Impact of the Resource Conservation and Recovery Act on FBC Residue Disposal

May 1980

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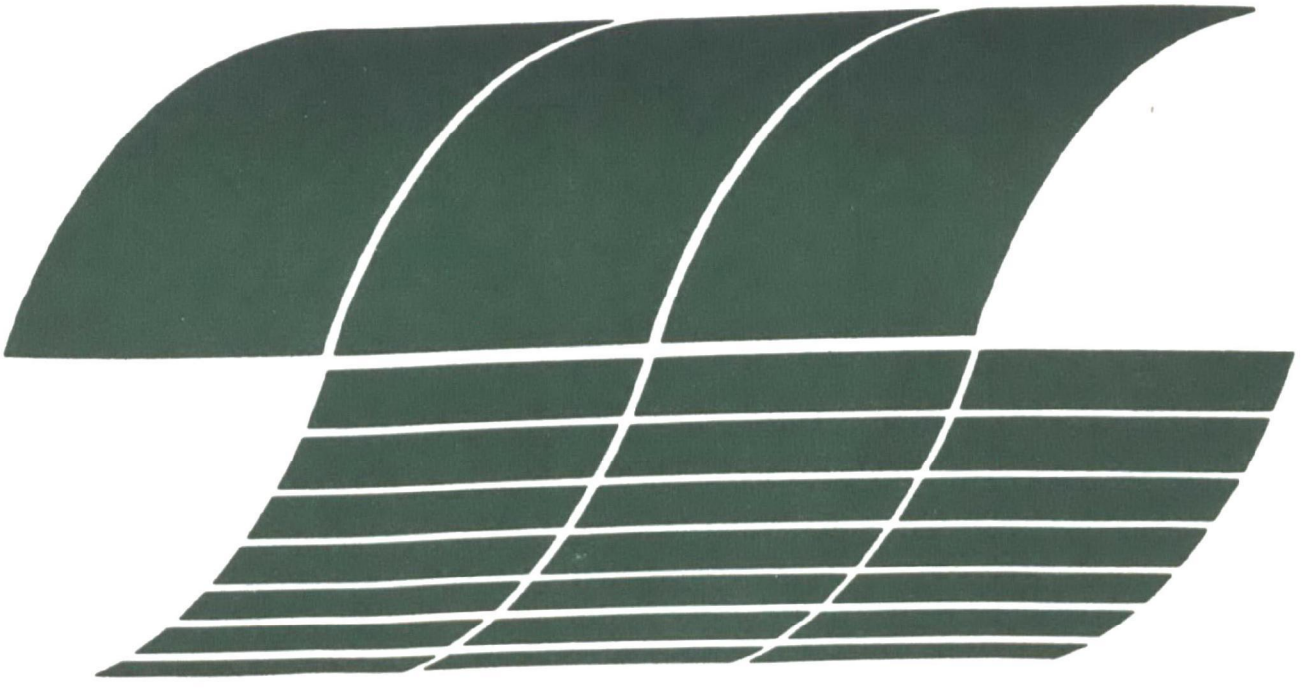

IMPACT OF THE RESOURCE CONSERVATION AND RECOVERY ACT

ON

FBC RESIDUE DISPOSAL

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PREFACE

The Westinghouse R&D Center is carrying out a program to provide experimental and engineering support for the development of fluidized-bed combustion systems under contract to the Industrial Environmental Research Laboratory (IERL), U. S. Environmental Protection Agency (EPA), at Research Triangle Park, NC. The contract scope includes atmospheric (AFBC) and pressurized (PFBC) fluidized-bed combustion processes as they may be applied for steam generation, electric power generation, or process heat. Specific tasks include work on calcium-based sulfur removal systems (e.g., sorption kinetics, regeneration, attrition, modeling), alternative sulfur sorbents, nitrogen oxide (NO_x) emissions, particulate emissions and control, trace element emissions and control, spent sorbent and ash disposal, and systems evaluation (e.g., impact of new source performance standards (NSPS) on FBC system design and cost).

This report on the impact of RCRA contains the results of work defined and completed as part of the spent sorbent and ash disposal task of the contract. Work on this specific task was performed from January 1979 to March 1980. Related documentation is found in the following reports:

- "Disposal of Solid Residue from Fluidized-Bed Combustion: Engineering and Laboratory Studies," EPA-600/7-78-049 (NTIS PB 283-082), issued in March 1978, which presented the results of work performed from January 1976 to January 1977
- "Experimental/Engineering Support for EPA's FBC Program: Final Report, Vol. III, Solid Residue Studies, EPA-600/7-80-015c, issued in January 1980. The report documents work performed from January 1977 to January 1979

and subsequent extensions from review of the draft through October 1979.

Since proper disposal of solid residue is of primary importance to the commercialization of the FBC process, continuing effort is directed toward solid residue studies under the current Westinghouse contract to EPA (68-02-3110).

Work on the other tasks performed under this contract has also been reported:

- Experimental/Engineering Support for EPA's FBC Program: Final Report Volume 1, Sulfur Oxide Control, EPA-600/7-80-015a, January 1980.
- Experimental/Engineering Support for EPA's FBC Program: Final Report Volume II, Particulate, Nitrogen Oxide, and Trace Element Control, EPA-600/7-80-015b, January 1980.
- Experimental/Engineering Support for EPA's FBC Program: Final Report Volume IV, Engineering Studies, EPA-600/7-80-015d, January 1980.
- Effect of SO_2 Emission Requirements on Fluidized-Bed Combustion Systems: Preliminary Technical/Economic Assessment, EPA-600/7-78-163, August 1978.
- Regeneration of Calcium-Based SO_2 Sorbents for Fluidized-Bed Combustion: Engineering Evaluation, EPA-600/7-78-039, NTIS PB 281-317, March 1978.
- Alternatives to Calcium-Based SO_2 Sorbents for Fluidized-Bed Combustion: Conceptual Evaluation, EPA-600/7-78-005, January 1978.
- Evaluation of Trace Element Release from Fluidized-Bed Combustion Systems, EPA-600/7-78-050, NTIS PB 281-321, March 1978.

ABSTRACT

The Resource Conservation and Recovery Act of 1976 (RCRA) created a new level of regulatory control of solid waste disposal. The emphasis of the act is on identifying hazardous wastes, regulating hazardous waste from cradle to grave (RCRA Subtitle C), and improving nonhazardous waste disposal practices (Subtitle D). The fluidized-bed combustion (FBC) process for electric power generation produces large quantities of residue (spent sorbent and ash) which are subject to RCRA control. The key provisions of RCRA that have the greatest impact on FBC residue disposal are Subtitles C and D. This report provides an assessment of RCRA and its current regulations with respect to FBC residue disposal and, of special importance, the proposed Sec. 3001 regulations for hazardous waste identification. RCRA tests, in particular the Sec. 3001 extraction procedure (EP), were performed on a variety of FBC residues representing several process variations. Results indicate that FBC residue is nonhazardous. The impact of RCRA regulations and criteria proposed prior to promulgation on May 19, 1980 on FBC residue disposal is assessed.

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NOMENCLATURE

AFBC - atmospheric-pressure fluidized-bed combustion
ANPR - Advance Notice of Proposed Rulemaking
CAA - Clean Air Act
CBC - carbon burnup cell
CWA - Clean Water Act
DOE - Department of Energy
DWS - drinking water standard
EP - extraction procedure
EPA - Environmental Protection Agency
FBC - fluidized-bed combustion
FGD - flue-gas desulfurization
HWM - Hazardous Waste Management program
NEPA - National Environmental Policy Act
NIPDWR - National Interim Primary Drinking Water Regulations
NPDES - National Pollution Discharge Elimination System
NSDWR - National Secondary Drinking Water Regulations
NSPS - New Source Performance Standard
ORNL - Oak Ridge National Laboratory, Oak Ridge, TN
OSHA - Occupational Safety and Health Act
OSW - Office of Solid Waste
PCB - polychlorinated biphenyl
PFBC - pressurized fluidized-bed combustion
PSD - Prevention of Significant Deterioration Program
RCRA - Resource Conservation and Recovery Act
SIT - Structural Integrity Test
TDS - total dissolved solids
TEP - toxic extraction procedure
TOC - total organic carbon
TSCA - Toxic Substances Control Act
UIC - Underground Injection Control program

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Our special thanks go to J. T. McAdams for his technical assistance in carrying out the laboratory experiments. We should also like to express our appreciation to many members of the Analytical Chemistry and Biology Departments within the Westinghouse Research and Development Center for their valuable contributions in sample characterization.

1. SUMMARY/CONCLUSIONS

In the fall of 1976, President Ford signed into law P.L. 94-580, the Resource Conservation and Recovery Act (RCRA),[1] which attempts to close the circle of environmental regulation by controlling those substances that pose a threat to human well-being or to the environment but that were not covered by the earlier laws governing air and water pollution. Despite its name, the thrust of the act is on creating a comprehensive scheme for regulating hazardous waste (Subtitle C - Hazardous Waste Management) and for improving solid waste disposal practices (Subtitle D - State and Regional Solid Waste Plans). Regulations proposed under RCRA Sec. 3001 or Subtitle C on identification of hazardous wastes in the Federal Register, December 18, 1978[2] received special emphasis.

The fluidized-bed combustion (FBC) process for electric power generation produces solid wastes that fall under the jurisdiction of RCRA. The purpose of this report is to determine if FBC residues are hazardous, according to RCRA procedures as proposed in December 1978, and to assess the impact of RCRA and the RCRA regulations (promulgated or proposed prior to the completion of this report in April 1980) on FBC residue disposal.

The key provisions of RCRA that could have the greatest impact on FBC residue disposal are Subtitle C on hazardous waste management, in particular the hazardous waste identification criteria under Sec. 3001, and Subtitle D, which regulates disposal of nonhazardous waste.

IMPACT OF HAZARDOUS WASTE IDENTIFICATION CRITERIA ON THE CLASSIFICATION OF FBC RESIDUE (Subtitle C)

RCRA Sec. 3001 of Subtitle C requires EPA - Office of Solid Waste (OSW) to promulgate criteria for identification of hazardous waste, which OSW began to develop in 1977. In March of 1978, a first draft

was released which contained tentative hazardous identification methods.[3] A toxic extraction procedure (TEP) was drafted to determine the toxicity of a waste. Those wastes whose TEP leachate had 10 times the National Interim Primary Drinking Water Regulations (10 x NIPDWR) would be considered hazardous. Public comments were requested on the draft regulations. We responded by testing typical FBC residues and reference materials (raw sorbent and conventional FGD residue). Results of our TEP testing and recommendations on the TEP procedure were communicated to EPA in 1978 (Appendix A).

On December 18, 1978, EPA formally proposed in the Federal Register[2] RCRA Sec. 3001 regulations which were scheduled to be promulgated in April 1980, following completion of this report. In that proposal the TEP was significantly modified on the basis of the additional information supplied by public comments (including our recommendations) and was renamed the "extraction procedure" (EP) with 10 x NIPDWR of heavy metal elements as the hazardous criteria. According to proposed Sec. 3001, a waste can be classified as hazardous either by being on the hazardous lists (proposed by EPA on December 18, 1978 and August 22, 1979)[2,4] or by possessing any of the proposed hazardous characteristics. The FBC residue is not on the hazardous lists, and, therefore, its classification must be determined from the proposed criteria for hazardous characteristics - ignitability, corrosivity, reactivity, and toxicity. Of the four characteristics, toxicity, for which EPA has proposed an extraction procedure (EP) and hazardous criteria (10 x NIPDWR), causes the most concern for FBC residue. Because of the potentially large volume of residues from various industrial sources and the limited data on their potential hazard, EPA has proposed a list of "special wastes" under Sec. 3004; "utility waste" is among these five special wastes. Should FBC waste be deemed hazardous according to Sec. 3001, we expect it would be classified as a utility waste under the special waste category and would be regulated with partial exemption from the cradle-to-grave regulations under hazardous waste management Sec. 3002 to 3005.

On the other hand, should FBC waste be identified as nonhazardous, it would fall under the jurisdiction of Subtitle D and its disposal would then be regulated as a sanitary landfill waste.

FBC residue is not ignitable, corrosive, or reactive according to the proposed criteria. To determine if it is toxic, 17 FBC residues representing several process variations, [atmospheric (AFBC) and pressurized (PFBC) fluidized-bed boilers/PFBC adiabatic combustor, bed/carry-over, with/without carbon burnup cell (CBC), once-through/regenerative operation, limestone/dolomite sorbents] together with reference materials (FGD residues, conventional ash, and raw sorbent) were tested using the former TEP and the proposed EP tests. Results that showed the EP leachates to have silver (Ag), arsenic (As), barium (Ba), cadmium (Cd), chromium (Cr), mercury (Hg), lead (Pb) and selenium (Se) below 10 x NIPDWR indicated the FBC residue to be nontoxic and, thus, nonhazardous. The only exception among the EP leachates of 17 FBC residues was the leachate from an Exxon PFBC run with sorbent regeneration, which had an average arsenic concentration of 0.94 ppm (compared to the criterion of 0.5 ppm). AFBC and PFBC fines (<15 μm) from the third-stage cyclone and bag filter and PFBC regenerator bed material had chromium concentrations in their EP leachates (0.15 to 0.4 ppm) much higher than the others (<0.1 ppm) and were close to the criterion for chromium, 0.5 ppm. Future investigations, therefore, should emphasize samples from these sources.

We assumed that the FBC residues would not contain chlorinated organic pesticides and herbicides and, thus, did not perform EP analyses for Lindane, Methoxychlor, Toxaphene, or 2.4-D and 2.4.5-TP Silvex, which were also proposed in Sec. 3001.

Bioassays and testing for radioactivity were not included in the proposed identification methods for hazardous characteristics (ignitability, corrosivity, reactivity, and toxicity) and thus were not

carried out in our investigation on FBC residues. However, EPA is considering expanding the hazardous characteristics to include radioactivity, genetic activity, bioaccumulation, and additional aspects of toxicity (Advanced Notice for Proposed Rulemaking, Federal Register, December 18, 1978).[2] Oak Ridge National Laboratory (ORNL)[5,6] conducted bioassays on fossil fuel residues under DOE and EPA contracts and reported that FBC residue showed negative results in mutagenicity, in aquatic and phytotoxicity, and in metal elements, agreeing with our conclusion that the FBC residue is nonhazardous. ASTM D19.12[7] also carried out bioassay tests; results are less conclusive due to difficulties encountered in sample preparation test procedures and interpretation of test results.

IMPACT OF NONHAZARDOUS WASTE DISPOSAL REGULATIONS ON FBC RESIDUE DISPOSAL (SUBTITLE D)

According to the current regulations promulgated on September 13, 1979,[8] eight criteria, including site selection and leachate monitoring, apply to the nonhazardous solid waste sanitary landfills, where FBC waste would most likely be disposed of. The most important issues that can affect the FBC residue disposal, however, are the standards for ground- and surface water. Compliance with RCRA and the National Pollution Discharge Elimination System (NPDES) under the Clean Water Act (CWA)[9] is required of a sanitary landfill. Efforts by EPA are under way to consolidate the solid waste permit system. Since effluent guidelines for FBC units and FBC residue disposal facilities are currently unavailable, engineering judgment must be applied for designing, operating, and managing the disposal facility to avoid potential adverse environmental effects. Because FBC leachates meet the primary DWS, which consists of eight heavy metals, fluoride (F), and NO_3, FBC residue disposal is expected to meet the current standards for sanitary landfill: groundwater at the "disposal facility boundary" must satisfy the primary drinking water standards (NIPDWR). Should the secondary DWS (NSDWR) be

included as they are currently proposed (Federal Register, September 13, 1979),[8] however, FBC leachate pH would be a major concern,as the pH of a typical FBC leachate ranges from 9 to 12 while the pH of NSDWR ranges from 6.5 to 8.5. Total dissolved solids (TDS) and sulfate (SO_4) are of passing values if a ten times attenuation/dilution factor is assumed. As soil attenuation and dilution can play a major role in reducing leachate pH, TDS, SO_4, and calcium, site selection and disposal facility design are critical factors in controlling potential groundwater contamination. In addition, contamination of groundwater due to those trace metal elements and the microbiological activity included in the DWS is not expected because FBC test leachates meet both the NIPDWR and the secondary drinking water regulations (NSDWR). Radioactivity, if any, should be similar to that of a conventional power plant residue.

IMPACT OF RCRA ON SITING OF FBC FACILITIES

The key aspects of RCRA that would affect the siting of new FBC facilities are provisions for hazardous and solid waste disposal (Subtitles C and D) and provisions for resource recovery (Subtitle E). The increased costs of transportation and disposal of the waste brought on by RCRA,as well as the marketability and transportation costs of FBC waste products (should FBC residue be utilized),will play an important role in siting FBC facilities. Also, in light of the public awareness created by RCRA, public support or opposition is becoming increasingly important in determining sites for fossil-fuel energy facilities.

IMPACT ON FBC ECONOMICS

The economics of FBC systems are sensitive to the total cost of sorbent, including purchase, transportation, and disposal. The major increase in disposal costs resulting from RCRA are expected to be associated with disposal site selection, site operation, and solid residue transportation. The sensitivity of FBC economics to total sorbent cost may lead FBC developers to consider more seriously alternatives for

reducing the total amount of sorbent consumed or methods to reduce disposal cost, such as residue processing or utilization, if the expected increase in the cost of solid waste disposal resulting from RCRA is significant. The technical and cost effects of RCRA on FBC residue disposal are such that they must be incorporated in the development of the integrated FBC system.

2. RECOMMENDATIONS

This report presents an assessment of the effect of RCRA on FBC residue disposal based on current regulations, some of which were proposed but not promulgated until this study was completed. We, therefore, recommend close review of RCRA development and updating its impact as new rules and amendments come into existence, with specific attention to the issues that follow.

HAZARDOUS/NONHAZARDOUS WASTE IDENTIFICATION

This investigation was based on the proposed RCRA Subtitle C regulations in the Federal Register of December 18, 1978,[2] in particular Sec. 3001, hazardous waste identification. Changes in the following may have an additional impact on FBC residue disposal, and reassessment may be required:

- EP test and leachate criteria
- Corrosivity/pH criteria
- Reactivity criteria with respect to exothermic hydration of CaO and CaS/concentration
- Bioassays, radioactivity testing methods, and interpretation. Although currently not a requirement, FBC residues should be investigated for radioactivity and genetic effects, both in terms of legislative requirement and in terms of better understanding of the potential hazard from a technical point of view.
- Approach to identifying hazardous waste - single test versus multistage screening.

In addition, chromium and arsenic in the leachate from FBC carry-over fines (<15 μm) and from the residue resulting from regenerative runs should be closely examined in future investigations to confirm their classification as nonhazardous.

FBC DISPOSAL PRACTICE

Based on this investigation, FBC residue is nonhazardous and, therefore, will be disposed of in a sanitary landfill. Regulations and disposal criteria for sanitary landfills under the RCRA Secs. 4004 and 1008 and the CWA will determine FBC disposal practice.

Since the groundwater criteria are applicable at the "disposal facility boundary," which will incorporate effects of soil attenuation and dilution, these effects should be investigated further. These effects are especially important with respect to leachate pH, TDS, SO_4, and calcium should the secondary DWS be included as part of the groundwater criteria in the future. Control technologies for major leachate variables, i.e., pH, TDS, SO_4, and calcium, should be evaluated in the event that dilution/attenuation effects might not be sufficient for some specific sites.

Other aspects of disposal, such as the proper procedures for handling the FBC residue, disposal site selection, facility design, construction, operation, and management need to be investigated. Engineering and economic evaluations of FBC waste disposal should be carried out, incorporating RCRA requirements as part of an integrated effort to develop commercial FBC systems.

3. INTRODUCTION

With the enactment of the National Environmental Policy Act of 1969 (NEPA), we are charged with a "responsibility to contribute to the preservation and enhancement of the environment." Efforts to protect the environment have led us to recognize the interplay of the components of our physical environment --air, water, and land.

Historically, the first important piece of legislation passed after NEPA was the Clean Air Act of 1970 (CAA), amended again in 1977,[10] which set forth the mechanisms for establishing national ambient air quality standards and new source performance standards (NSPS). To meet these standards industries employed air pollution control devices, such as scrubbers, that could control emissions to the air but would also leave residue that could contaminate surface and groundwater if not carefully controlled.

In October 1972, Congress passed another piece of legislation, the Federal Water Pollution Control Act, amended in 1977 as the Clean Water Act (CWA),[9] to restore and maintain the chemical, physical, and biological integrity of the nation's waters. This act prohibited discharge of toxic pollutants in toxic amounts. As a result of the Clean Air Act, the Water Pollution Control Act, and other federal and state laws respecting public health and the environment, greater amounts of solid waste in the form of sludge and other pollution treatment residues have been created. Similarly, inadequate and environmentally unsound practices for the disposal or use of solid waste have created greater amounts of air and water pollution and other problems for the environment and for health.

In the fall of 1976, President Ford signed into law PL 94-580, the Resource Conservation and Recovery Act of 1976 (RCRA),which represented

a substantial amendment of the Solid Waste Disposal Act of 1965 (as amended previously by the Resource Recovery Act of 1970).[1] The passage of RCRA created a federal and state regulatory authority over solid and hazardous waste. In essence the act attempts to close the circle of environmental regulation by controlling those substances that pose a threat to human well-being or the environment but that were not covered by earlier laws governing air and water pollution. Despite its name, the main thrust of the RCRA is neither resource conservation nor recovery. Although the Act does deal with these topics, it concentrates on creating a comprehensive scheme for regulating hazardous wastes and for improving solid waste disposal practices.

The fluidized-bed combustion (FBC) process for electric power generation produces solid wastes that fall under the jurisdiction of RCRA. The purpose of this report is to provide data based on proposed RCRA tests on a variety of FBC residues and to assess the impact of RCRA and its regulations on FBC residue disposal. The report identifies probable classification of FBC solid waste and applicable standards for their disposal. The potential impact on plant design and cost is mentioned but is not within the scope of this study. We have particularly emphasized regulations proposed under RCRA Sec. 3001 for the identification of hazardous wastes. To determine if FBC residues are hazardous we carried out an experimental program based on the proposed extraction procedure (EP). In addition, in assessing the impact of RCRA on FBC solids disposal we have reviewed related work reported by other investigators to supplement our own experimental results.

Since RCRA has been only recently enacted, however, and its guidelines are still in the developmental stage, the assessment of the impact of RCRA on FBC residue disposal presented in this report will require periodic updating as the proposed regulations are promulgated or modified and as new rules are implemented.

4. THE FLUIDIZED-BED COMBUSTION PROCESS

Fluidized-bed combustion is an emerging technology that is being developed to utilize coal in an environmentally acceptable manner. Fluidized-bed combustion processes, operated at atmospheric (AFBC) or at elevated (PFBC) pressure, employ limestone or dolomite to remove sulfur during combustion, thus eliminating the need for flue gas desulfurization (FGD). Unlike the scrubber sludges, dry, granular solids of 0 to 6 mm in diameter result from the FBC process. The characterization and disposal of the FBC residue have been investigated.[11-13]

SOURCES OF FBC RESIDUE

There are two major sources of solid residue from an FBC system: spent bed overflow material and entrained carry-over. The former consists largely of partially sulfated limestone or dolomite sorbent (calcium sulfate [$CaSO_4$], calcium oxide [CaO], calcium carbonate [$CaCO_3$], magnesium oxide [MgO]); and the latter consists of finer particles of partially sulfated sorbent and coal ash and char entrained from the bed and captured by a particulate control system. The carry-over is typically collected in several stages of the particulate control system commonly represented by cyclones, baghouses, electrostatic precipitators, granular-bed filters, etc. Figure 1 is a general sorbent flow diagram for FBC. A fluid-bed combustor is shown with three stages of particulate control equipment: the first stage represents recycling of elutriated coarse sorbent and coal ash (or carbon) to the combustor, and the second and third stages represent capture of coal ash and sorbent fines from the combustion products to be disposed of. The solid waste to be disposed of then consists of the solids stream withdrawn from the

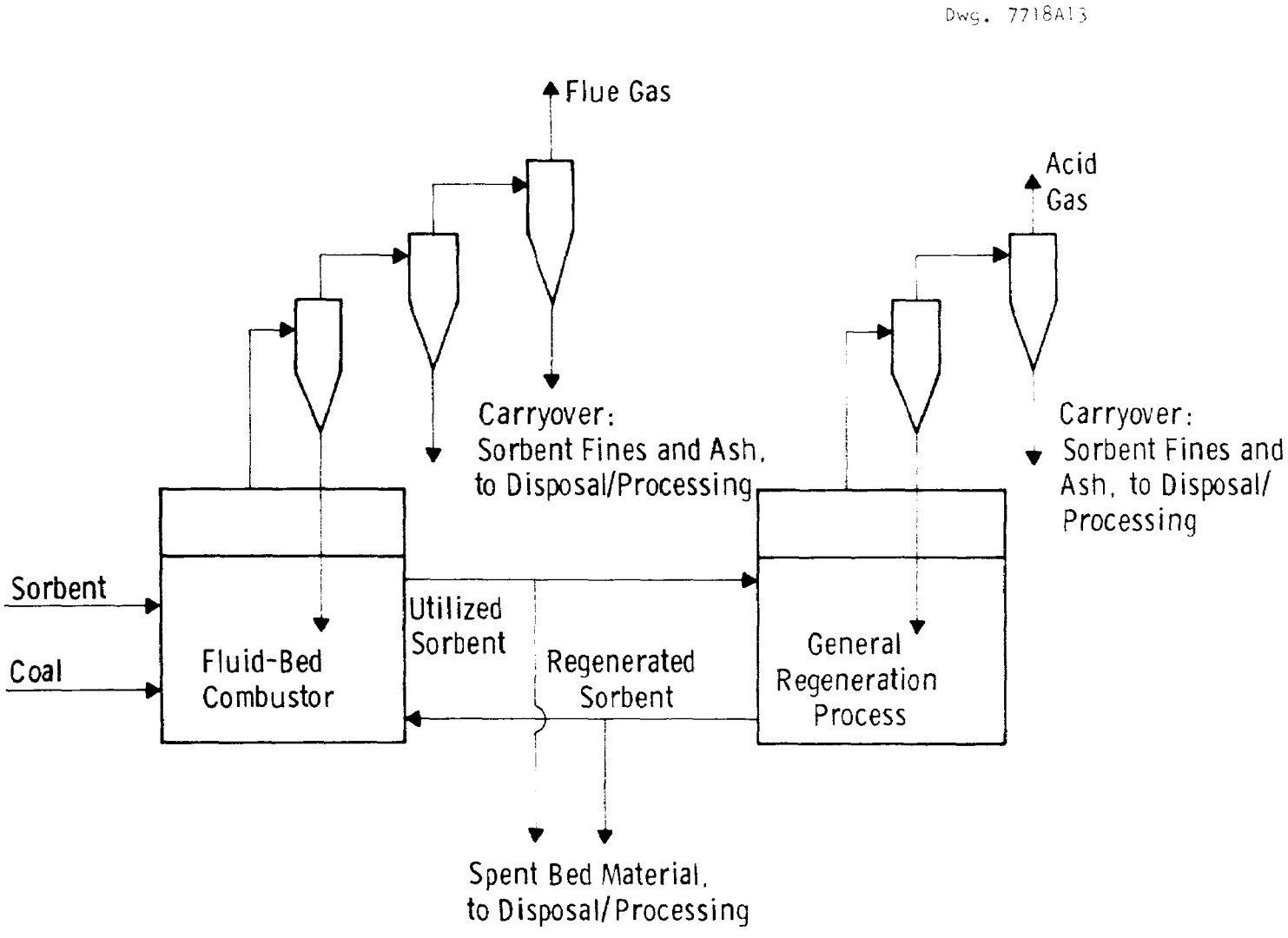

Figure 1. Fluidized-Bed Combustion General Solid Flow Diagram

combustor, having the bulk bed characteristics, and the fines-particle stream withdrawn from the particulate control system.

Figure 1 also shows an FBC system with sorbent regeneration. The regenerated sorbent is recycled to the combustor. The solid waste is represented by the stream withdrawn from either the combustor or the regenerator bulk beds, plus the fine material withdrawn from the combustor and regenerator particulate control systems. Sorbent regeneration has not reached the same stage of development as has once-through operation. Several feasibility questions remain unanswered. Several other FBC process variations are possible. The actual samples investigated in this study and their sources will be discussed in Section 6.

SOLID WASTE DISPOSAL RATES

The following factors can significantly influence the characteristics of the solid waste produced by FBC systems:[11]

- Coal properties - sulfur content, heating value, and ash content
- Fresh sorbent properties - type of sorbent (limestone or dolomite), composition, physical structure, and attrition behavior
- Fluid-bed combustion system concept - power cycle (atmospheric-pressure boiler, pressurized boiler, adiabatic combustor), fluid-bed mode (bubbling, fast fluidized, multisolids, etc.), particulate control system, fines recycle
- Fluid-bed combustor design and operating conditions - temperature, pressure, excess air, residence times of sorbent and gas, Ca/S feed ratio, superficial velocity, coal and sorbent feed size, coal and sorbent feeding, internals design, distributor design, turndown operating conditions, and so forth.

- Sulfur removal system - once-through, sorbent pretreatment (precalcination, salt exposure, thermal exposure, etc.), sorbent reactivation (hydration, agglomeration), sorbent regeneration.

The range of quantity of solid waste produced by FBC processes is very broad. The mass fraction of ash in coal may range between 0.02 and 0.30 for U.S. coals. Figure 2 shows how sorbent activity and size affect sulfur removal performance for once-through AFBC.[14] The resulting mass ratio of ash to waste sorbent calcium may range between about 0.1 and 200 for once-through operation. For regenerative operation Ca/S may range between 0.2 and 2.0, and the ash/sorbent ratio may range between about 0.15 and 150, a range not much different from the once-through case.

Table 1 shows total solid waste produced in a once-through, AFBC system as a function of the sorbent activity category, the required sulfur removal efficiency, and the type of coal. These values would be representative of both electrical utility and industrial operations.[15]

Predicted solid waste rates for advanced sulfur removal systems are shown in Figures 3 and 4 and compared with once-through operation. For eastern coals, Figure 3, a significant reduction in solid waste can be realized by an advanced system, while for western coal, Figure 4, the reduction is negligible. Process variations such as these must be considered in assessing the impact of RCRA on FBC.

REVIEW OF FBC RESIDUE STUDIES

Since 1969, Westinghouse has been providing engineering and experimental support of the development of the FBC processes. Fluidized-bed combustion solid residue studies, which include characterization,

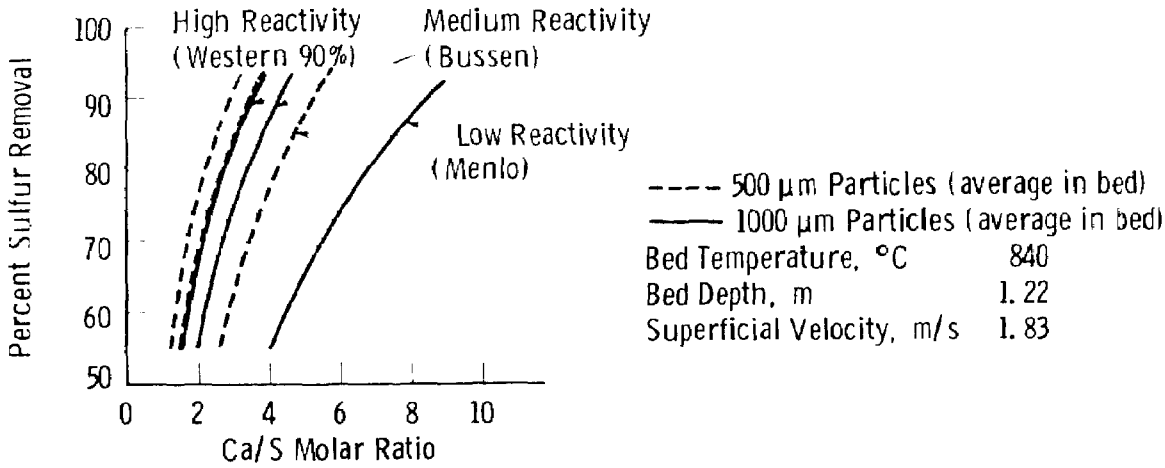

Figure 2 - Effect of Sorbent Activity Category and Particle Size on Ca/S Molar Feed Ratio Requirement (Once-through Operation)[14]

Table 1

TOTAL WASTE SOLIDS WITH 500 µm AVERAGE BED PARTICLE DIAMETER[a]

Sorbent Activity Category	High (Western 90% CaL Stone)	Medium (Bussen Quarry)	Low (Menlo Quarry)
	ng/kJ		
SO_2 Emissions Control Standard (% S removal)	Eastern High-S Coal (3.5 wt.% S, 10.58 wt.% ash)		
Stringent (90)	15.17	19.22	21.42
Intermediate (85)	14.21	17.54	19.80
Moderate (78.7)	13.00	15.97	18.22
	Eastern Low-S Coal (0.9 wt.% S, 6.9 wt.% ash)		
Stringent & Intermediate (84.7)	5.57	6.28	6.78
Moderate (75)	5.23	5.85	6.33
	Western Subbituminous Coal (0.6 wt.% S, 5.4 wt.% ash)		
Stringent & Intermediate (84)	5.76	6.44	6.92
Moderate (75)	5.44	6.03	6.49

[a]Source: Reference 14.

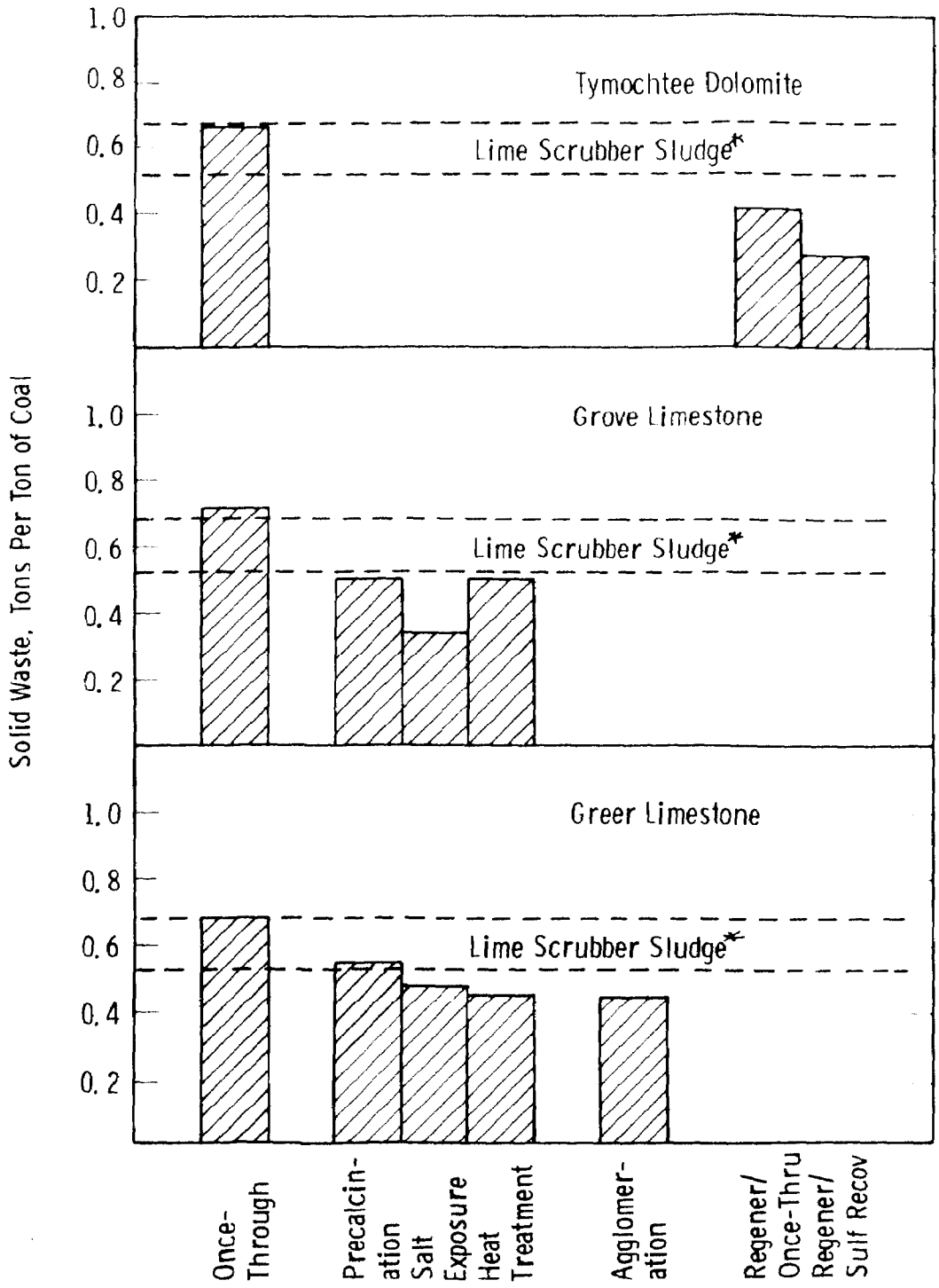

Figure 3 - Solid Waste Production for Eastern Coal - 90% Sulfur Removal (*Wet Basis)[15]

Figure 4 - Solid Waste Production for Western Coal - 70% Sulfur Removal[15]

disposal, and further processing of the solids, have been discussed extensively in our previous reports.[11-13] To provide background information on the disposal of FBC residue, we have condensed conclusions from the previous studies, which were based on a comprehensive test program on a variety of FBC residues:

- Major concerns for FBC residue disposal are the high pH, TDS (total dissolved solids), calcium, and sulfate levels (SO_4) in the leachate; the thermal activity; and the large quantity of solid to be disposed of.
- Trace metal element levels in FBC leachate are low. With only two exceptions (one AFBC bagfilter sample and one PFBC third cyclone catch), leachates of all FBC residues (>40 samples) tested throughout this and previous studies met all the existing drinking water standards (DWS) for heavy metals.
- The total organic carbon (TOC) level in FBC leachates is low. All (>40 samples) except one (TOC = 30 ppm for leachate of an AFBC bagfilter sample) were below or near the detection level (≤10 ppm).
- Trace elements are more concentrated in the carry-over and in its leachate than in that of bed material. The spent bed material, on the other hand, consists predominantly of spent sorbent, and, therefore, its leachate has higher pH, calcium, SO_4, and TDS levels.
- Leaching property is a function of leachate pH. In general, higher levels of trace metal elements exist in leachates having a lower pH.
- The pH, calcium, and TDS levels of an FBC leachate depend largely on the amount of unutilized CaO present in the solid. Higher pH, calcium, and TDS levels are found in the leachates of residues with lower CaO utilization. On

the average, the leachate of AFBC residue has a higher pH, calcium, and TDS level than that of PFBC residue, which generally contains less CaO. Similarly, the leachate of spent limestone sorbent contains higher concentrations of calcium, TDS, and pH than that of spent dolomite.

- Substantial heat is released from AFBC residue upon its initial contact with water and may require special handling and disposal procedures to minimize this thermal activity.
- The thermal activity is largely dependent on the amount of CaO present in the residue and is also a function of the FBC operating conditions, which may result in either calcined or uncalcined sorbent in the form of CaO or $CaCO_3$. Thus, thermal activity is higher for the AFBC than for the PFBC residue and higher in bed material than in carryover.
- Processing FBC residue can effectively reduce thermal activity and lower the permeability of the solid to be disposed of, thus minimizing potential leachate contamination.
- Although an absolute comparison may not be possible, general trends have shown that the physical, chemical, and leaching properties of FBC residue are superior to the nonstabilized FGD sludge with regard to disposal and are comparable to the chemically and physically stabilized FGD residue from a conventional power plant.[16]

On the basis of our findings, we have concluded that residue disposal may not be an obstacle in the commercialization of the FBC process, but further investigation is required. The next few sections of this report provide an assessment of RCRA and RCRA regulations on FBC residue disposal.

5. RESOURCE CONSERVATION AND RECOVERY ACT

OVERVIEW

The Resource Conservation and Recovery Act[1] is comprehensive, with numerous provisions aimed at the environmentally safe disposal of solid waste and the recovery of resources from these wastes. The act greatly expands the role of the federal government in the field of solid waste management, with particular emphasis on creating a major new federal hazardous waste regulatory program while encouraging state and regional solid waste planning. The act is divided into eight subtitles:

- Subtitle A - General Provisions
- Subtitle B - Office of Solid Waste; Authorities of the Administrator
- Subtitle C - Hazardous Waste Management
- Subtitle D - State or Regional Solid Waste Plans
- Subtitle E - Duties of the Secretary of Commerce in Resource and Recovery.
- Subtitle F - Federal Responsibilities
- Subtitle G - Miscellaneous Provisions
- Subtitle H - Research, Development, Demonstration, and Information.

According to the definition in Sec. 1004(27) in Subtitle A, the term "solid waste" means "any garbage, refuse, sludge from a waste treatment plant, water supply treatment plant or air pollution control facility and other discarded material, including solid, liquid, semi-solid, or contained gaseous material resulting from industrial, commercial, mining and agriculture activities and from community activities...." The definition is broad and includes all solid and liquid wastes. Subtitle B is important in that it establishes the "Office of

Solid Waste" (OSW) within EPA and authorizes it to implement RCRA. The key sections that could affect FBC residues, however, are Subtitles C and D on hazardous and nonhazardous waste management.

KEY SECTIONS OF RCRA

Hazardous Waste Management

According to the definition provided in RCRA Sec. 1004(5), the term "hazardous waste" is

> A solid waste, or combination of solid wastes, which because of its quantity, concentration, or physical, chemical, or infectious characteristics may --
>
> (a) Cause, or significantly contribute to an increase in mortality or an increase in serious irreversible, or incapacitating reversible, illness; or
>
> (b) Pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported, or disposed of, or otherwise managed.

Subtitle C - Hazardous Waste Management - establishes a federal program to provide comprehensive regulation of hazardous waste. When fully implemented, this program will provide cradle-to-grave regulation of hazardous wastes. It contains the following sections:

Sec. 3001 - Identification and Listing of Hazardous Waste
Sec. 3002 - Standards Applicable to Generators of Hazardous Waste
Sec. 3003 - Standards Applicable to Transporters of Hazardous Waste
Sec. 3004 - Standards Applicable to Owners and Operators of Hazardous Waste Treatment, Storage and Disposal Facilities
Sec. 3005 - Permits for Treatment, Storage, or Disposal of Hazardous Waste
Sec. 3006 - Authorized State Hazardous Waste Programs
Sec. 3007 - Inspections
Sec. 3008 - Federal Enforcement

Sec. 3009 - Retention of State Authority

Sec. 3010 - Effective Date

Sec. 3011 - Authorization of Assistance to States.

Section 3001 requires EPA - OSW to promulgate criteria for identification of hazardous waste, which OSW has been developing since 1977.[17] In March 1978, a draft containing tentative hazardous waste identification methods was released.[3] A procedure for determining the toxicity of a waste - toxic extraction procedure (TEP) - was drafted. If its TEP leachate exceeded ten times the National Interim Primary Drinking Water Regulations (NIPDWR) the waste would be considered toxic.

Public comments on the draft regulations were solicited. Westinghouse responded by testing typical FBC residues and reference materials (raw sorbent and conventional FGD residue) and communicating the results of TEP testing and our recommendations on TEP procedure to EPA (Appendix A).

On December 18, 1978, EPA formally proposed in the Federal Register[2] RCRA Sec. 3001 regulations, scheduled for promulgation in April 1980. The TEP was significantly modified on the basis of additional information supplied by the public comments (including the Westinghouse recommendations) and was renamed "extraction procedure" (EP). The criterion for hazardous waste was the EP leachate containing higher than 10 x NIPDWR of heavy metal elements, toxic organic herbicides, and pesticides. Extraction procedure testing of FBC residues and reference materials is presented in Section 6. According to the proposed regulations, a waste can be classified as hazardous through either one of the two routes presented in Figure 5:

- By being on the hazardous waste list proposed in the Federal Register, December 18, 1978[2] and August 22, 1979[4] and based on waste sources and processes (at the right of Figure 5)

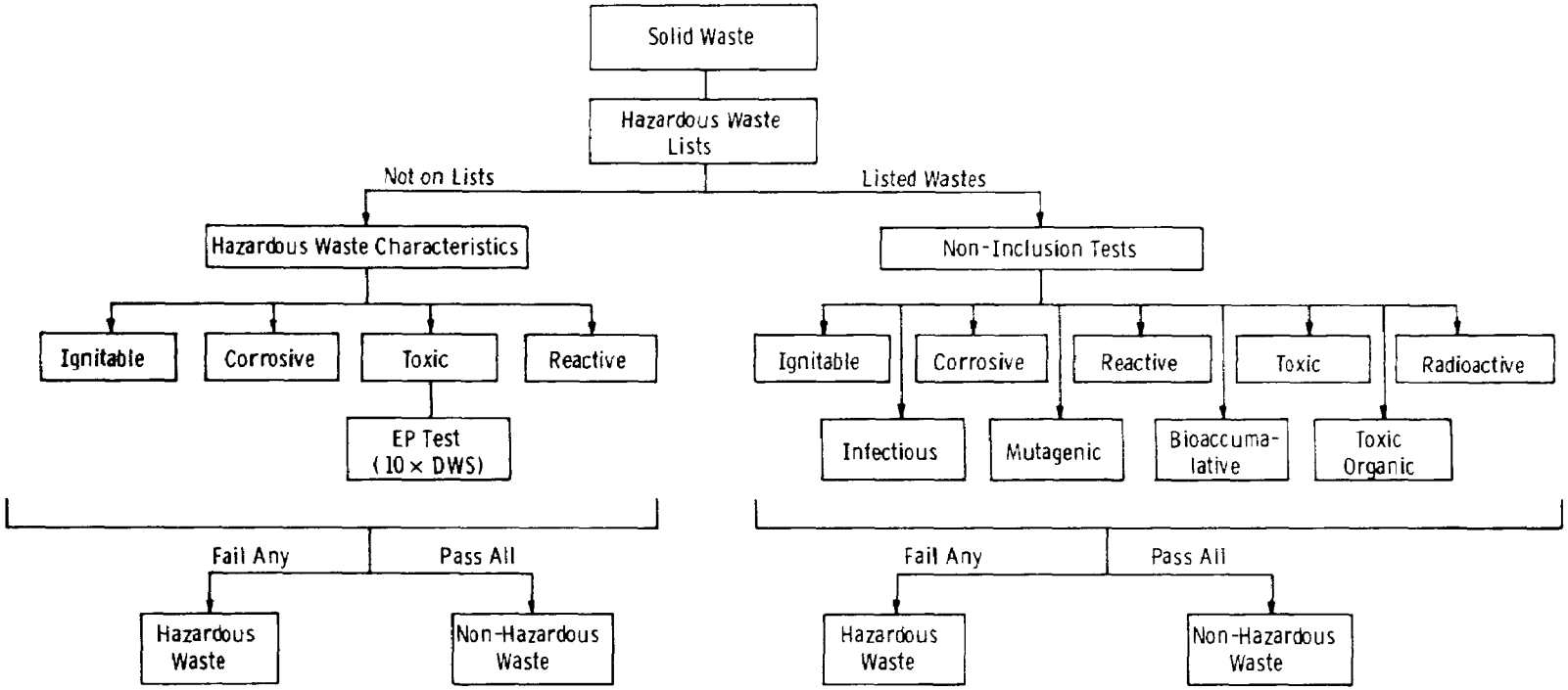

Figure 5. Hazardous Waste Identification Mechanism

- By not being on the list but by possessing one or more hazardous characteristics (ignitability, corrosivity, toxicity, and reactivity left side of Figure 5).

A waste placed on the hazardous list may be demonstrated to be nonhazardous by passing the noninclusion tests on the right in Figure 5.

Fluidized-bed combustion waste is not on the hazardous waste lists, and, therefore, a determination of its hazardous or nonhazardous nature must be made by the mechanism shown on the left of Figure 5. Among the hazardous characteristics considered - ignitability, corrosivity, toxicity, and reactivity - toxicity, for which EPA has proposed an EP and a hazardous criterion (10 x NIPDWR), causes the most concern for FBC residue. Because of the large volume of residue and the limited data on its potential hazard, EPA has proposed a list of "special wastes" under Sec. 3004. These wastes are:[2]

- Cement kiln dust
- Utility waste (fly ash, bottom ash, scrubber sludge)
- Phosphate mining, beneficiation, and processing waste
- Uranium mining and other mining waste
- Gas and oil drilling muds and oil production brines.

Should any of the above wastes be determined to be hazardous according to the criteria in Sec. 3001 they will be regulated by special standards with partial exemption from the cradle-to-grave regulations under Sec. 3002-3005.

In addition to ignitability, corrosivity, reactivity, and toxicity currently proposed, four additional characteristics are to be considered for hazardous waste identification - mutagenicity, genetic activity, bioaccumulation, and additional aspects of toxicity - as indicated by an Advanced Notice for Proposed Rulemaking (ANPR) EPA issued in the same Federal Register (Dec. 18, 1978) to solicit comments and information. Although these are being considered, they are not part of the currently proposed Sec. 3001 regulations.

Sections 3002 and 3003 provide standards for generators and transporters of hazardous wastes. These regulations were promulgated on February 26, 1980.[18] Waste generators are required to determine if their wastes are hazardous according to the criteria to be set forth in Sec. 3001. Generators and transporters of hazardous waste must comply with requirements provided by Sec. 3002-3 (i.e., EPA/DOT regulations) on packaging, labeling, record-keeping and manifest systems to assure that the hazardous waste is delivered to the permitted treatment, storage, or disposal facility designated by the shipper on the manifest.

Section 3004[2] proposes standards for owners and operators of hazardous waste treatment, storage, and disposal facilities. Standards for landfill site selection and designs are provided in these regulations. In essence, a landfill must be located at least 1.5 m (5 ft) above the historical high water table and 150 m (500 ft) from any functioning public and private or livestock water supply, and its leachate must be contained with 1.5 m (5 ft) of natural, in-place soil with permeability (10^{-7} cm/s) or a membrane liner with leachate collection/removal system. The owner/operator of a disposal facility must not only comply with the requirements of the manifest system, record-keeping, and reporting,but must also fulfill the technical and financial requirements for postclosure care of at least 20 years.

Under Sec. 3005 a facility treating, storing, and disposing of hazardous waste must apply for a permit confirming that the facility is complying with Sec. 3004 standards. Under Secs. 3006, 3009, and 3011, federal programs to assist and to authorize states in the development of state hazardous waste programs are provided, if the state so desires, provided the state's program is equivalent to (or more stringent than) and consistent with the federal program.[19]

Sections 3007 and 3008 provide regulations for on-site inspection and federal enforcement. Violation of standards set forth in Secs. 3001-6 could result in a fine of $25,000/day or one year's imprisonment (double for second offenders).

Under Sec. 3010 anyone generating or transporting hazardous waste, or owning or operating a treatment, storage,or disposal facility, is required to file with EPA a notification of its hazardous waste activity within 90 days of the promulgation of regulations of Sec. 3001 on identification and listing of hazardous waste.

Nonhazardous Waste Disposal

If a waste is hazardous, it is subject to the cradle-to grave regulations of Subtitle C, as discussed in the previous section. On the other hand, the disposal of a nonhazardous waste falls under the jurisdiction of Sec. 4004 (Criteria for Sanitary Landfills) of Subtitle D (State and Regional Solid Waste Plans) as well as Sec. 1008 (Solid Waste Management Information and Guidelines). These regulations have been proposed (Federal Register Feb. 6, 1978 and March 26, 1979)[20,21] and recently promulgated (Sept. 13, 1979)[8] to provide "Criteria for Classification of Solid Waste Disposal Facilities and Practices; Final, Interim Final, and Proposed Regulations." This regulation contains minimum criteria for determining what solid waste disposal facilities and practices pose a reasonable probability of adverse effects on health or the environment. Those disposal facilities that meet these criteria are called "sanitary landfills." Those facilities that violate the criteria are "open dumps." EPA is directed to make an inventory of all open dumps except those operating under compliance schedules not to extend beyond five years from the date of inventory. The inventory will provide for the state to provide a plan for closing or upgrading all existing open dumps according to Sec. 4003, as open dumping is prohibited under Sec. 4005.

Subtitle D of the act fosters this cooperative effort by providing for the development of state and regional solid waste management plans that involve all three levels of government - federal, regional, and state EPA. As the federal partner in this process, EPA seeks, through regulations and financial assistance, to aid state initiatives in the formulation and implementation of plans.

The three most important criteria published on sanitary landfills for nonhazardous solid waste disposal[8] with the greatest impact on FBC residue disposal are:

- Surface Water. The leachate and runoff from solid waste disposal must not contaminate surface water. If it is a "point source" discharge, it must comply with any National Pollution Discharge Elimination System (NPDES)[22] requirements developed under the CWA; if the runoff is considered a nonpoint discharge, then the facility must comply with any applicable water quality management plan prepared by a state pursuant to Sec. 208 of CWA.
- Groundwater. Solid waste disposal must not contaminate groundwater beyond its boundary. Should the groundwater be a drinking water source, the groundwater at the disposal facility boundary must not exceed the NIPDWR (Appendix B) or cause an increase in the concentration of that substance in the groundwater where the existing concentration of that substance exceeds NIPDWR. The NIPDWR materials covered in this groundwater requirement include not only the species indicated previously in connection with the EP, but also fluoride, nitrate, certain radioactive contaminants (radium-226, radium-228, and gross alpha particle activity), and microbiological contaminants.
  The September 13, 1979 Federal Register also includes a proposed amendment to the promulgated Sec. 4004 criteria for disposal facilities. This proposed amendment would expand the list of contaminants considered in determining groundwater contamination to include those species contained in the National Secondary Drinking Water Regulations (NSDWR) (Appendix B).[23] These species include pH, SO_4, and TDS, as well as chloride, color, copper, foaming agents, iron, manganese, odor, and zinc. This proposed

expansion in the list of contaminants could have a significant impact on FBC residues under Sec. 4004, should it become part of the leachate criteria in the future.

- Application to Land Used for Production of Food-Chain Crops. Standards based on health and environmental effect have been specified for cadmium and polychlorinated biphenyls (PCB) in the application of solid residue to agricultural land. These criteria for cadmium could affect FBC residue should it be utilized in agriculture.

INTEGRATION WITH OTHER LEGISLATION

Environmental laws in addition to RCRA that are of interest to solid waste disposal include the following:

- Clean Water Act, 1977
  - Federal Water Pollution Control Act, 1972
  - Safe Drinking Water Act, 1974
- Clean Air Act Amendments, 1977
  - Clean Act Act, 1970
- Toxic Substances Control Act (TSCA), 1977
- Occupational Safety and Health Act (OSHA), 1970
- Marine Protection, Research and Sanctuaries Act, 1972.

The integration of RCRA with this and other legislation represents an important challenge to EPA to avoid duplicate effort and overlapping authority. An example of such overlap has been seen in the previous section between Sec. 4004 regulations of RCRA and the NPDES program under the Clean Water Act, when a solid waste disposal facility involves a point source discharge to the surface water.

The EPA has already proposed consolidated permit program regulations and application forms (Federal Register, June 14, 1979) for five programs under four federal environmental laws:[24]

- The Hazardous Waste Management (HWM) program under the Resource Conservation and Recovery Act
- The Underground Injection Control (UIC) program under the Safe Drinking Water Act
- The National Pollutant Discharge Elimination System (NPDES) program under the Clean Water Act
- The Prevention of Significant Deterioration (PSD) program of the Clean Air Act
- State Section 404 (Dredge or Fill) programs under the Clean Water Act.

If a state wishes, each of the permit programs included in the consolidated regulations may be administered by a state instead of the federal government. To obtain program authority from the U.S. EPA, states must ensure that their programs comply with the federal requirements.

6. EXPERIMENTAL CRITERIA AND RESULTS

HAZARDOUS WASTE IDENTIFICATION CRITERIA

As discussed previously, should FBC waste prove to be hazardous according to RCRA Sec. 3001 guidelines, it would be regulated by the provision "Hazardous Waste Management" under Subtitle C, most likely as "utility" waste under the "Special Waste" category. On the other hand, should FBC waste be identified as nonhazardous, it would fall under the jurisdiction of Subtitle D, and its disposal would then be regulated as a sanitary landfill waste.

As FBC waste is not on the list of hazardous wastes by processes and sources under Sec. 3001, we need to determine if it possesses any of the four hazardous characteristics - ignitability, corrosivity, reactivity, and toxicity - as illustrated in the previous section in Figure 5 and further defined in Table 2.

Ignitability

Some residual carbon resulting from incomplete combustion of the coal will remain in FBC waste. This residue, however, is considered unlikely to cause fires through friction, absorption, moisture, spontaneous chemical changes, or retained heat.[17,25,26]

Corrosivity

Although corrosivity is of some concern because of the high pH (in the range of 9 to 13) of leachate of FBC bed material, the pH criteria (≤ 3 or ≥ 12) applies only to aqueous wastes and not to the leachate from a dry, solid waste. Thus, FBC residue is not considered corrosive

Table 2

DEFINITION OF THE CHARACTERISTICS OF A HAZARDOUS WASTE*

Characteristics	Definition
Ignitable Waste	• Is a liquid and has a flash point lower than 60°C
	• Is not a liquid and is liable to cause fires through friction, absorption of moisture, spontaneous chemical changes, or retained heat from manufacturing or processing, or when ignited burns so vigorously and persistently as to create a hazard during its management
	• Is an ignitable compressed gas
	• Is an oxidizer
Corrosive Waste	• Is aqueous and has a pH less than or equal to 3 or greater than or equal to 12
	• Corrodes SAE 1020 steel at a rate greater than 0.250 inches per year at a test temperature of 130°F
Reactive Waste	• Is normally unstable and readily undergoes violent chemical change without detonating; reacts violently with water, forms potentially explosive mixtures with water, or generates toxic gases, vapors, or fumes when mixed with water; or is a cyanide- or sulfide-bearing waste which can generate toxic gases, vapors, or fumes when exposed to mild acidic or basic conditions
	• Is capable of detonation or explosive reaction but requires a strong initiating source or must be heated under confinement before initiation can take place, or reacts explosively with water
	• Is readily capable of detonation or of explosive decomposition or reaction at normal temperatures and pressures
	• Is a forbidden explosive, a Class A explosive, or a Class B explosive
Toxic Waste	• Any material whose extract, after applying the Extraction Procedure, is equal to or greater than 10 x the NIPDWS

*Source: Reference 2.

according to Sec. 3001. It is also worth noting that available data suggest that the pH of leachate can be reduced to less than 12 by codisposal of FBC bed overflow and carry-over materials.

Reactivity

The CaO content of the FBC waste is unlikely to be considered "reactive." Although CaO releases heat when initially exposed to water, this reaction should not be sufficiently violent to classify the residue as "reactive."[17,25,26]

Toxicity

Of the four hazardous characteristics currently proposed, the toxicity criterion could have the greatest impact on FBC wastes. Experimental efforts, therefore, have been directed toward determining, by the EP test, whether FBC residue is a toxic waste according to the RCRA definition of toxicity.

HAZARDOUS WASTE IDENTIFICATION TESTS

Extraction Procedure Test Development

Table 3 summarizes the history of regulation development under RCRA Sec. 3001 and the efforts Westinghouse has undertaken accordingly. Table 4 lists the key differences among the leaching tests contained in the previous draft versions, TEP,[3] and the (Fed. Reg. Dec. 18, 1978) proposed regulations, EP.

The results of Westinghouse efforts in testing the TEP procedures with residues from FBC processes and our recommendations were summarized in an informal document entitled "Assessment of RCRA/TEP test results on FBC residue, Part I" and communicated to EPA in December of 1978 (Appendix A). Partial results and conclusions from our RCRA/EP tests on some FBC residues were previously summarized and communicated to EPA and subsequently published in the Federal Register on Oct. 2, 1979. This section represents our continued effort with the proposed EP procedures.

Table 3

RCRA 3001 REGULATION DEVELOPMENT

Draft Regulations	Proposed Regulations	Key Issues	Westinghouse Actions
March 1978		Toxic Extraction Procedure, TEP, drafted for hazardous waste identification	"TEP" initiated on selected samples • to assist RCRA Sec. 3001 development • to provide initial indication of "hazardous" or "non-hazardous" nature of residues.
	Dec. 18, 1978	• Extraction Procedure, EP, proposed--significantly different from the previous TEP. • A structural integrity test, SIT specified for monolithic block. • "Special Waste" Category created (including utility waste): subjected to partial exemption of hazardous waste regulations. • Advance notice for Proposed Rulemaking on radioactivity and bioassay.	"EP" initiated on selected FBC, reference materials, and raw sorbents.

Table 4

DEVELOPMENT OF EPA LEACH TEST

Parameters \ Draft Date	TEP (Draft, March 1978)	EP (Proposed in Federal Register Dec. 18, 1978)
Sample Size	Not specified	> 100 g
Sample Preparation	Grinding to 3/8 in	Grinding to 3/8 in, or "SIT" hammer test on monolithic block
Leaching Medium	Deionized water with NaOH or acetic acid added	Deionized water with 0.5N acetic acid added
Titrating Agent	1N NaOH or 1:1 acetic acid	0.5N acetic acid
Maximum Titration	No limit	Maximum=4ml/g solid
Final pH	4.9 - 5.2	4.9 - 5.2 or controlled by maximum acid allowed
Temperature	Room temperature	20 - 40°C
Extraction Time	2 x 24 hr = 48 hr total	24 hr single extraction
Solid/Liquid Ratio	1:10 for each extraction, plus original liquor	1:20 plus original liquor
Agitator	Not specified	Not specified, but overhead stirring suggested

Samples

We investigated a total of 26 samples for potential hazard due to toxicity by using RCRA/TEP and/or RCRA/EP tests. These were

- FBC residue. Seventeen FBC residues were selected to include process variations: limestone/dolomite sorbent, AFBC/PFBC boiler/PFBC adiabatic combustor, bed/carry-over from different particulate collection stages, with/ without carbon burnup cell (CBC), and with/without sorbent regeneration. These samples are summarized in Table 5. The composition of the solids, as well as their leaching and thermal activities, have been investigated previously; Appendix C presents data summaries of the sample categories tested here for RCRA. Detailed results of the FBC residue study (on these and other samples) carried out by Westinghouse since 1974 and the specific operating conditions under which the residues were produced can be found in other EPA reports.[11,12,27]
- FGD residue. Three FGD residues (untreated and stabilized) were tested to provide a comparison of FBC results with those from conventional sulfur-removal wastes. The FGD sludge typically consists of calcium sulfite ($CaSO_3$), calcium sulfate ($CaSO_4$), calcium carbonate ($CaCO_3$), and coal ash. The chemical and physical properties of the treated and untreated FGD residues are discussed in our previous EPA report.[12] Appendix C presents a data summary table.
- Conventional coal ash. Three bottom and fly ash samples from two Western Pennsylvania conventional coal-burning power plants were tested to provide comparison. The ash samples typically contain quartz (SiO_2), hematite (α-Fe_2O_3), mullite ($3Al_2O_3 \cdot 2SiO_2$), and spinel. Their

Table 5

SUMMARY OF FBC SAMPLES TESTED USING RCRA/TEP AND RCRA/EP

Sample*	Sorbent	Process Variation
Battelle Bed[28]	Limestone	AFBC, once through
Battelle Carry-over, cyclone	Limestone	AFBC, once through
MERC Carry-over,[29] bagfilter	Limestone	AFBC, once through
PER Carry-over,[30] CBC residue	Limestone	AFBC, once through, with CBC
Argonne C2/C3 Bed[31]	Dolomite	PFBC, once through
Leatherhead Carry-over,[32] primary cyclone	Dolomite	PFBC, once through
Leatherhead Carry-over, secondary cyclone	Dolomite	PFBC, once through
Exxon 73 Bed	Dolomite	PFBC, once through
Exxon 73 Carry-over,[33] 2nd cyclone	Dolomite	PFBC, once through
Exxon 73 Carry-over, 3rd cyclone	Dolomite	PFBC, once through
Exxon 67 Carry-over, 3rd cyclone	Dolomite	PFBC, once through
Exxon 105 Combustor Bed	Limestone	PFBC, with sorbent regeneration
Exxon 105 Regenerator Bed	Limestone	PFBC, with sorbent regeneration
Exxon 105 Carry-over, 2nd cyclone	Limestone	PFBC, with sorbent regeneration
Exxon 105 Carry-over, 3rd cyclone	Limestone	PFBC, with sorbent regeneration
Exxon 105 Regenerator Carry-over	Limestone	PFBC, with sorbent regeneration
Combustion Power P-403[34] Carry-over, baghouse	Dolomite	PFBC adiabatic, once through

*AFBC Units: Battelle (24 in); MERC (18 in); PER (0.46 x 1.83 m)

PFBC Units: Argonne (6 in); Exxon miniplant (32 cm combustor with 21.6 cm regenerator); Leatherhead (3 x 2 ft); Combustion Power CPU - 400 PDU (adiabatic).

chemical, physical and leaching properties have been summarized elsewhere;[35] data summaries are presented in Appendix C.

- Raw Sorbent. A limestone and a dolomite sorbent were tested to provide perspective on sorbent prior to utilization in FBC processes.
- Natural gypsum. A natural gypsum was tested to provide perspective on the extraction procedure on a natural mineral, since $CaSO_4$ is the major component of the FBC residue.

Procedures and Equipment

The EP procedures (Appendix D) as specified in the Federal Register December 18 were followed, allowing for the following interpretations or adjustments:

- "Representative Sample". We used 25 g instead of 100 g because of the limited quantities of FBC solids available. Based on our experience with FBC residue and because of the granular nature of the solids, however, we believe that the samples (25 g) were representative.
- Neither the structural integrity test (SIT) nor the handling of liquor was required for FBC residue because of the nature of the solids (dry granular, <3/8 in).
- "Suitable extractor". We used an Eberbach automatic shaker at its highest speed (140 excursions per min) and found that it provided good solid/water mixing and prevented stratification (see Appendix A). The high-speed shaker was selected also because of the following:
  - The suggested extractor by Associated Design amd Manufacturing Co., Alexandria, VA was not commercially available[36] at the time we initiated the EP tests.

- Oak Ridge National Laboratories (ORNL), who were testing the EP procedures under contract to the EPA Office of Solid Waste, designed and built their own extraction apparatus.[37]
- After trying various agitation modes, including magnetic stirring and agitation by automatic shaker at 70, 88, 108, and 140 excursions/min, we chose to use the automatic shaker at 140 excursions/min (see Appendix A for preliminary TEP studies).

- A Chemtrix Type 45A pH controller was used for automatic titration of some samples. Prior to obtaining the automatic titrator, we followed the manual pH adjustment procedures. Both performed satisfactorily.

Results and Discussion

Table 6 summarizes the trace elements found in the EP leachates and compares them to the criteria for hazardous waste, 10 x NIPDWR. In addition to the metal elements for which EP criteria are currently proposed, NO_3 and F were determined for some samples because criteria for these species were included in the earlier draft (March 1978) of TEP. All EP leachates had Ag, As, Ba, Cd, Cr, Hg, Pb, and Se at concentrations below 10 x NIPDWR except for the leachates of Exxon 105 (a PFBC run with sorbent regeneration) carry-over from the 2nd cyclone which had a larger amount of As. The higher than 10 x DWS value of arsenic would cause this particular solid to be designated as "hazardous waste" should it need to be disposed of alone. Since the bed material and carry-over from other cyclones are not toxic, however, with arsenic values several orders of magnitude lower, and solids from different sources in the same process would most likely be disposed of together, we believe that the EP leachate of the mixture would be nontoxic. Nevertheless, it is important to note that the EP leachate of the second cyclone carry-over from a regenerative PFBC run alone had much higher levels of arsenic than did the other EP leachates and warrants special attention. Although lower than the criterion, chromium was at much higher levels in

Table 6

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LEACHATE CHARACTERISTICS (TRACE ELEMENTS) FROM RCRA/EP TEST

	Trace Elements, mg/ℓ									
Sample	Ag	As	Ba	Cd	Cr	Hg	Pb	Se	F	NO_3 (as N)
Battelle Bed	<0.02	0.001	<1	<0.01	0.09	<0.0005	<0.04	0.001	<1	<5
Battelle Carry-over, cyclone	<0.02	0.001	1	<0.005	0.06	0.0007	<0.04	<0.001	<1	1.6
MERC Carry-over, bag filter	<0.02	0.004	<1	<0.005	0.4	0.0008	<0.04	0.01	<1	15
PER Carry-over, CBC residue	<0.02	<0.001	<1	<0.01	0.04	0.0007	<0.03	<0.001	-	-
Argonne C_2/C_3 Bed	0.02	0.023	<1	<0.01	0.02	<0.0005	<0.04	0.003	1.7	<5
Leatherhead Carry-over, Primary cyclone	<0.04	0.002	<1	<0.01	<0.05	0.0005	<0.04	0.007	<1	<1
Leatherhead Carry-over, 2nd cyclone	<0.04	0.012	<1	<0.01	<0.05	0.0021	<0.04	0.008	<1	<1
Exxon No. 73 Bed	<0.04	0.002	<1	<0.01	<0.05	<0.0005	<0.04	0.003	<1	<1
Exxon No. 73 Carry-over, 2nd cyclone	<0.04	0.002	<1	<0.01	0.06	0.001	<0.04	0.020	<1	<1
Exxon No. 73 Carry-over, 3rd cyclone	<0.04	<0.001	<1	<0.01	0.35	0.0022	<0.04	0.017	<1	<1
Exxon No. 67 Carry-over, 3rd cyclone	<0.02	0.007	<1	0.045	<0.02	0.0008	<0.04	0.005	<1	<1
Exxon No. 105 Combustor Bed	<0.02	<0.001	<1	<0.01	<0.05	0.0006	<0.05	<0.001	-	-
Exxon No. 105 Regenerator Bed	<0.02	<0.001	<1	<0.01	0.15	0.0015	<0.01	0.004	-	-
Exxon No. 105 Carry-over, 2nd cyclone	<0.02	0.68 to 1.12	<1	<0.01	<0.05	0.0019	<0.05	0.008	-	-
Exxon No. 105 Carry-over, 3rd Cyclone	<0.02	0.004	<1	<0.01	<0.05	0.0012	<0.05	0.007	-	-
Exxon No. 105 Regenerator Carry-over	<0.02	<0.001	<1	<0.01	<0.05	0.0014	<0.05	<0.001	-	-
Combustion Power P-403 Carry-over, baghouse	<0.02	<0.001	<1	<0.005	<0.02	0.0009	<0.04	<0.001	-	-
Untreated FGD Residue	<0.04	0.069	<1	<0.01	<0.05	0.0013	<0.04	0.017	4.2	≤1
Stabilized FGD Residue	<0.04	0.058	<1	<0.01	<0.05	0.001	<0.04	0.08	1.7	≤1
Fly Ash No. 1	<0.02	0.065	<1	<0.005	<0.02	0.0006	<0.04	0.02	<1	<1
Fly Ash No. 2	<0.02	0.005	<1	<0.01	0.03 to <0.05	0.0013	<0.03	0.009	-	-
Bottom Ash	<0.02	<0.001	<1	<0.01	<0.03	0.0011	<0.03	<0.001	-	-
Reference, dolomite sorbent	<0.02	<0.001	<1	<0.005	<0.02	0.0009	<0.04	<0.001	<1	<1
Reference, natural gypsum	<0.02	0.001	<1	<0.005	<0.02	0.0011	<0.04	<0.001	<1	1.4
Criterion, 10x NIPDWR	0.5	0.5	10.0	0.1	0.5	0.02	0.5	0.1		

- = not analyzed

▨ = exceeds 10 X NIPDWR

three EP leachates than in the others: AFBC and PFBC fines from the 3rd cyclone and bagfilter, and PFBC regenerator bed material had chromium concentrations in their EP leachates (0.15 to 0.4 ppm) close to the chromium criterion, 0.5 ppm. Samples from these sources, therefore, should also be emphasized in future investigations.

As there is no reason to believe that the FBC residue would contain chlorinated organic pesticides and herbicides, EP analyses for Lindane, Methoxychlor, Toxaphene, 2.4-D and 2.4.5-TP Silvex, which were also proposed in Sec. 3001, were not performed.

The characteristics of EP leachates in addition to their trace element concentrations are summarized in Table 7. As expected, the major species, such as calcium, SO_4, and specific conductance (an approximation of TDS), were high in the EP leachates of FBC residues, although no hazardous criteria were proposed for these substances. In most cases the maximum allowable acid (4 ml of 0.5N acetic acid per gram of solid) was reached so that the final pH was much higher than 5.

Table 8 summarizes Westinghouse results of Subtitle C tests based on the currently proposed hazardous waste identification methods. Work by other investigators has been closely monitored and is incorporated in the next section to assess the impact of RCRA on the disposal of FBC residue.

NONHAZARDOUS WASTE DISPOSAL CRITERIA AND RESULTS

Because the EP test results indicated that FBC residue would most likely be nonhazardous, its disposal would be regulated under "sanitary landfill" for nonhazardous waste under RCRA Subtitle D.

According to the regulations promulgated in the Federal Register on September 13, 1979, leachate of a sanitary landfill should comply with the NPDES requirements according to the Clean Water Act if it is a point source discharge. Accordingly, the facility would have to employ the best technology for reducing effluent emissions. Current regulations and

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Table 7

LEACHATE CHARACTERISTICS (MAJOR SPECIES) FROM RCRA/EP TEST

Sample	Total Volume 0.5 N Acetic Acid Added/mℓ	Final pH	Specific Conductance μmho/cm	Ca, mg/ℓ	Mg, mg/ℓ	$SO_4^=$ mg/ℓ
Battelle Bed	100[a]	11.99	12,000	3,144	0	2192.5
Battelle Carry-over, cyclone	100[a]	12	11,730	3,156	7.2	902.5
MERC Carry-over, bag filter	100[a]	10.7	7,040	2,416	28.8	1,000
PER Carry-over, CBC residue	100[a]	11.73	11,400	2,752	21.6	840
Argonne C_2/C_3 bed	100[a]	9	7,800	1,440	926.4	1,150
Leatherhead Carry-over, primary cyclone	100[a]	9.52	7,520	1,512	787.2	1896.2
Leatherhead Carry-over, secondary cyclone	44	5.3	4,910	960	446.4	2,330
Exxon No. 73 Bed	100[a]	10.1	7,090	2,432	81.6	1,200
Exxon No. 73 Carry-over, 2nd cyclone	100[a]	11.12	7,670	2,560	7.2	1,060
Exxon No. 73 Carry-over, 3rd cyclone	100[a]	9.2	7,100	1,520	667.2	1,395
Exxon No. 67 Carry-over, 3rd cyclone	16	5.02	5,900	472	931.2	2,800
Exxon No. 105 Combustor Bed	100[a]	11.78	12,600	3,156	< 10	850
Exxon No. 105 Regenerator Bed	100[a]	11.85	12,600	3,128	< 5	931
Exxon No. 105 Carry-over,[b] 2nd cyclone	100[a]	7.72 to 7.78	7,140 to 7,620	2,296 to 2,420	69.6 to 74.4	960 to 1,162
Exxon No. 105 Carry-over, 3rd cyclone	43	5.18	3,940	1,136	21.6	1,094
Exxon No. 105 Regenerator Carry-over	100[a]	11.73	12,100	3,016	24	682
Combustion Power P-403 Carry-over, Baghouse	100[a]	9.71	7,980	1,288	1051.2	2,800
Untreated FGD residue	100[a]	6.32	6,440	2,140	88.8	1,020
Stabilized FGD residue	88	5.35	5,550	1,744	64.8	737.5
Fly Ash No. 1	24	5.05	1,620	372	21.6	1,010
Fly Ash No. 2	35	4.98	2,630	580	64.8	590
Bottom Ash	8	5.13	790	152	14.4	151.5
Reference, dolomite sorbent	95	5.08	4,640	776	460.8	10.6
Reference, natural gypsum	11	5.02	2,190	600	9.6	830

[a] Maximum allowable amount of 0.5 N acetic acid

[b] Several samples tested

Table 8

HAZARDOUS WASTE CRITERIA (RCRA SECTION 3001)

Characteristics	Status	Preliminary Indications FBC Residue	Comment
1. Ignitability	Proposed Dec. 18, 1978 in Fed. Reg. Scheduled to be promulgated in April 1980. Not intended to be static; to be reviewed periodically after promulgation	No	
2. Corrosivity		No	Current proposed regulations apply only to liquid waste pH >12 or <3, but not to leachates of dry solid wastes.
3. Reactivity		No	"Sulfide-bearing waste which can generate toxic gases" ...or, "reacts violently with water"....Some uncertainty may arise from the interpretation of this qualitative statement, especially with regard to regenerative, PFBC residue.
4. Toxicity		No	Based on results of "EP" leachates; pass 10 x primary DWS
5. Radioactivity	Advanced Notice for Proposed Rulemaking, Dec. 18, 1978 Comments/information invited before formal proposal.	Preliminary results from ORNL and ASTM indicated FBC residue to be non-toxic with respect to mutagenicity, aquatic and phytotoxicity[5-7]	
6. Genetic Activity			
7. Bioaccumulation			
8. Additional Aspects of Toxicity			

standards under CWA--in particular, effluent limitation guidelines and new source performance standards for steam electric power plants--do not specifically define "best technology" and effluent emission limits for FBC. At the present time, therefore, effluent controls for utility (or industrial) FBC units, including FBC residue disposal sites, would have to be designed utilizing best engineering judgment. Among the current guidelines for conventional steam electric power plants,[38] the effluent guidelines for heavy metals (Fe and Cu) which are equal to or less stringent than DWS are not expected to cause problem, since the FBC leachates meet DWS. Similarly, the total suspended solids (TSS), oil and grease from the FBC leachate, are expected to meet the standards. However, pH guidelines, 6.0 to 9.0 for power plant effluent,will, of course, cause the most concern should the leachate from an FBC residue disposal facility constitute a point-source discharge, since the pH of a typical FBC leachate is frequently higher than 9.

According to the currently published RCRA Subtitle D regulations, a sanitary landfill should not contaminate the groundwater at the facility boundary to levels above the NIPDWR. In the same Federal Register (Sept. 13, 1979), an amendment was proposed to add the secondary DWS (NSDWR) to the standards. The primary and secondary DWS are given in Appendix B. Table 9 summarizes typical FBC leachate characteristics, and compares them with the primary and secondary DWS (NIPDWR and NSDWR). The FBC leachate was generated by the 200-hr continuous shake test (reported in detail in previous Westinghouse reports) and thus represents the maximum contamination release. Effects of soil attenuation and further dilution before reaching the groundwater as well as dilution by the groundwater are not incorporated in the 200-hr shake results.

Comparison of FBC leachate with primary DWS (NIPDWR) and secondary DWS (NSDWR) indicate the following:

- Heavy metal elements meet DWS even without dilution and are not expected to cause environmental problems. FBC

Table 9

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COMPARISON OF A TYPICAL FBC LEACHATE WITH THE DWS
(Leachate Generated by 200-hr Shake Method)

Substance	FBC Leachate, mg/ℓ	DWS, mg/ℓ	
		NIPDWR	NSDWR
Al	0 to > 2		
Ag	< 0.05	0.05	
As	< 0.05	0.05	
B	0 to > 5		
Ba	< 1	1.0	
Be	< 0.02		
Bi	< 0.04		
Ca	> 500		
Cd	< 0.01	0.01	
Co	< 0.1		
Cr	< 0.05	0.05	
Cu	< 1		1.0
Fe	< 0.3		0.3
Hg	< 0.002	0.002	
Mg	< 30		
Mn	< 0.05		0.05
Mo	< 5		
Na	0 to > 100		
Ni	< 0.1		
Pb	< 0.05	0.05	
Sb	< 0.5		
Se	< 0.01	0.01	
Si	0 to 30		
Sn	< 1.0		
Sr	0 to > 10		
Ti	< 2		
V	< 1		
Zn	< 3		5.0
Zr	< 1		
SO_3	< 10		
SO_4	1000-2000		250
Cl	< 250		250
F	< 2.4	2.4	
NO_3 (as N)	< 10	10.0	
TOC	< 30		
pH	9 to 12		6.5-8.5
TDS	2000 to 4000		500
Specific Conductance millimho/cm	0.5 to 10.0		
Color	None		15 color units
Odor	None		3 threshold odor number
Foaming Agents	None		0.5
Radioactivity	Not determined	5 pCi/ℓ Ra 226 & 228	
Biological Activity	None	4 coliform/ 100 mℓ	

▨ - exceeds DWS

leachate has Ag, As, Ba, Cd, Cr, Hg, Pb, and Se below the primary DWS; and Cu, Fe, Mn, Cu, and Zn below the secondary DWS.

- Nitrate and fluoride meet the NIPDWR without dilution and, thus, will be no problem.
- Chloride meets the NSDWR and is not expected to cause environmental concern.
- Although the NSDWR are not part of the current standards for groundwater, we have selected 10 x DSDWR as the criterion for comparing with the worst-case leachate,following the assumption by EPA and attenuation/dilution faction of 10 in formulating hazardous waste criteria. Sulfate and TDS exceed NSDWR but are within 10 x NSDWR and would not be expected to contaminate the groundwater, provided that the disposal landfill is properly designed to incorporate the site-specific parameters.
- The pH of a typical FBC leachate without dilution and soil attenuation is higher than NSDWR (6.5 to 8.5) and may possibly require further control, should NSDWR become incorporated in the standards. Note, however, that interaction with soil, which frequently is acidic, may play a critical role in reducing the leachate pH to below the NSDWR. Preliminary data from the current Westinghouse laboratory studies (under the same EPA contract) indicate that the leachate pH can be effectively reduced after exposure to clay materials--for example, montmorillonite and kaolinite.
- Color, odor, and foaming agents which are in the NSDWR are not expected to cause problems since the FBC leachate is generally colorless, odorless and does not contain foaming agents.

- Radionuclides (Ra-226, Ra-228, and gross α-particle radioactivity) were not tested in this study, as we expect them to be similar to the leachate of the conventional power plant residue.
- Microbiological contaminant in FBC leachate was tested by the Westinghouse Biological Group. The FBC leachate causes little environmental concern due to biological activity. No coliform bacteria were found in any of the leachates tested--from bed material, secondary, and third cyclone catches. Both the high FBC process temperature and the highly alkaline leachate are factors attributing to zero microbiological activity.
- The low Cd content in FBC solid and the high pH of leachate assure that the Cd standard for agricultural application (annual application rate less than 0.5 to 2.0 kg per hectare on land use with a higher rate allowed for higher pH) can be met without difficulty.

The NSDWR, which defines criteria for copper, iron, manganese, zinc, chlorine, SO_4, TDS, pH, color, odor, and foaming agents, is not currently part of RCRA. We have assessed these criteria, however, because they have been proposed for inclusion in addition to those in the NIPDWR for groundwater.[8]

7. ASSESSMENT OF RCRA IMPACT ON FBC RESIDUE DISPOSAL

RCRA test results indicate that the FBC residue would be nonhazardous according to the currently proposed definition under RCRA Sec. 3001 as would the conventional utility wastes (FGD residue and coal ash), based on test results from limited samples. Since FBC residue appears to be nonhazardous according to the current RCRA Sec. 3001 definition, it would not be subject to the costly cradle-to-grave regulation under RCRA Subtitle C--Hazardous Waste Management. Instead, it would be regulated as a "sanitary landfill" residue under Subtitle D--state and regional solid waste plans--which is almost as stringent in regulating site selection and disposal facility design, operation, and monitoring but is much more relaxed in the requirements for generation, transportation,and manifest system of the solid waste.

IMPACT OF NONHAZARDOUS WASTE DISPOSAL REGULATIONS ON FBC RESIDUE DISPOSAL (Subtitle D)

According to the current regulations promulgated on September 13, 1979, eight criteria, including site selection and leachate monitoring, apply to the nonhazardous solid waste sanitary landfills where FBC waste would most likely be disposed of. The most important issues are the protection of ground- and surface water. Compliance with RCRA and NPDES under CWA is required. Efforts by EPA are under way to consolidate the solid waste permit system. Since effluent guidelines for FBC units and FBC residue disposal facilities are unavailable, the best engineering judgment for designing, operating, and managing the disposal facility is required to avoid potential adverse environmental effects. FBC residue disposal is expected to meet the current standards for sanitary landfill--groundwater at the disposal facility boundary meeting the primary drinking water standards (NIPDWR, Appendix B). Should the

secondary DWS (NSDWR) be included as is proposed, however, FBC leachate pH would be a major concern: the pH of a typical FBC leachate ranges from 9 to 12, while the pH NSDWR ranges from 6.5 to 8.5. The TDS and SO_4 are of marginally passing values if a ten times attenuation/dilution factor is assumed. As soil attenuation can play a major role in reducing leachate pH, TDS, SO_4, and calcium, site selection and disposal facility design are critical factors in determining if leachate control might be required. The potential environmental impact of FBC residue depends, in general, not only on waste characteristics but also on site-specific factors (such as hydrology, geology, climate, and soil characteristics) and the design, operation, and management of the disposal facility. Contamination due to trace metal elements and microbiological activity is not expected. Radioactivity, if any, should be similar to that of a conventional power plant residue.

IMPACT OF HAZARDOUS WASTE MANAGEMENT REGULATIONS ON FBC RESIDUE DISPOSAL (Subtitle C)

With the exception of Sec. 3002 and 3003 (standards on generators and transporter (Fed. Reg. Feb. 26, 1980)), regulations under Subtitle C for "Hazardous Waste Management" had not been promulgated prior to the completion of this study. The assessment presented here, therefore, is based on the proposed regulations of December 1978. (Fed. Reg. Dec. 18, 1978).

- FBC residue nonhazardous. We have identified FBC residue as nonhazardous according to the proposed Sec. 3001 regulations prior to their promulgation. Although satisfying the current standards, specific elements (As, Cr) have been identified for specific FBC solids (carry-over fines <15 μm and PFBC residue with sorbent regeneration) as being in much higher concentration than in the average FBC leachate and therefore warranting special attention in future investigations.

- Special Waste Category. Because of their large volume, as well as the limited information available on them, six wastes, including utility waste, are proposed as "special wastes" and will be subject to partial exemption from the cradle-to-grave regulation of Subtitle C, should they be determined to be hazardous. Although results indicate that the FBC residue would be nonhazardous and, therefore, need not be subject to the regulations on "special waste category" under RCRA Sec. 3004, the proposed "special waste," utility wastes included, do not mention FBC residue. We recommend, therefore, that the FBC waste (both from utility and industrial units) be added to the list of utility wastes that currently includes FGD, bottom ash, and fly ash, should any FBC residues produced under specific conditions be determined to be hazardous.
- The Structural Integrity Test (SIT). Should FBC residue be disposed of as a monolithic mass (after being processed to reduce its environmental impact), the structural integrity test (SIT)--the sample preparation procedure preceding the EP test for leachability--will be relevant to its disposal. Since the unprocessed FBC solids were found to be nonhazardous, however, we do not expect the processed forms to prove hazardous unless other solids which may prove hazardous are processed with them.
- Bioassays and Radioactivity. Although bioassays and radioactivity have been considered in listing the hazardous wastes by processes and sources, they are not included in the currently proposed identification methods for hazardous characteristics (ignitability, corrosivity, reactivity, and toxicity) and, thus, were not tested in our investigation on FBC residues. EPA, however, is considering an expansion of the hazardous characteristics to include radioactivity, genetic activity, bioaccumulation,

and additional aspects of toxicity (Advance Notice for Proposed Rulemaking, Fed. Reg. Dec. 18, 1978).[2] Uncertainties still exist in many dimensions such as the compatibility of biological testing with the acetate-based EP leachate, reliability of the various specified procedures (mutagenicity, bioaccumulation, aquatic toxicity, and phytotoxicity), and interpretation of the results. EPA is currently inviting information and comments. Oak Ridge National Laboratory has conducted bioassays on fossil fuel residues under a DOE and EPA contract and found the following results (Table 10).[5,6] FBC residue showed negative results in mutagenicity, aquatic toxicity, phytotoxicity, and metal elements, which agreed with our conclusion that it would be nonhazardous. ASTM D19.12 also carried out bioassay tests; the results are less conclusive because of difficulty encountered in preparing the sample in test procedures and in interpreting the test results.[7] Radioactivity was not part of the proposed tests in the identification mechanism and thus was not measured in this study, but we expect it to be similar to that of a conventional power plant residue.

- Best Approach for Identifying Hazardous Waste. Experts differ in their opinions about the best approach to identifying hazardous waste: the "single-test" approach (which differentiates solid wastes into hazardous or nonhazardous) versus "multitest" screening (which may classify wastes into degree of hazardousness). In the former approach, EPA-OSW has proposed an extraction procedure to which we react favorably on the basis of our experience with FBC solids, which are primarily inorganic in nature. On the other hand, because solid wastes differ in their chemical and physical characteristics, and because a waste can be hazardous or nonhazardous depending not only on the

Table 10

TOXICITY OF EP EXTRACTS FROM FOSSIL-FUEL PROCESS RESIDUES BY ORNL[a]

Solid Waste	Metal Toxicity	Bioassay		
		Aquatic Toxicity	Phytotoxicity	Mutagenicity
FBC Residue	-	-	-	-
Power Plant No. 1 - Fly Ash		-	+	-
- Bottom Ash	-	-	+	-
- Scrubber Sludge	-	-	+	-
- Treated Scrubber Sludge	-	-	+	-
Power Plant No. 2 - Fly Ash	-	-	-	-
Gasification Bottom Ash No. 1	-	-	-	-
Gasification Bottom Ash No. 2	-	+	-	-
Gasification Bottom Ash No. 3	-	-	+	-

[a]Source: Reference 6
+ Toxicity
- Nontoxicity

intrinsic properties of the waste but also on where and how it is disposed of, we feel that an approach based on "degree of hazardousness" on a site-specific, multitest screening basis deserves serious consideration.

- Hazardous Waste Disposal Facility Design. Should any FBC residue be found to be hazardous, it must be disposed of in a permitted hazardous disposal facility. According to the proposed Sec. 3004 regulations (Federal Register, Dec. 18, 1978), the landfill shall be designed at least 1.5 meters above the historical high water table and at least 150 m from any public or private water supply. The design of the landfill shall be such that leachate can be collected, removed, and treated. This is accomplished by having an underlying liner, either of >1.5 m of natural in-place soil with a permeability equal to or less than 1×10^{-7} cm/s or by using a membrane liner system for leachate collection. In addition to the requirements for landfill site selection and design, a hazardous disposal facility must comply with stringent standards including security, emergency plan, manifest system, and closure and postclosure care. The cost impact can be significant.

Should any FBC residue be designated as hazardous, further processing to render it nonhazardous would be highly recommended. The decision, of course, would depend on the economic trade-off between the costs for hazardous disposal and the cost for processing the residue to render it nonhazardous for disposal based on the waste-specific and site-specific factors.

IMPACT OF RCRA ON FOSSIL-FUEL ENERGY FACILITIES

Impact of RCRA on Utility Solid Waste

The regulations implementing RCRA pose new levels of control for the traditional solid waste disposal process and establish a new set of

cradle-to-grave standards for hazardous waste. Recent EPRI[39] studies indicated that some utility wastes could be classified hazardous. EPA has recognized the seriousness of these possibilities and has designated utility waste among the high volume "special wastes" should they be determined to be hazardous. Solid residues from emerging coal technologies, such as FBC, are expected to belong to this category should any be identified as hazardous. The same EPRI study concluded that among the hazardous characteristics the major concern for utility waste is toxicity, followed by corrosivity and radioactivity. The regulation framework used in the EPRI study was the March draft of Sec. 3001 regulations, which was substantially different from the currently proposed version. It is fair to conclude, however, that there is an insufficient data base for the utility waste, particularly in radioactivity and bioassays, and further investigation is required.

Impact of RCRA on Siting of Fossil-Fuel Energy Facilities

RCRA will affect not only the technology and costs of existing fossil-fuel plants, but probably also future facility siting decisions. The key aspects of the Act that probably will influence the siting of new energy facilities are provisions for hazardous and solid waste disposal (Subtitle C and D) and provisions for resource recovery (Subtitle E).

RCRA Subtitle D discourages facilities from being sited in areas with sandy soils, with high groundwater tables, in floodplains, in high seismic risk areas, in critical habitats, in areas characterized by heavy rains, or in areas with high alternative use values. Energy developers will favor sites that are high, dry, and close to clay deposits (e.g., bentonite) for less expensive waste storage and disposal. Urban areas will be avoided because most cities already face serious problems in disposing of municipal waste. Low-ash coal will be more attractive because of the smaller amount of waste produced.[40,41] Calzonetti indicates that because the largest deposits of low-ash coal

occur in the West, RCRA may increase the attractiveness of western sites over eastern ones.[40] RCRA encourages resource recovery, and markets for ash utilization and sulfur recovery will play a role in siting. Locations adjacent to rivers or other bodies of water will be preferred because they provide inexpensive transportation for wastes and recovered materials. Finally, in light of the awareness created by RCRA, public support or opposition is becoming increasingly important in deciding the siting of fossil-fuel energy facilities.

Impact of RCRA on FBC Economics

The economics of fluidized-bed combustion systems (cost of electricity, steam cost, etc.) are very sensitive to the total cost of sorbent (sorbent purchase, delivery, and solid waste disposal cost reported on a fresh sorbent basis). While the waste solids from FBC processes are not likely to be classified as hazardous, some increase in sorbent disposal cost may occur. The major cost increase would result from the need to find a suitable disposal site that fulfills the RCRA requirements but may have associated with it high transportation costs. Other disposal site costs are expected to result in less significant increases in FBC costs. Such increases would be site dependent. Figure 6 indicates the impact of the total cost of sorbent on the cost of electricity for electric utility AFBC and PFBC systems.[42] A conventional plant with lime slurry scrubbing is also shown. Greater sensitivity to total sorbent cost is seen for the FBC systems, and the required Ca/S ratio is an important factor.

The sensitivity shown may lead FBC developers to consider more seriously alternatives to reduce the Ca/S ratio if RCRA does result in an increase in solid waste disposal cost (e.g., optimum operating conditions or advanced sulfur removal systems), or methods to reduce cost increases resulting from RCRA (e.g., solid waste processing or utilization).

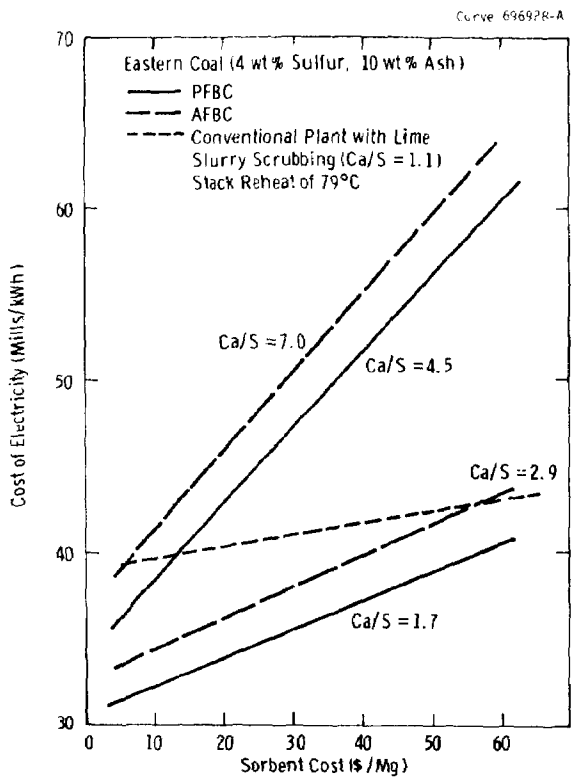

Figure 6 - Effect of Sorbent Cost on the Economics of AFBC and PFBC Systems*,[42]

*Sorbent cost can be defined to include disposal costs.

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APPENDIX A

ASSESSMENT OF RCRA/TEP TEST RESULTS ON FBC RESIDUE
PART I - EPA DRAFT PROCEDURE OF MARCH 1978

I. INTRODUCTION

The most important environmental law affecting solid waste disposal is the Resource Conservation and Recovery Act (RCRA) of 1976 (the Solid Waste Disposal Act of 1965, as amended by P.L. 94-580, 1976).[1]

Under the initial implementation strategy,[2] EPA is focusing on three provisions: identification of hazardous waste characteristics; listing of hazardous wastes; and preparation of guidelines for handling and disposition of wastes. Subtitle C of RCRA covers hazardous waste management and deals with identification and listing of hazardous waste. Under the authority of Sec. 3001, EPA is currently developing criteria for identification methods (tentatively) for hazardous waste, which may be one or more of the following: ignitable, corrosive, infectious, reactive, radioactive, or toxic.[3]

Under title 40, Chapter 1, Part 250 - "Hazardous Waste Guidelines and Regulations," Subpart A and Sec. 250.13 - of the March draft, a TEP procedure has been identified to serve as a standard leaching test. The resultant leachate (TEP extract) will be compared with the criteria set forth in Sec. 205.12 for hazardous waste.

Since the RCRA/TEP test is designed to provide a generalized standard test with which to evaluate the "hazardous" or "nonhazardous" nature of all solid wastes, we feel that it is important to carry out such tests (draft procedure) on "typical" FBC residues and to communicate to the EPA Hazardous Waste Management Division any difficulties or

problems encountered with this type of waste. The information may then assist EPA personnel to make further modification and complete the final version of RCRA/TEP.

2. EXPERIMENT

The sections on equipment and procedures are direct excerpts from Sec. 250.13 of the March draft of "Hazardous Waste Guidelines and Regulations."[3]

2.1 Equipment

1. An agitator which, while preventing stratification of sample and extraction fluid, also insures that all sample surfaces are continuously brought into contact with well mixed extraction fluid.
2. Equipment suitable for maintaining the pH of the extraction medium at a selected value.

2.2 Procedure

1. Weigh a representative sample of the waste to be tested. Separate sample into liquid and solid phases by either centrifugation followed by filtration of the liquid through a 0.4 to 0.5 micron filter media or by pressure filtration using a 0.4 to 0.5 micron filter having a surface area of at least 0.5 cm sq per gram of sample. Save the liquid for further use.
2. Grind the solid material, if necessary, to pass through a 9.5 mm (3/8 in) standard sieve.
3. The solid material is taken and added to eight times its weight of deionized water. The pH of the solution is then adjusted to pH 5 with 1:1 acetic acid or 1N sodium hydroxide. Samples are to be agitated during pH adjustment. pH measurements are to be determined electrometrically following standard calibration procedures.
4. Samples are to be maintained at room temperature during extraction. Samples are to be agitated for a period of 24 ± 0.5

hours with pH to be maintained during leaching within the range of 4.9 to 5.2. The preferred method of maintaining pH is with automatic titration. If the necessary equipment is not available, manual procedures can be employed.

5. At the end of the 24 hour extraction period the solution is filtered as in step 1. The filtrate is then adjusted with deionized water so that its volume is 10 times the initial weight of solid sample [v(cc)/w(gm)]. The liquid is combined with the original liquid phase and the solid reextracted with fresh extractant as in steps 3 and 4.
6. At the end of the second extraction period the mixture is filtered, the concentration adjusted as in step 5, and the liquid phase combined with that from the previous separations. This combined liquid, and any precipitate that later forms, is designated as the Toxicant Extraction Procedure eluate.

The TEP eluate generated from the above procedure is hereby referred to also as the leachate unless specified otherwise.

2.3 Samples

Six FBC residue samples were selected for preliminary RCRA/TEP tasks to include process variations: limestone/dolomite, AFBC/PFBC/adiabatic, bed/cyclone/additional filter. A FGD sludge was also tested for comparison. Raw sorbents (limestone and dolomite) and natural gypsum were tested in parallel to provide references. These samples are listed in Table 1.

2.4 Results

Since agitation mode is not specified in the draft RCRA/TEP procedure, we chose to use magnetic stirring, which provides a vigorous stirring action, for initial testing in order to provide the worst-case leachate. All solids became very fine powder after leaching (through physical abrasion and chemical neutralization and dissolution). The

resultant leachates - the "TEP eluate" - were analyzed for major species and trace elements, the latter being dictated by the draft hazardous criteria under the authority of RCRA Sec. 3001.

Table 2 summarizes pH, specific conductance, calcium, magnesium, SO_4, and the total amount of 1:1 acetate acid (8.75N) used to reach pH = 5.0 ± 0.1. Clearly, a large quantity of acid was required to neutralize the highly alkaline FBC residue to achieve final pH = 5. This was also true for the raw limestone and dolomite sorbents. Magnesium, which previously has been found to be nonsoluble in the alkaline leachate, is highly leachable in acetic acid leachate of pH = 5. (Note the high magnesium concentrations in leachates of spent Argonne and PDU dolomite as well as of raw Tymochtee dolomite.)

Table 3 summarizes the trace element concentrations and compares them with the toxic criteria, 10 x DWS. Several elements were found to exceed the criteria when leachates were induced by the TEP method. It must be pointed out that the vigorous magnetic stirring action probably results in nearly complete extraction, which is not the objective of the RCRA/TEP test.[4]

Since the degree of agitation is obviously important to the resultant leachate quality, we then attempted to determine the leachate characteristics as a function of agitation - 70, 88, 108, and 140 excursions/min on the automatic shaker and magnetic stir. Two samples were selected for the investigation - Battelle spent limestone and Argonne spent dolomite. Table 4 summarizes the major species in leachates (TEP eluate) and the total amount of 1:1 acetic acid required. A greater degree of agitation resulted in increased solid dissolution (Ca, Mg, SO_4, and TDS) and required a larger amount of acid to produce leachate of final pH = 5. Again, the high magnesium concentrations are noted. Trace elements are summarized in Table 5 for three agitation speeds and compared with the hazardous criteria. It is interesting to note that leachates induced by gentler agitation (shaker) did not exceed the 10 x DWS criteria.

Thus far, the leachates discussed have been the TEP eluate, i.e., combined leachates generated by two consecutive shakings. In Tables 6 and 7 the leachate quality (as indicated by specific conductance) and the total amount of acid required to reach pH of 5 for the first and second 24-hr extracts and the final eluate (two extracts combined) are summarized. High-speed agitation caused nearly total extraction from the first 24-hr shake so that only very small amounts of acid were needed in the second extract. The quality of the second 24-hr leachate was much better than that of the first 24-hr eluate, where most of the extractable species had been leached out. Another point to be noted from Tables 6 and 7 is that the total amount of acid required and the total dissolved solids in the leachates increased with increased agitation because of the greater dissolution accelerated by physical abrasion.

3. DISCUSSION

Preliminary results from RCRA/TEP tests indicated that some uncertainties and potential problems exist in the draft (March 1978) TEP procedure:

- Nonreproducibility may result from an unspecified agitation mode, as it has been demonstrated that leachate characteristics are agitation dependent.
- A large amount of acid is required to bring the extract of alkaline solid such as limestone or dolomite-based sorbent to a final pH of 5. This may be unnecessarily harsh on alkaline wastes, since the leaching conditions are unrealistic.
- The 1:1 acetic acid is a very concentrated solution of 8.75 N, therefore more likely to introduce titration error than would a more dilute solution.
- The temperature of the mixture may be higher than room temperature because of the exothermic hydration of spent limes.

These difficulties were communicated to the EPA Office of Hazardous Waste Management (RCRA Sec. 3001), during a visit from Mr. Don Viviani[4] and our subsequent conversations with him and Mr. David Friedman.[5]

Since our preliminary experiments with the Martch draft RCRA/TEP, a new draft (September 1978) has been issued which incorporates many changes including those recommended. The major changes are:

- The concentration of acetic acid used has been reduced from 8.75 N to 0.5 N.
- It sets a limit to the maximum amount of acid added, not exceeding 4 ml of 0.5 N acetic acid per gram of solid. Thus, the final leachate of an alkaline waste may not reach pH = 5.
- Only one 24-hr extraction is required.
- A wider range of temperature is allowed during leaching (20° to 40°C), eliminating the need for cooling in slightly exothermic systems.
- A structural integrity procedure is required for samples larger than 95 mm (3/8-in) particle size or block. The latter is of particular importance to the processed FBC residue in compact form.
- An agitation method is suggested in the up-to-date draft, but uncertainties still exist and further modification may be expected.[5-7]

We are currently carrying out tests employing the most recent draft procedure. Results should provide a data base with which to judge the "hazardous" or "nonhazardous" nature of the FBC residue.

Table 1

SUMMARY OF SAMPLES STUDIES USING RCRA/TEP TEST

Sample	Sorbent	Source	Process
Battelle Bed	Limestone	Bed	AFBC
Battelle Carry-over	Limestone	Cyclone	AFBC
MERC Carry-over	Limestone	Bag-filter	AFBC
Argonne C2/C3 Bed	Dolomite	Bed	PFBC
Exxon 67 Carry-over	Dolomite	3rd cyclone	PFBC
PDU-P403 Carry-over	Dolomite	Baghouse	PFBC, adiabatic
Tymochtee Dolomite	---	---	Raw sorbent, reference
1359 Limestone	---	---	Raw sorbent, reference
Gypsum, Iowa No. 114	---	---	Calcium sulfate, reference
CSO Sludge	---	---	FGD sludge, reference
			>98% fly-ash removal

Table 2

LEACHATE CHARACTERISTICS (MAJOR SPECIES) FROM RCRA/TEP TEST*

Sample	Total Volume of 1:1 Acetic Acid Added to Achieve ℓ pH=5	pH	S.C., millimho/cm	Ca, mg/ℓ	Mg, mg/ℓ	SO_4, mg/ℓ
Battelle Bed**	61.8	4.98	25.5	16,400	542	1,273
Battelle Bed	61.0	5.03	17.7	8,712	372	768
Battelle Carry-over	48.2	5.12	15.2	6,952	288	778
MERC Carry-over**	42.3	4.9	20.2	9,560	408	730
Argonne Bed	77.8	5.0	20.8	4,080	5,340	2,803
Exxon Carry-over	1.5	5.05	5.23	456	946	4,100
PDU Carry-over	74.7	5.03	21.2	5,120	4,128	2,240
Tymochtee Dolomite	47.2	5.0	14.5	3,388	1,596	6.2
1359 Limestone	120.6	5.02	26.2	18,440	144	6.2
Iowa Gypsum	6.25	5.0	3.16	632	28.8	1,000
CSO FGD Sludge**	17.0	5.0	5.8	1,560	254	2,193

*Agitation by magnetic stir.
**One 24-hr extraction only.

Table 3

LEACHATE CHARACTERISTICS (TRACE ELEMENTS) FROM RCRA/TEP TEST*

Sample	Trace Elements, mg/ℓ									
	Ag	As	Ba	Cd	Cr	F	Hg	NO_3 (as N)	Pb	Se
Battelle Bed**	<0.03	0.13	2.5	0.036	0.92+	0.37	<0.001	<1	0.18	0.004
Battelle Bed	<0.03	0.075	1.8	0.018	0.60+	0.06	0.0012	<1	0.13	0.001
Battelle Carry-over	<0.03	0.06	1.2	0.02	0.24	0.42	0.0012	<1	0.13	0.003
MERC Carry-over**	<0.03	0.96+	2.0	0.08	1.65+	0.33	0.0014	80	0.17	0.39+
Argonne Bed	<0.03	0.14	<1	0.014	0.2	1.0	<0.001	<1	0.16	0.005
Exxon Carry-over	<0.03	0.005	<1	0.052	0.1	0.45	0.0012	8	0.05	0.004
PDU Carry-over	<0.03	0.073	<1	0.13+	0.18	0.18	0.0021	36	0.17	0.008
Tymochtee Dolomite	<0.03	0.001	<1	0.012	0.1	1.8	<0.001	1	0.1	0.001
1359 Limestone	<0.03	0.001	4	0.071	0.1	0.28	<0.001	<1	0.23	0.001
Iowa Gypsum	<0.03	0.001	<1	0.003	0.1	0.22	0.0014	5	0.06	<0.001
CSO FGD Sludge**	<0.03	0.01	<1	0.005	0.12	----	<0.001	8	0.03	0.015
10 x DWS (NIPDWR, 1976)	0.5	0.5	10.0	0.1	0.5	14 to 24	0.02	100.0	0.5	0.1

*Agitation by magnetic stir
**One 24-hr extraction only
+Exceed 10 x DWS

Table 4

LEACHATE CHARACTERISTICS (MAJOR SPECIES) AS A FUNCTION OF DEGREE OF AGITATION

Sample	Agitation, excursions/min	Total Volume of 1:1 Acetic Acid Added to Achieve pH=5	pH	S.C., millimho/cm	Ca, mg/ℓ	Mg, mg/ℓ	SO_4 mg/ℓ
Battelle Bed	70	26.4	5.0	10.8	4160	48	710
	88	37.1	5.1	13.0	5840	72	940
	108	55.4	5.1	17.0	8400	240	994
	140	54.6	5.0	18.1	8040	336	1200
	Hi-speed magnetic stir	61.0	5.0	17.7	8712	372	768
Argonne Bed	70	9.8	5.0	5.64	1100	576	1445
	88	20.1	5.1	8.79	1560	1392	1993
	108	40.7	5.0	13.9	2120	3000	2803
	140	54.4	5.0	17.9	2820	3900	2718
	Hi-speed magnetic stir	77.8	5.0	20.8	4080	5340	2803

Table 5

LEACHATE CHARACTERISTICS (TRACE ELEMENTS) AS A FUNCTION OF DEGREE OF AGITATION

Sample	Agitation, excursions/min	Trace Elements, mg/ℓ									
		Ag	As	Ba	Cd	Cr	F	Hg	NO_3 (as N)	Pb	Se
Battelle Bed	70	<0.02	0.007	<1	<0.01	0.12	0.5	0.001	<10	<0.04	0.003
	140	<0.02	0.042	<1	<0.01	0.28	0.3	<0.001	<10	<0.04	0.002
	Hi-speed magnetic stir	<0.03	0.075	1.8	0.02	0.60+	0.13	0.0012	<10	0.13	0.001
Argonne Bed	70	<0.02	0.004	<1	<0.01	0.02	0.5	<0.001	<10	<0.04	0.003
	140	<0.02	0.051	<1	<0.01	0.04	0.4	0.0012	<10	<0.04	0.003
	Hi-speed magnetic stir	<0.03	0.135	<1	0.014	0.2	1.0	<0.001	<10	0.16	0.005
10 x DWS (NIPDWR 1976)		0.5	0.5	10.0	0.1	0.5	14 to 24	0.02	100.0	0.5	0.1

+Exceed 10 x DWS

Table 6

SPECIFIC CONDUCTANCE (millimho/cm) OF TEP EXTRACTANT

Sample	Extraction	Agitation, excursions/min				
		70	88	108	140	Hi-Speed Magnetic Stir
Battelle Bed	1st - 24 hr	11.90	17.2	24.10	24.6	14.9
	2nd - 24 hr	9.72	9.89	7.49	4.5	5.32
	Final mix	10.80	13.0	17.0	18.1	17.7
Argonne Bed	1st - 24 hr	6.26	9.93	16.7	18.4	28.1
	2nd - 24 hr	5.56	8.87	13.2	17.4	6.27
	Final mix	5.64	8.79	13.9	17.9	20.8

Table 7

TOTAL VOLUME (mℓ) OF 1:1 ACETIC ACID REQUIRED TO ACHIEVE pH = 5

Sample	Extraction	Agitation, excursions/min				
		70	88	108	140	Hi-Speed Magnetic Stir
Battelle Bed	1st - 24 hr	16.0	26.4	49.2	51.1	59.1
	2nd - 24 hr	10.4	10.7	6.2	3.5	1.9
	Total	26.4	37.1	55.4	54.6	61.0
Argonne Bed	1st - 24 hr	5.7	11.4	24.3	29.4	75.0
	2nd - 24 hr	4.1	8.7	16.4	25.0	2.8
	Total	9.8	20.1	40.7	54.4	77.8

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APPENDIX B

EPA INTERIM PRIMARY AND SECONDARY DRINKING WATER STANDARDS*

Parameter	Maximum Level
A. Interim primary	(mg/ℓ)
Arsenic	0.05
Barium	1.0
Cadmium	0.01
Chromium (VI)	0.05
Fluoride	1.4-2.4
Lead	0.05
Mercury	0.002
Nitrate (as N)	10
Selenium	0.01
Silver	0.05
Endrin	0.002
Lindane	0.004
Methoxychlor	0.1
Toxaphene	0.005
2.4-D	0.01
2.4.5-TP Silvez (sic)	0.01
Radium	5 pCi/l
Gross Alpha	15 pCi/l
Gross Beta	4 millirem/yr
Turbidity	1/TU
Coliform Bacteria	4/100 ml
B. Secondary	(mg/ℓ)
Chloride	250
Copper	1
Foaming Agents	0.5
Iron	0.3
Manganese	0.05
Sulfate	250
TDS	500
Zinc	5
Color	15 Color Units
Odor	3 Threshold Order Number
pH	6.5-8.5

*Source: Federal Register, 43 (243); December 18, 1978.

APPENDIX C

CHEMICAL CHARACTERIZATION OF RESIDUE SAMPLES

This appendix presents the solid compositions of those sample categories investigated under RCRA tests (Table 5 of text). In most cases data of the particular samples used for the RCRA/EP test are presented. In addition to the chemical compositions of solids prior to leaching, leachate characteristics obtained by using the Westinghouse screening tests - the 200-hr continuous shake method using three leaching media, i.e., deionized water, CO_2 - saturated water, and acetate buffer - are also summarized in these tables. The data presented here provide useful background for understanding and interpreting the RCRA test results. A detailed description of the solid residue study Westinghouse had carried out since 1974 can be found in our previous reports.[1-4]

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Table C-1

SOLID AND LEACHATE CHARACTERISTICS OF MERC-AFBC RESIDUES
(200-hr Continuous Shake Tests)

Substance	Solid, ppm[a]			Leachate, ppm[b]						Drinking Water Standards[c]
	(1)	(2)	(3)	(1A)	(2A)	(3A)	(1B)	(2B)	(2B)	
Al	Major	Major	Major	<1	2	>2	<1	<1	<0.1	
Ag	<1	<1	<1	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.05
As				<.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.05
B	50	500	500	<.1	<0.2	3	<0.1	<.1	0.1	
Ba				<1	2	<1	<1	<1	<1	1.0
Be	10	10	10	<0.01	<0.01	<.01	<0.01	<0.01	<0.01	
Bi	<10	<10	<10	<0.01	<0.01	<.01	<0.01	<0.01	<0.01	
Ca	39%	18%	16%	1276	16	200	1336	8	220	200
Cd	<3	<3	<3	<0.01	<0.01	<.01	<0.01	<0.01	<0.01	0.01
Co	5	15	15	<0.02	<0.02	<.02	<0.02	<0.02	<0.02	
Cr	60	100	100	0.04	0.3	1.9	0.04	0.35	0.67	0.05
Cu	30	100	100	<0.1	<0.1	<.1	<0.1	<.1	<0.1	1.0
Fe	Major	Major	Major	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	0.3
Hg				<0.002	<0.002	<0.002	<0.002	<.002	<0.002	0.002
Mg	>1000	>1000	>1000	<1	<1	1	<1	<1	<1	150
Mn	190	220	280	<.01	<0.01	<0.01	<0.01	<.01	<.01	0.05
Mo	30	10	10	0.04	0.4	>2	0.04	0.5	>2	
Na	>1000	>1000	>1000	4	>>4	>>4	9	206	209	
Ni	40	70	70	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	2.0
Pb	<10	100	130	<0.01	<0.01	0.04	<0.01	<0.01	<0.02	0.05
Sb	<33	<33	<33	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	
Se				<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01
Si	Major	Major	Major	<0.2	>2	>2	<0.02	2	>2	
Sn	<10	<10	<10	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	1.0
Sr	500	1000	1000	4	>4	>>4	4	>>4	>>4	
Ti	>1000	>1000	>1000	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	
V	40	100	80	<0.02	<0.03	0.4	<0.02	0.02	0.5	
Zn	<33	100	100	<1	<1	<1	<1	<1	<1	5.0
Zr				<1	<1	<1	<1	<1	<1	
Cl				16	17	148	16	120	335	250
F				<1	<1	<1	<1	<1	2.4	2.4
Br				<1	<1	2.6	<1	2.4	2.9	
NO_2				<1	<1	<1	<1	<1	<1	
NO_3 (as N)				<1	<1	<1	<1	<1	3	10
PO_4				<1	<1	<1	<1	<1	<1	
SO_4	20%	13%	12%	1350	370	830	1260	370	650	250
TOC				<10	<10	<30	<10	<10	<10	
pH				12.0	11.8	10.8	11.8	11.7	10.9	6.5 to 9.2
SC (μ hos/cm)				8930	4780	3440	8560	4390	3210	750

Note [a] MERC solids: (1), (2), and (3) denote bed, cyclone 2, and bag filter materials respectively

[b] Samples (1A), (2A), and (3A) are deionized water-induced leachates from the MERC bed, cyclone, and bag filter materials. Leachates (1B), (2B), and (3B) are generated using CO_2 – saturated deionized water from the MERC bed, cyclone, and bag filter materials respectively

[c] Drinking Water Standards: NIPDWR, USPHS, and WHO Drinking Water Standards

▨ Exceed the Drinking Water Standards

Table C-2

Dwg. 1714867

SOLID AND LEACHATE CHARACTERISTICS OF PER-AFBC CYCLONE CARRY-OVER MATERIAL, RUN 704-14, WITHOUT CARBON BURN-UP CELL (CBC)
(200-hr Continuous Shake Tests)

Substance	Solid, ppm	Leachate Deionized H_2O, mg/ℓ	Leachate Acetic Buffer, mg/ℓ	DWS, mg/ℓ
Al	4.58%	<1	<1	
Ag	<1	<0.02	<0.02	0.05
As		<0.001	<0.001	0.05
B	70	<1	<1	
Ba	700	<1	<1	1.0
Be	7	<0.03	<0.03	
Bi	5	<0.1	<0.1	
Ca	11.2%	1172	2736	200
Cd	<10	<0.005	<0.005	0.01
Co	<30	<0.1	<0.1	
Cr	100	<0.05	<0.05	0.05
Cu	100	<1	<1	1.0
Fe	5.56%	<0.3	<0.3	0.3
Ga	20	<0.03	<0.03	
Ge	20	<0.1	<0.1	
Hg		0.0013	0.0016	0.002
K	0.85%			
Mg	0.38%	<10	14.4	150
Mn	500	<0.03	<0.03	0.05
Mo	20	0.1	0.1	
Na	0.082%			
Ni	50	<1	<1	2.0
Pb	10	<0.05	<0.05	0.05
Sb	<30	<3	<3	
Se		<0.001	<0.001	0.01
Si	10.3%	<5	<5	
Sn	<10	<0.1	<0.1	1.0
Sr	500	3	7	
Ti	>1000	<1	<1	
V	100	<0.1	<0.1	
Zn	200	<3	<3	5.0
Zr	100	<1	<1	
SO_3				
SO_4	6.9%	1020	690	250
$S^=$	0.01%	11.4	13.7	
F		8.6	<1	2.4
Cl		4000	100	250
NO_3 (as N)		<1	<1	10
PO_4		<1	<1	
TOC		<5		
pH		11.85	11.78	6.5 to 9.2
SC, µmho/cm		8010	12500	~750

DWS - NIPDWR, USPHS, and WHO Drinking Water Standards

Exceeds DWS

Table C-3

Dwg. 1714B69

SOLID AND LEACHATE CHARACTERISTICS OF PFBC-EXXON CARRY-OVER, RUN 105 WITH SORBENT REGENERATION
(200-hr Continuous Shake Test)

Substance	Solid, ppm	Leachate Deionized H_2O, mg/ℓ	Leachate Acetic Buffer, mg/ℓ	DWS, mg/ℓ
Al	4.22%	<1	<1	
Ag	<1	<0.02	<0.02	0.05
As		<0.001	<0.001	0.05
B	200	<1	<1	
Ba	500	<1	<1	1.0
Be	1	<0.03	<0.03	
Bi	5	<0.1	<0.1	
Ca	22.3%	968	2632	200
Cd	<10	<0.005	<0.005	0.01
Co	<30	<0.1	<0.1	
Cr	100	0.05	0.1	0.05
Cu	33	<1	<1	1.0
Fe	5.95%	<0.3	<0.3	0.3
Ga	20	<0.03	<0.03	
Ge	<10	<0.1	<0.1	
Hg		0.0012	0.0014	0.002
K	0.23%			
Mg	0.91%	<10	19.2	150
Mn	500	<0.03	<0.03	0.05
Mo	20	0.1	0.1	
Na	0.28%			
Ni	50	<1	<1	2.0
Pb	10	<0.05	<0.05	0.05
Sb	<30	<3	<3	
Se		0.003	<0.001	0.01
Si	10.8%	<5	<5	
Sn	<10	<0.1	<0.1	1.0
Sr	500	4	7	
Ti	>1000	<1	<1	
V	100	<0.1	<0.1	
Zn	300	<3	<3	5.0
Zr	100	<1	<1	
SO_3				
SO_4	6.1%	757	632	250
$S^=$	0.027%	<10	10.6	
F		2.4	1	2.4
Cl		3500	100	250
NO_3 (as N)		<1	<1	10
PO_4		<1	<1	
TOC		<5		
pH		11.89	11.87	6.5 to 9.2
SC, μmho/cm		8,430	13,400	~750

DWS - NIPDWR, USPHS, and WHO Drinking Water Standards

▨ Exceeds DWS

Table C-4

Dwg. 2624C93

CHEMICAL CHARACTERISTICS OF SOLID AND LEACHATE FROM EXXON 73 RESIDUE (200-hr Continuous Shake Test)

Substance	Exxon 73 Bed Stone			Exxon 73 2nd Cyclone			Exxon 73 3rd Cyclone			DWS, mg/ℓ
	Solid, ppm	Leachate Deionized H_2O, mg/ℓ	Leachate Acetic Buffer, mg/ℓ	Solid, ppm	Leachate Deionized H_2O, mg/ℓ	Leachate Acetic Buffer, mg/ℓ	Solid, ppm	Leachate Deionized H_2O, mg/ℓ	Leachate Acetic Buffer, mg/ℓ	
Al	1.33%	< 1	< 0.1	3%	< 1	< 0.1	5.89%	< 1	< 1	
Ag	< 1	< 0.01	< 0.01	< 1	< 0.01	< 0.01	< 1	< 0.01	< 0.01	0.05
As		< 0.001	< 0.001		< 0.001	< 0.001		0.001	< 0.001	0.05
B	200	1	3	200	0.2	3	200	2	3	
Ba		< 1	< 1		< 1	< 1		< 1	< 1	1.0
Be	1	< 0.01	< 0.01	2	< 0.01	< 0.01	5	< 0.01	< 0.01	
Bi	< 1	< 0.01	< 0.01	< 1	< 0.01	< 0.01	< 1	< 0.01	< 0.01	
Ca	22.56%	1,560	2,896	18.48%	1,460	2,452	16.24%	880	2,256	200
Cd	< 33	< 0.01	< 0.01	< 33	< 0.01	< 0.01	< 33	< 0.01	< 0.01	0.01
Co	< 5	< 0.03	< 0.1	10	< 0.03	< 0.1	10	< 0.03	< 0.1	
Cr	150	0.02	< 0.03	150	0.02	< 0.03	350	3	0.33	0.05
Cu	10	< 0.3	< 1	10	< 0.3	< 1	20	< 0.3	< 1	1.0
Fe	2.53%	< 0.1	< 0.03	4.6%	< 0.1	< 0.03	3.66%	< 0.1	< 0.03	0.3
Ga	3	< 0.01	< 0.03	10	< 0.01	0.03	10	0.03	< 0.03	
Ge	20	< 0.01	< 0.03	10	< 0.01	< 0.03	20	< 0.01	< 0.03	
Hg		< 0.0005	0.0011		0.002	0.0006		0.0016	0.0014	0.002
K	0.19%			0.42%			1.01%			
Mg	12.33%	0	16.8	11.18%	< 5	< 5	7.72%	0	0	150
Mn	100	< 0.01	< 0.03	100	< 0.01	< 0.03	100	< 0.01	< 0.03	0.05
Mo	< 30	< 0.1	< 0.3	< 30	< 0.1	< 0.3	< 30	< 0.1	< 0.3	
Na	0.06%			0.14%			0.29%			
Ni	25	< 0.03	< 0.1	25	< 0.03	< 0.1	100	< 0.03	< 0.1	2.0
Pb	30	< 0.01	< 0.03	50	< 0.01	< 0.03	60	< 0.01	< 0.03	0.05
Sb	< 50	< 0.03	< 0.1	< 50	< 0.03	< 0.1	< 50	< 0.03	< 0.1	
Se		< 0.001	< 0.001		< 0.001	0.002		0.006	0.007	0.01
Si	3.21%	0.5	2	5.91%	0.5	2	9.63%	6	3	
Sn	30	< 0.01	< 0.03	< 10	< 0.01	< 0.03	< 10	= < 0.01	< 0.03	1.0
Sr	150	0.6	1	150	2	4	300	> 3	< 10	
Ti	300	< 0.1	< 0.1	1,000	< 0.1	< 0.1	> 1000	< 0.1	< 0.1	
V	40	< 0.01	< 0.03	50	< 0.01	< 0.03	90	0.06	0.03	
Zn	< 50	< 1	< 1	< 50	< 1	< 1	50	< 1	< 1	5.0
Zr	< 10	< 0.2	< 0.2	30	< 0.2	< 0.2	50	< 0.2	< 0.2	
SO_4	> 29%	1,380	830	26.34%	1,475	1,040	24.79%	1,667	1,150	250
$S^=$	0.073%	< 10	< 10	0.067%	< 10	< 10	0.051%	0	< 10	
F			< 1			< 1			< 1	2.4
Cl		6	4		22	17		61	31	250
NO_3 (as N)		< 1	< 1		< 1	< 1		< 1	< 1	10
TOC		< 10			< 10			< 10		
pH		12.12	12.02		12.12	11.8		11.05	9.49	6.5 to 9.2
SC, μmho/cm		8,770	12,810		8,300	1,		2,860	8,760	750

DWS - NIPDWR and WHO Drinking Water Standards

Exceeds DWS

Table C-5

Dwg. 2624C92

CHEMICAL CHARACTERISTICS OF SOLID AND LEACHATE
FROM LEATHERHEAD, AEP TEST 7 RESIDUE
(200-hr Continuous Shake Test)

Substance	Leatherhead Primary Ash			Leatherhead Secondary Ash			DWS, mg/ℓ
	Solid, ppm	Leachate Deionized H_2O, mg/ℓ	Leachate Acetic Buffer, mg/ℓ	Solid, ppm	Leachate Deionized H_2O, mg/ℓ	Leachate Acetic Buffer, mg/ℓ	
Al	3.8%	< 1	< 0.1	9.94%	< 1	< 0.01	
Ag	< 1	< 0.01	< 0.01	< 1	< 0.01	< 0.01	0.05
As		0.001	0.004		0.013	0.011	0.05
B	200	< 0.1	1	200	< 0.1	10	
Ba		< 1	< 1		< 1	< 1	1.0
Be	2	< 0.01	< 0.1	10	< 0.01	< 0.01	
Bi	< 1	< 0.01	< 0.01	< 1	< 0.01	< 0.01	
Ca	14.56%	680	2,040	3.84%	640	1,088	200
Cd	< 33	< 0.01	< 0.01	< 33	< 0.01	< 0.01	0.01
Co	10	< 0.03	< 0.1	20	< 0.03	< 0.1	
Cr	120	0.01	< 0.03	190	0.02	< 0.03	0.05
Cu	20	< 0.3	< 1	40	< 0.3	< 1	1.0
Fe	5.7%	< 0.1	< 0.03	8.93%	< 0.1	< 0.03	0.3
Ga	10	< 0.01	< 0.03	20	< 0.01	0.05	
Ge	10	< 0.01	< 0.03	30	< 0.01	< 0.03	
Hg		0.0005	0.0005		0.001	0.0011	0.002
K	0.83%			2.3%			
Mg	8,160	0	153.6	2,250	67.2	842.4	150
Mn	200	0.01	< 0.03	200	< 0.01	0.6	0.05
Mo	30	< 0.1	< 0.3	< 30	< 0.1	< 0.3	
Na	0.14%			0.35%			
Ni	40	< 0.03	< 0.1	80	< 0.03	< 0.1	2.0
Pb	60	< 0.01	< 0.03	80	< 0.01	< 0.03	0.05
Sb	< 50	< 0.03	< 0.1	< 50	< 0.03	< 0.1	
Se		0.001	0.005		0.016	0.011	0.01
Si	8.03%	6	3	19.21%	2	20	
Sn	< 10	< 0.01	< 0.03	< 10	< 0.01	< 0.03	1.0
Sr	100	2	2	150	> 3	5	
Ti	> 1,000	< 0.1	< 0.1	> 1,000	< 0.1	< 0.1	
V	60	0.01	< 0.03	150	0.1	0.1	
Zn	50	< 1	< 1	50	< 1	< 1	5.0
Zr	100	< 0.2	< 0.2	100	< 0.2	< 0.2	
SO_4	12.36%	1,510	1,380	7.06%	1,867.5	2,717.5	250
$S^=$	0.05%	< 10	< 10	0.05%	< 10	< 10	
F			< 1			< 1	2.4
Cl		29	15		7	4	250
NO_3 (as N)		< 1	< 1		< 1	< 1	10
TOC		< 10			< 10		
pH		11.18	8.59		8.57	5.6	6.5 to 9.2
SC (μmho/cm)		2,720	8,590		2,620	8,620	~750

DWS - NIPDWR, USPHS, and WHO Drinking Water Standards

Exceeds DWS

Table C-6

SOLID AND LEACHATE CHARACTERISTICS OF PFBC-EXXON COMBUSTOR BED RESIDUE, RUN 105 WITH SORBENT REGENERATION
(200-hr Continuous Shake Test)

Substance	Solid, ppm	Leachate Deionized H_2O, mg/ℓ	Leachate Acetic Buffer, mg/ℓ	DWS, mg/ℓ
Al	1.38%	< 1	< 1	
Ag	< 1	< 0.03	< 0.03	0.05
As		< 0.001	< 0.003	0.05
B	300	30	100	
Ba	200	< 1	< 1	1.0
Be	3	< 0.03	< 0.03	
Bi	100	< 0.1	< 0.1	
Ca	39.52%	1344	3004	200
Cd	< 10	< 0.005	< 0.005	0.01
Co	< 30	< 0.1	< 0.1	
Cr	100	0.02	0.02	0.05
Cu	33	< 0.1	< 0.1	1.0
Fe	1.24%	< 0.3	< 0.3	0.3
Ga	20	0.5	1	
Ge	20	< 0.1	< 0.1	
Hg		0.0012	0.001	0.002
K	0.22%			
Mg	0.28%	12	0	150
Mn	100	< 0.03	< 0.03	0.05
Mo	10	0.1	0.1	
Na	0.063%			
Ni	50	< 0.1	0.1	2.0
Pb	10	< 0.05	< 0.05	0.05
Sb	< 30	< 1	< 1	
Se		< 0.002	< 0.002	0.01
Si	2.93%	< 3	< 3	
Sn	< 10	< 0.1	< 0.1	1.0
Sr	300	< 5	< 5	
Ti	> 1000	< 1	< 1	
V	100	< 0.1	< 0.1	
Zn	300	< 5	< 5	5.0
Zr	30	< 1	< 1	
SO_3				
SO_4	51.78%	1272	1040	250
$S^=$	0.016%	< 2	< 10	
F		7	< 1	2.4
Cl		20	45	250
NO_3 (as N)		< 1	< 1	10
PO_4		< 1	< 1	
TOC		< 5		
pH		11.7	11.79	6.5 to 8.5
SC, μmho/cm		9230	15600	~ 750

DWS - NIPDWR, USPHS, and WHO Drinking Water Standards

Exceeds DWS

Table C-7

Dwg. 1214B66

SOLID AND LEACHATE CHARACTERISTICS OF PFBC-EXXON CARRY-OVER, RUN 105 WITH SORBENT REGENERATION
(200-hr Continuous Shake Test)

Substance	Second Cyclone			Third Cyclone			DWS, mg/ℓ
	Solid, ppm	Leachate Deionized H_2O, mg/ℓ	Leachate Acetic Buffer, mg/ℓ	Solid, ppm	Leachate Deionized H_2O, mg/ℓ	Leachate Acetic Buffer, mg/ℓ	
Al	8.09%	1	< 1	9.09%	< 1	5	
Ag	< 1	< 0.03	< 0.03	< 1	< 0.03	< 0.03	0.05
As		0.006	0.24		0.011	0.005	0.05
B	600	2	100	400	1	100	
Ba	300	< 1	< 1	300	< 1	< 1	1.0
Be	5	< 0.03	< 0.03	7	< 0.03	< 0.03	
Bi	100	< 0.1	< 0.1	8	< 0.1	< 0.1	
Ca	11.68%	568	2288	9.84%	680	2032	200
Cd	< 10	< 0.005	< 0.005	< 10	< 0.005	< 0.005	0.01
Co	< 30	< 0.1	< 0.1	< 30	< 0.1	< 0.1	
Cr	100	0.15	0.04	100	0.08	0.02	0.05
Cu	100	< 1	< 1	100	< 1	< 1	1.0
Fe	10.3%	2	< 0.3	6.89%	5	< 0.3	0.3
Ga	30	1	1	30	1	0.5	
Ge	30	< 0.1	< 0.1	30	< 0.1	< 0.1	
Hg		0.0012	0.0014		0.0011	0.0014	0.002
K	0.96%			1.09%			
Mg	0.57%	< 5	< 5	0.43%	< 1	67.2	150
Mn	150	< 0.03	< 0.03	150	< 0.03	< 0.03	0.05
Mo	20	0.33	0.33	10	0.33	0.33	
Na	0.22%			0.26%			
Ni	50	< 0.1	0.1	50	< 0.1	0.2	2.0
Pb	30	< 0.05		30		< 0.05	0.05
Sb	< 30	< 1	< 1	< 30	< 1	< 1	
Se		< 0.002	0.005		0.002	0.007	0.01
Si	15%	10	50	14.9%	10	30	
Sn	< 10	< 0.1	< 0.1	< 10	< 0.1	< 0.1	1.0
Sr	500	5	5	500	5	10	
Ti	> 1000	< 1	< 1	> 1000	< 1	< 1	
V	100	0.1	0.5	100	0.6	0.1	
Zn	300	< 5	< 5	300	< 5	< 5	5.0
Zr	70	< 1	< 1	70	< 1	< 1	
SO_3							
SO_4	17.9%	1162	1236	15.8%	1645	1116	250
$S^=$	0.016%	< 5	< 5	< 0.01%	< 2	0	
F		1.5	2.2		2.2	1.4	2.4
Cl		25	20		40	40	250
NO_3 (as N)		< 1	< 1		< 1	< 1	10
PO_4		< 1	< 1		< 1	< 1	
TOC		< 5			< 5		
pH		10.76	9.35		9.1	6.1	6.5 to 9.2
SC, μmho/cm		2580	9850		2630	9380	~ 750

DWS - NIPDWR, USPHS, and WHO Drinking Water Standards

Exceeds DWS

Table C-8

Dwg. 1714865

SOLID AND LEACHATE CHARACTERISTICS OF PFBC-EXXON REGENERATOR BED AND CARRY-OVER, RUN 105
(200-hr Continuous Shake Test)

Substance	Regenerator Bed			Regenerator Carry-over			DWS, mg/ℓ
	Solid, ppm	Leachate Deionized H_2O, mg/ℓ	Leachate Deionized H_2O, mg/ℓ Anaerobic	Solid, ppm	Leachate Deionized H_2O, mg/ℓ	Leachate Acetic Buffer, mg/ℓ	
Al	4.07%	< 1	< 1	4.92%	< 1	< 1	
Ag	< 1	< 0.02	< 0.02	< 1	< 0.03	< 0.03	0.05
As		< 0.001	< 0.001		< 0.001	< 0.001	0.05
B	300	< 1	< 1	800	30	100	
Ba	500	< 1	< 1	300	< 1	1	1.0
Be	3	< 0.03	< 0.03	5	< 0.03	< 0.03	
Bi	3	< 0.33	< 0.33	70	< 0.1	< 0.1	
Ca	42.8%	1392	1380	29.4%	1204	2840	200
Cd	< 10	< 0.01	< 0.01	< 10	< 0.005	< 0.005	0.01
Co	< 30	< 0.1	< 0.1	< 30	< 0.1	< 0.1	
Cr	< 10	0.10	0.20	100	< 0.02	< 0.02	0.05
Cu	10	< 1	< 1	100	< 1	< 1	1.0
Fe	4.75%	< 0.3	< 0.3	8.48%	< 0.3	< 0.3	0.3
Ga	30	< 0.1	< 0.1	30	3	0.5	
Ge	10	< 0.1	< 0.1	30	< 0.1	< 0.1	
Hg		0.0015	0.0014		0.0014	0.0014	0.002
K	0.43%			0.32%			
Mg	1.1%	< 10	19.2	1.05%	< 3	< 10	150
Mn	300	< 0.03	< 0.03	150	< 0.03	< 0.03	0.05
Mo	10	< 0.1	< 0.1	20	0.33	0.33	
Na	0.078%			0.075%			
Ni	50	< 1	< 1	50	< 0.1	< 0.1	2.0
Pb	< 10	< 0.01	< 0.01	< 10	< 0.05	< 0.05	0.05
Sb	< 30	< 1	< 1	< 30	< 1	< 1	
Se		0.002	0.001		0.003	0.002	0.01
Si	7.99%	< 5	< 5	7.74%	< 3	< 3	
Sn	< 10	< 0.1	< 0.1	< 10	< 0.1	< 0.1	1.0
Sr	500	< 5	< 5	500	5	5	
Ti	> 1000	< 1	< 1	> 1000	< 1	< 1	
V	100	< 0.1	< 0.1	100	< 0.1	< 0.1	
Zn	100	< 3	< 3	300	< 3	< 3	5.0
Zr	100	< 1	< 1	70	< 1	< 1	
SO_3							
SO_4	9.74%	1325	1325	7.88%	1082	850	250
$S^=$	0.05%	19.7	80.5	0.096%	106.4	99.5	
F		5.8	5.9		< 1	1.8	2.4
Cl		12	13		30	250	250
NO3 (as N)		< 1	< 1		6	7	10
PO_4		< 1	< 1		< 1	< 1	
TOC		< 5	6		< 5		
pH		11.75	11.9		11.72	11.79	6.5 to 9.2
SC, μmho/cm		10,120	10,170		8,320	15,200	~ 750

DWS - NIPDWR, USPHS, and WHO Drinking Water Standards

▨ Exceeds DWS

Table C-9 Dwg. 1709B92

SOLID AND LEACHATE CHARACTERISTICS OF ADIABATIC PFBC BAGHOUSE RESIDUE FOR COMBUSTION POWER CP-403 RUN (200-hr Continuous Shake Test)

Substance	Solid, ppm	Leachate, mg/ℓ	DWS,[a] mg/ℓ
Al	Major	2	
Ag	< 1	< 0.01	0.05
As		< 0.003	0.05
B	500	> 5	
Ba		< 1	1.0
Be		< 0.01	
Bi	< 10	< 0.01	
Ca	16%	696	200
Cd	< 3	< 0.01	0.01
Co	15	< 0.01	
Cr	100	< 0.02	0.05
Cu	100	< 0.05	1.0
Fe	Major	< 0.05	0.3
Hg		< 0.002	0.002
Mg	8.7%	0	150
Mn	220	< 0.01	0.05
Mo	50	0.2	
Na	> 1,000	> 5	
Ni	80	< 0.05	2.0
Pb	50	< 0.01	0.05
Sb	< 33	< 0.01	
Se		< 0.003	0.01
Si	Major	> 4	
Sn	< 10	< 0.01	1.0
Sr	100	> 10	
Ti	> 1,000	< 0.05	
V	60	0.02	
Zn	150	< 1	5.0
Zr		< 1	
SO_4	18.5%	1,813	250
$S^=$	0.02%	< 5	
TOC		< 10	
pH		10.8	6.5 to 9.2
SC, μmho/cm		3,770	~750

[a] DWS - NIPDWR, USPHS, and WHO drinking water standards

▨ exceeds DWS

Table C-10

Dwg. 2618C 35

CHEMICAL CHARACTERISTICS OF FGD SLUDGE, LIQUOR, AND LEACHATE[a]

Substances	Sludge, ppm[a] (on dry basis)	Liquor, ppm			Leachate from dried solids, ppm (after 200-hr continuous shake)				DWS, mg/ℓ
		Untreated	Ponded	Oxidized	Untreated[a]	Ponded[b]	Oxidized[c]	Stabilized[d]	
Al	0.2 - 20%	< 2	0.4	20	< 1	< 1	< 1	< 1	
Ag	< 1	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.05
As	3 to 30	0.03	0.03	0.01	0.01 to 0.06	0.09	0.01	0.05	0.05
B	30 to 300	1 to 20	> 7	> 20	0 to 2	> 3	> 1	1	
Ba	10 to 1000	< 1	< 1	< 1	< 1	< 1	< 1	< 1	1.0
Be	0 to 15	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.1	
Bi	< 10	< 0.02	< 0.02	< 0.02	< 0.01	< 0.01	< 0.01	< 0.01	
Ca	10 to 30%	500 to 1500	1824	2408	300 to 1000	760	660	630	200
Cd	< 3	< 0.01	< 0.02	0.2	< 0.01	< 0.01	< 0.01	< 0.01	0.01
Co	0 to 10	< 0.05	< 0.05	< 0.06	< 0.05	< 0.05	< 0.05	< 0.05	
Cr	1 to 100	< 0.04	< 0.03	< 0.06	< 0.03	< 0.03	< 0.03	< 0.03	0.05
Cu	1 to 60	< 1	< 1	< 1	1	< 1	< 1	< 1	1.0
Fe	0.1 to 10%	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3	0.3
Hg	0.1 to 3	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	0.002
Mg	0.1 to 10%	0 to 600	< 30	1104	10 to 250	< 30	200	16	150
Mn	10 to > 1000	0 to 0.07	0.02	20	< 0.05	< 0.05	< 0.07	< 0.05	0.05
Mo	0 to 20	< 0.5	7	0.7	< 0.2	< 0.2	0.1	0.3	
Na	0.01 to 5%	0 to 100	111	106	5 to 15	5	3	6	
Ni	0 to 30	< 1	< 1	< 1	< 0.05	< 0.05	< 0.05	< 0.05	2.0
Pb	0 to 200	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	0.05
Sb	< 33	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	
Se	1 to 5	0.005 to 0.03	0.01	0.32	0.01 to 0.05	0.007	0.1	0.006	0.01
Si	0.5 to 20%	2 to 20	2.7	5	0.1 to 4	2	1	3	
Sn	< 10	< 1.0	< 1.0	< 1.0	< 0.05	< 0.05	< 0.05	< 0.05	1.0
Sr	100 to 1000	< 2	> 7	40	< 1	1	2		
Ti	100 to > 1000	< 1	< 1	< 2	< 1	< 1	< 1	< 1	
V	0 to 100	< 0.05	2	< 0.06	< 0.05	< 0.05	< 0.05	< 0.05	
Zn	20 to 200	< 3	< 3	< 3	< 3	< 3	< 3	< 3	5.0
Zr	1 to 1000	< 2	< 2	< 2	< 1	< 1	< 1	< 1	
CO_3	0.1 to 15%								
SO_3	0.05 to 50%	0 to 40	< 10	< 10	< 10	< 10	< 10	< 10	
SO_4	3 to 65%	1000 to 7000	1200	1450	500 to 2500	1700	1500	1400	250
Cl	0 to 1%	300 to 1000	2800	5100	30 to 120	180	170	2	250
Br		0 to 40			0 to 3			< 1	
F	10 to 50	2 to 23	22	35	1 to 6	1.3	4.5	5	2.4
NO_3 (as N)		0 to 100	< 10	60	< 10	< 10	< 10	< 10	10
NO_2		0 to 40			< 10			< 10	
PO_4		0 to 10			< 1			< 1	
TOC		< 30	< 30	< 30	< 30	< 30	< 30	< 30	
pH		8 to 10	8.6	6.1	7.5 to 8.5	8.0	8.2	8.0	6.5 to 9.2
Sp. Cond. (μmho/cm)		4000 to 9000	5920	16900	2000 to 3000	2640	2830	2350	~ 750

(a) Range of 3 untreated sludge samples (LGE, CSO, DLC)
(b) 1 ponded sludge sample (TVA)
(c) 1 oxidized sludge sample (TVA)
(d) Chemically treated by Dravo's "Calcilox"
▨ exceed drinking water standards (NIPDWR, USPHS and WHO)

Table C-11

Dwg. 2626C28

SOLID AND LEACHATE CHARACTERISTICS OF
CONVENTIONAL FLY ASH SAMPLES
(200-hr Shake Test)

Substance	Fly Ash No 1			Fly Ash No. 2			DWS, mg/ℓ
	Solid, ppm	Leachate: Deionized H_2O, mg/ℓ	Leachate: Acetate Buffer, mg/ℓ	Solid, ppm	Leachate: Deionized H_2O, mg/ℓ	Leachate: Acetate Buffer, mg/ℓ	
Al	11.8%	0.2	3	10.58%	<1	1	
Ag	<1	<0.02	<0.02	<1	<0.01	<0.01	0.05
As		0.174	0.13		0.005	0.021	0.05
B	150	5	25	300	>1	>10	
Ba	600	<1	<1		<1	<1	1.0
Be	3	<0.01	<0.01	8	<0.01	<0.01	
Bi	<10	<0.01	<0.01	<1	<0.01	<0.01	
Ca	1.8%	192	696	2.08%	320	1256	200
Cd	<5	<0.005	<0.005	<33	<0.01	<0.01	0.01
Co	<10	<0.02	<0.02	5	<0.02	<0.1	
Cr	150	<0.02	<0.02	60	0.1	0.2	0.05
Cu	100	<0.1	<0.1	10	<0.1	<0.1	1.0
Fe	9.2%	<0.02	<0.3	10.68%	0.1	1	0.3
Ge	5			30	0.01	0.03	
Hg		0.0009	0.0009	30	0.0009	0.0013	0.002
Li	300				0.01	0.2	
K	1.6%			1.15%			
Mg	0.096%	4.8	52.8	0.38%	<5	115	150
Mn	1000	<0.01	3	200	<0.01	8	0.05
Mo	30	0.1	0.8	<30	0.3	0.5	
Na	0.62%	>1	Major	0.55%	>>1	>>10	
Ni	80	<0.05	0.08	60	<0.05	0.2	2.0
Pb	50	<0.04	<0.04	40	<0.01	<0.03	0 05
Sb	<50	<0.1	<0.1	<50	<0.05	<0.1	
Se		0.03	0.02		0.004	0.017	0.01
Si	30.1%	2	<10	20.25%			
Sn	<10	<0.1	<0.1	<10	<0.05	<0.1	1.0
Sr		>1	>10	1000	>1	10	
Ti	>1000	<0.1	<0.1	>1000	<1	<1	
V	50	<0.02	0.08	150	0.1	0.1	
Zn	100	<1	2	100	<1	<1	5.0
Zr	300	<0.5	<0.5	500	<1	<1	
SO_3	1.3%						
SO_4	0.65%	489	457	3.58%	542	850	250
$S^=$	0.04%	0	0	0.06%	<5	<5	
F		<1	<1		<1	<1	2.4
Cl		2	<1		2	<1	250
Br		<1	<1				
NO_3 (as N)		<1	<1		<1	<1	10
PO_4		<1	<1				
Unburned C	10%			7%			
TOC		<10			<10		
pH		7.88	5		11.08	5.1	6.5 to 9.2
SC μmho/cm		800	5970		1650	7390	~750

DWS-NIPDWR and WHO Drinking Water Standards

▨ Exceeds DWS

▩ Exceeds 10 x DWS

Table C-12

Dwg. 2626C29

SOLID AND LEACHATE CHARACTERISTICS OF
CONVENTIONAL BOTTOM ASH SAMPLES
(200-hr Shake Test)

Substance	Bottom Ash No.1			Bottom Ash No.2			DWS, mg/ℓ
	Solid, ppm	Leachate: Deionized H_2O, mg/ℓ	Leachate: Acetate Buffer, mg/ℓ	Solid, ppm	Leachate: Deionized H_2O, mg/ℓ	Leachate: Acetate Buffer, mg/ℓ	
Al	6.04%	0.5	>4	8.05%	<1	>6	
Ag	<1	<0.01	<0.01	<1	<0.01	<0.01	0.05
As		0.005	<0.001		0.012	0.003	0.05
B	200	1	3	200	1	4	
Ba		<1	<1		<1	<1	1.0
Be	5			3	<0.01	<0.01	
Bi	<1	<0.01	<0.01	<1	<0.01	<0.01	
Ca	<1.28%	<5	<5	1.92%	172	412	200
Cd	<33	<0.01	<0.01	<33	0.01	<0.02	0.01
Co	10	<0.1	<0.1	10	<0.1	<0.1	
Cr	110	<0.02	0.02	120	<0.02	0.06	0.05
Cu	10	<0.1	2	20	<0.1	<0.1	1.0
Fe	21.98%	0.2	2	13.02%	1	2	0.3
Ga	<3	0.05	4	3	0.2	<0.03	
Ge	<3	<0.05	<0.05	<3	<0.02	<0.03	
Hg		0.0013	0.0015		0.0008	0.0012	0.002
K	1.37%			1.16%			
Mg		<5	<10	0.192%	<10	26.4	150
Mn	200	0.04	0.2	200	0.07	10	0.05
Mo	<30	<0.05	<0.05	<30	<0.1	<0.1	
Na	0.39%			0.37%	7	>>6	
Ni	20	<0.04	<0.04	30	0.07	0.2	2.0
Pb	<10	0.4	0.02	25	0.02	<0.02	0.05
Sb	<50	<0.05	<0.05	<50	<0.1	<0.1	
Se		<0.001	<0.001		<0.004	0.002	0.01
Si	19.01%			20.95%			
Sn	<10	<0.05	<0.05	<10	<0.1	<0.1	1.0
Sr	500	0.2	0.2	500	1	6	
Ti	>1000	<0.5	<0.5	>1000	<1	<1	
V	80	<0.05	<0.05	60	<0.02	0.03	
Zn	50	<1	<1	50	<1	<1	5.0
Zr	500	<1	<1	500	<1	<1	
SO_3		<1	<1				
SO_4	0.026%	17	<10	1.247%	376	245	250
$S^=$	0.027%	<10	<10	0.041%	<5	<10	
F		<1	<1		<1	<1	2.4
Cl		<1	1.6		3	1	250
Br							
NO_2		<1	<1				
NO_3 (as N)		<1	<1		<1	<1	10
PO_4		<1	<1				
TOC		<10			<10		
pH		7.5	4.4		7.8	4.7	6.5 to 9.2
SC, μmho cm		83	3380		790	4880	~750

DWS - NIPDWR and WHO Drinking Water Standards

Exceeds DWS

Exceeds 10 x DWS

APPENDIX D

RCRA EXTRACTION PROCEDURE (43 FR 58956)

(A) EQUIPMENT

(I) An agitator which, while preventing stratification of sample and extraction fluid, also insures that all sample surfaces are continuously brought into contact with well-mixed extraction fluid.

(II) Equipment suitable for maintaining the pH of the extraction medium at a selected value.

(B) PROCEDURE

(I) Take a representative sample (minimum size 100 g) of the waste to be tested. Separate sample into liquid and solid phases. The solid phase is defined as that fraction which does not pass through a 0.45-μm filter medium under the influence of either pressure, vacuum, or centrifugal force. Reserve the liquid fraction under refrigeration (1-5°C) for further use.

(II) The solid portion of the sample, resulting from the separation procedure above or the waste itself (if it is already dry), shall be prepared either by grinding to pass through a 9.5-mm (3/8 in) standard sieve or by subjecting it to the structural integrity procedure.

(III) Add the solid material from Paragraph II to 16 times its weight of deionized water. This water should include any water used during transfer operations. Begin agitation and extract the solid for 24 ± 0.5 h. Adjust the solution to pH 5

and maintain that pH during the course of the extraction using 0.5 N acetic acid. If more than 4 ml of acid for each g of solid would be required to maintain the pH at 5, then once 4 ml per g of solid has been added, complete the 24-h extraction without adding any additional acid. Maintain the sample between 20-40°C during extraction.

(IV) At the end of the 24-h extraction period, separate the sample into solid and liquid phases as in Paragraph I. Adjust the liquid phase with deionized water so that its volume is 20 times that occupied by a quantity of water at 4°C equal in weight to the initial sample of solid (e.g., for an initial sample of 1 g, dilute to 20 ml). Combine this liquid with the original liquid phase of the waste. This combined liquid, including precipitate which later forms from it, is the Extraction Procedure extract.