-haul requirements of 100 and 200 miles (one-way) for the offsite mine disposal cases, which represent "outer bounds" rather than typical distances to off-site disposal areas. Thus, the estimates and comparisons for onsite disposal are probably more realistic than those for off-site disposal.

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The complete report, entitled "An Evaluation of the Disposal of Flue Gas Cleaning Wastes in Coal Mines and at Sea: Refined Assessment," (Order No. PB 84-145 101; Cost: $19.00, subject to change) will be available only from:
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