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liquors from different depths vary because of changes in the waste produced, liquid and solid contact time, as well as the number of "waste strata" the water has percolated through. Surface pond liquor composition may not reflect leachate composition in terms of readily leachable species that are not solubility limited. But in cases where the major species in the pond liquor have reached solubility limitations (i.e., some FGD ponds), their concentrations in the leachate can be quite similar to the pond liquor composition.

8.6.2.2.3 Dilution/Mixing of Interstitial Liquors -- For partially saturated wastes that contain residual process liquor (as in landfills), leachate generation, which occurs after influent water - rain or groundwater - locally saturates the waste, would cause the influent liquor to be admixed with the residual liquor. Thus, the quality of this mixture may provide the starting point for determining leachate composition. However, the original liquor may be diluted by mixing with several components (depending on the rain and groundwater chemical composition), and solubility limitations originally present in the residual process liquor may not prevail in the mixed liquor. Also, the ionic strength and other factors (such as buffering capacity, pH, complexing ion concentrations) of the resultant mixture may be modified to change leaching ability of that solution relative to the original liquor. Thus, depending on the extent of "dilution," the final leachate may be quite different from the original liquor. The extent of modification is related to many factors that affect the degree of leaching from the waste.

In some cases, waste saturation may not be necessary before liquor (leachate) is forced out of the waste. This could happen when all the pores where the entrapped air could escape from are filled with liquor.

8.6.2.2.4 Dissolution of Readily Available Species -- Readily soluble species in FGC wastes may include the inorganic major and minor components of FGD solids (e.g., Ca^{+2}, SO_4^{-2}, Cl^-, Na^+, K^+, Mg^{2+}), major species with limited solubility that arrive to their saturated levels within relatively short periods of contact time (such as $CaSO_3$), and trace components that are readily available to the liquid phase due to their preconcentrations on surfaces of the waste (As on ash) or their presence as readily soluble pure fine particles. In general, most solid phase species that are not encapsulated by other solid phases (see Section 8.6.2.2.5) may be considered readily available species. These can be more rapidly leached from the waste than those species limited by matrix dissolution.

Concentrations of these species can thus be limited either by their solubility in the particular liquid phase or by the total amount present in the solids. If the total amount present were the limiting factor, the ratio of liquid to solid in the disposal site would affect the final concentration. If solubility were limiting, the ratio will have no effect.

8.6.2.2.5 Dissolution of Matrix Species and Associated Trace Components -- Many factors can limit the rates at which trace components are leached from FGD and ash wastes. These include:

- Bulk matrix solubilization due to encapsulation (i.e., $CaSO_4$ and aluminosilicate matrix).

- Diffusion through hydrated layers of waste particles.

Leaching rates of encapsulated trace components may be increased by variables that raise the rate of bulk matrix solubilization. These variables include temperature and chemical composition of leaching fluid (pH, ionic strength, weak and strong complexing agents). The total quantity leached into solution will also depend on the contact time of the liquid and solid. Concentrations may be limited after a given period of time by adsorption from solution onto the solid and by solubility constraints.

Thus, to estimate the extent of leaching of trace components, their distribution in the waste (i.e., as surface concentrated, bulk matrix, encapsulated species, readily available) must be known. Laboratory tests may be required to provide this information.

8.6.2.2.6 Solubility Limited Species -- The major components of FGD waste ($CaSO_4$ and $CaSO_3$) result in levels of calcium, sulfate, and sulfite that are limited by their solubility product in the particular ionic strength and chemical composition of the liquor. Concentrations can be determined based on thermodynamic calculations and estimates of solubility. Solubility limitations are unlikely for other ash and FGD waste components, such as very soluble sodium and potassium salts. Some trends have been observed for certain trace elements (such as lower solubility at high pH due to formation of hydroxides), but it is difficult to predict routinely trace metal solubilities in various media.

8.6.2.2.7 Concentration Limitations Due to Availability -- Leachate concentrations of components that are readily and totally leached from wastes are determined by the quantity available from the solid and the liquid-to-solid ratio. Another contributing factor is the amount of "fresh" unleached waste that contacts this leachate as it percolates through the waste disposal site. Examples would be ash particles where all of the As and sulfate are present on the surface and, in some cases, Na and K salts.

8.6.2.2.8 Speciation of Elements in Leachates -- Speciation in leachates is discussed here in two parts. The first is oxidation states of particular elements; the second is formation of complexes in solution. Speciation is important both in terms of environmental effects (for instance, certain oxidation states of As are more toxic than others) and further reactions in the environment (such as attenuation).

The oxidation state of many elements in leachates under normal conditions is defined by the presence of only one stable form of the element (i.e., Na^{+}, Ca^{+2}, Cl^{-}, Sr^{+2}). For other elements, (notably transition elements and As), various oxidation states are possible. Since experimental data on speciation of elements are lacking, most of this discussion is based on the expected chemistry of particular elements under conditions of solution redox potential. Direct measurements under actual field conditions provide the best estimates,

but such tests are difficult. Most measurements to date on trace metal concentrations in leachates provide total element concentrations with no attempt at speciation.

Given a leachate chemical composition and oxidation/reduction potential, the most stable thermodynamically oxidation form of an element can be defined. However, the kinetics of the rate required to achieve that thermodynamically stable state may not be known if the species is not initially present in that state. Thus, both As^{+3} and As^{+5} have been determined under reducing and oxidizing conditions in ash pond leachates, while Cr^{+6} has been observed in extracts of some FGD wastes. The oxidation states of readily oxidizable ions (Fe^{+2}) under weakly complexing environments will tend to the higher value (Fe^{+3}) under aerobic (oxidizing) conditions. Similarly under anaerobic conditions, bacterial action may cause the reduced oxidation state. Interelement redox reactions can also occur.

Complex formation occurs to a greater extent in leachates of higher ionic strength than in dilute solutions. In any case, most complexes formed in these leachates are expected to be "kinetically labile." That is, rates of conversion of the complex to another form are extremely rapid when the chemical composition of the leachate media is changed. For example, Ca^{+2} may form [$CaCl^{+}$] and [$CaSO_4$] complexes in solution, but when the leachate is diluted with water under the site, these complexes will rapidly form a new equilibrium concentration. This is important, since subsequent reactions will be determined by speciation in the solution undergoing reaction and not by the original leachate.

Experimental determination of these types of complexes in solution has not been performed for FGC waste leachates. Computer programs are available that use thermodynamic complexation constants to predict the relative concentration of a particular species, given the total element concentration and complexing species present in solution.

8.6.2.2.9 Leachate Chemical Quality Decision Tree -- The purpose of the leachate chemical quality decision tree (Figure 8.8) is to estimate the concentrations (and speciation, if needed) of particular elements in the leachate that may exist in the disposal site.

Mobility of waste-related species occurs by migration of aqueous phases. Thus, composition of the aqueous phase in the waste itself as well as those of the aqueous phases generated by contact with leaching media are important in determining environmental effects. The initial step in determining leachate quality would be to correlate the specific disposal scenario with available data for similar situations. This may provide enough information. If not, more detailed data may be obtained, as shown in Figure 8.8.

If the waste has an aqueous phase (as in a pond), the primary leachate composition will be related to that of the interstitial liquor. Since the chemical properties of the waste will vary within a given disposal site, different spatial distributions and changes with depth can be expected. In addition, site-specific conditions, such as the redox environment may cause

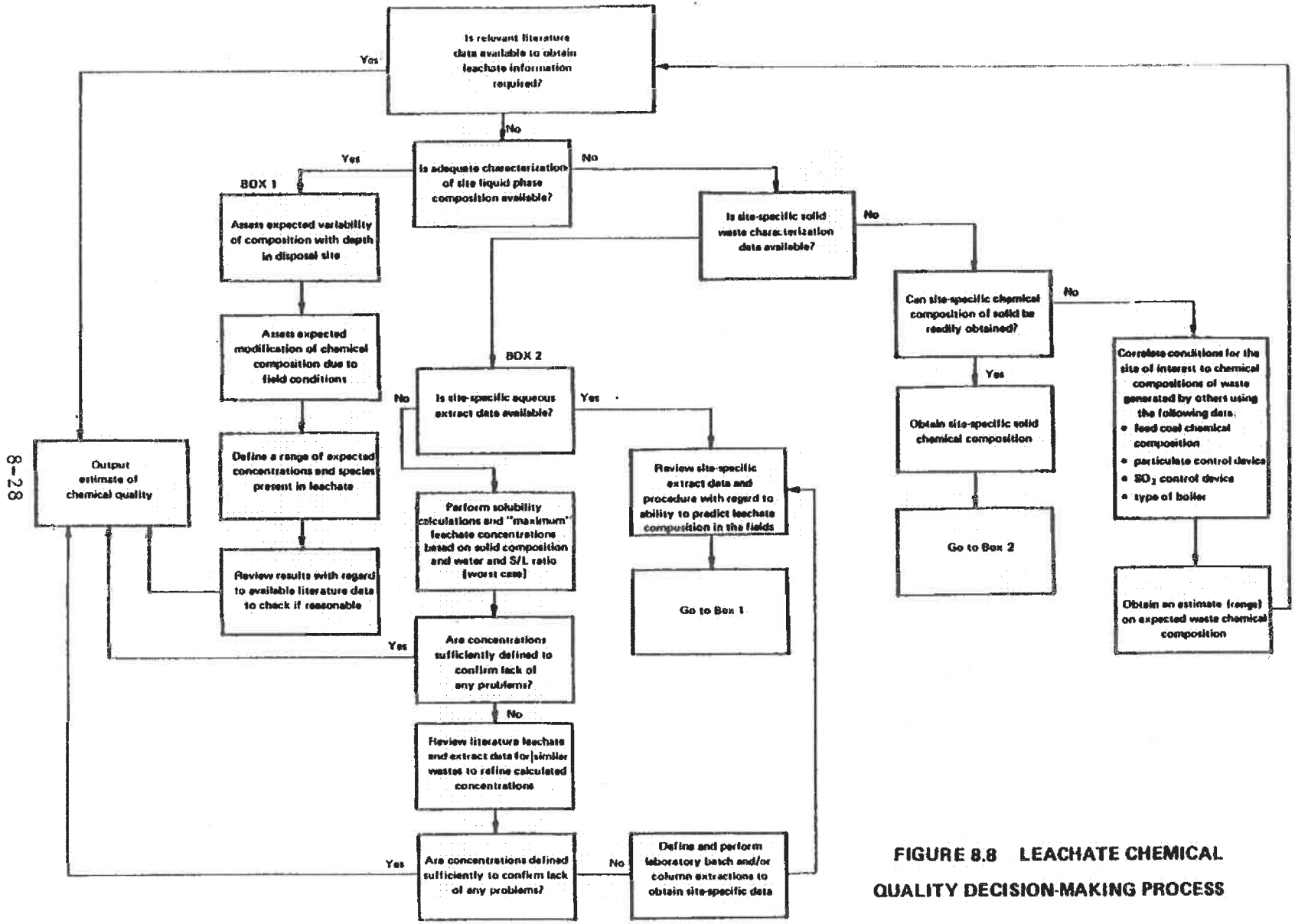

FIGURE 8.8 LEACHATE CHEMICAL QUALITY DECISION-MAKING PROCESS

variations of both concentration and speciation between surface samples and interstitial waste liquors. Also, because liners retard water movement, the liquid-to-solid contact time can be increased, resulting in more dissolution and hence higher concentrations of trace species. Thus, although an initial estimate of the liquid phase composition may be available, the effects of site-specific conditions must be considered.

If no site-specific data on waste liquor are available, the next best source is the composition of the waste solid phase. Given data for solid composition but no extract data for leachate concentrations, a three-step process can be applied:

- Leachate "worst case" levels can be initially estimated by using available thermodynamic data to calculate maximum solubility of waste species in the leaching media. If species are unlikely to be limited by solubility, the maximum level can be defined by assuming that all of the element is leached for each waste layer the water contacts as it percolates through the site. This step may be sufficient for some questions.

- If a better estimate is required, literature data on comparable extracts of the particular waste can be used to estimate the rate of leaching. This step may be necessary when the experimental data suggest that only a small fraction of the total present is available for leaching in a reasonable period of time, or observed leachate/extracts are very different from calculated levels.

- If further refinement is desired, site-specific laboratory and field tests may be needed.

If sufficient extract data for the waste are available, this three-step process should be undertaken before the data are used. When no adequate solids data are available, two options are open. One approach is to determine composition by conducting experiments. The other is to estimate the composition of the waste solids by comparison with less specific literature data for similar disposal conditions.

8.6.3 Leachate Admixing

Leachate admixing refers to the physical and chemical processes whereby leachate concentrations are changed by admixing with receiving waters. This discussion focuses on physical processes that may be readily evaluated in decision-making by examining chemically conservative leachate species. If the receiving water shows negligible concentrations of the constituents in question, the admixing process may be one of simple dilution. In several environmental settings, however, the preexisting levels for constituents generally associated with utility waste leachate may be elevated in receiving waters. This means that the admixing process will only have a negligible dilution effect. In general, where receiving waters exhibit comparable, or greater, levels of species of interest than the leachate, little or no adverse impacts would result from the disposal activity. At other sites where

leachate is admixed with relatively larger volumes of receiving water, examining leachate generation, movement, and admixing processes may by itself indicate negligible adverse effects on water quality. In such cases, there would be no need to study the chemical attenuation processes before admixing.

Evaluating the effects of admixing generally requires an understanding of leachate flow rates and quality, receiving water flow rates and quality, and the nature and rates of dispersion and chemical fate processes that control the admixing process. It is be important to define the location at which the admixed concentration is desired (i.e., drinking water well, critical habitat location directly proximate to the waste) as well as a representative volume of the receiving water body (i.e., aquifer, stream) over which the concentration of species of interest may be averaged. These considerations are discussed below.

8.6.3.1 Admixing in Groundwaters--

Consider the simplified disposal site environment depicted in Figure 8.9. Leachate percolates down to the water table, laterally toward a stream discharge point. (There may be no unsaturated zone under some sites. This will affect leachate movement and admixing, and is discussed separately.) For the situation shown in Figure 8.9, vertical movement in the aquifer is assumed negligible relative to horizontal movement. This condition tends to prevail if leachate movement rates are small compared with lateral underflow rates of the aquifer.

First, one must consider whether vertical or lateral gradients of leachate contaminants in the aquifer are significant. Dispersion, the tendency of solutes to spread out from the predicted path according to hydraulics of flow, can usually be ignored under the following circumstances:

- The disposal site is immediately adjacent to a groundwater discharge area - a stream or lake bed.

- A production well that draws water from the full saturated thickness of the aquifer is or will be downgradient of the disposal site.

In both cases, the contaminant will be rapidly admixed at the discharge point. At a natural discharge, such as a stream bed, a shallow aquifer almost invariably discharges all of its flow with relatively rapid admixing in the surface water body. A production well also mixes the groundwater during the drawdown. At maximum sustainable yield, such wells draw from the full aquifer thickness. A well that is screened or otherwise open through the full saturated thickness will also artificially mix the groundwater in the open portion of the well itself, regardless of pumping rate. In considering the effect on production wells that may be developed in the future, one must account for their zone of influence in determining whether the well will be "downgradient" of the site after development. In each case, the admixed concentration can be estimated by assuming that leachate mixes through the full depth of the aquifer.

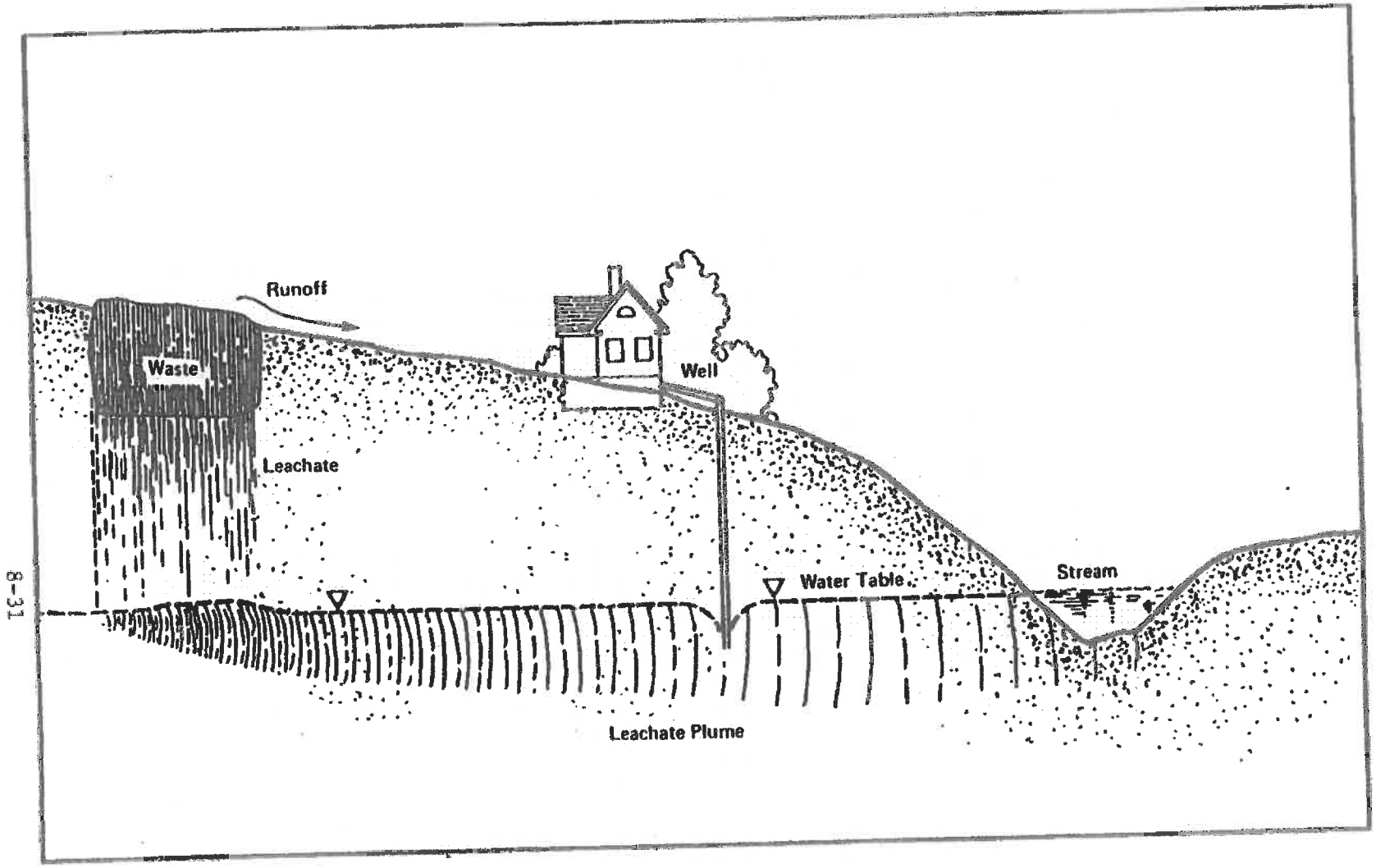

FIGURE 8.9 GENERAL WASTE DISPOSAL SETTING

Dispersion effects need not be explicitly accounted for if the contaminant will be well mixed throughout the aquifer thickness at the location where concentration estimates are desired and if that location is roughly in the "middle" of the contaminant plume (see Figure 8.10). But dispersion phenomena must be implicit in this determination. The "width" of the fill, b, is defined directly upgradient from the site. The plume width, W, will roughly increase along downgradient flow lines as:

$$W = b + 6\left(\sqrt{2\ \alpha_T\ X}\right) \qquad (9)$$

where

X is the distance downgradient (along a flow line) and α_T is the transverse dispersivity.

The vertical spread of the plume, T, is approximated by:

$$T = 3\left(\sqrt{2\ \alpha_T\ X}\right) \qquad (10)$$

Measured values of α_T have been reviewed by Anderson and may range from approximately 0.01 to 10 m (74). Sykes et al., in a recent study of disposal site scale contaminant migration phenomena(75), recommend values of 0 to 0.15 m, suggesting that the larger dispersivities cited by Anderson may only be appropriate for plume migration at larger spatial scales. Values of 0.01 to 1 m seem appropriate based on the available information.

If T is greater than aquifer thickness, uniform vertical mixing can be assumed. For example, at the new Elrama landfill studied under this project (see Section 5.0), leachate may seep vertically to an alluvial aquifer that has a saturated thickness of about 8 m (25 ft). Looking directly upgradient, the fill intercepts about 800 m (2,500) feet of aquifer width. The alluvial aquifer discharges to the Youghiogheny River at Elrama roughly 250 m (800 feet) downgradient of the fill. The width of the potentially contaminated portion of the aquifer at the discharge area is:

$$W = 2500 + 6\left(\sqrt{2(\alpha_T)\ 100}\right) \qquad (11)$$

where W = width in feet.

If α_T = .03 to 3.0 ft,
then W = 2540 to 2860 ft

Thus, lateral dispersion causes a small amount of plume spreading, which in this case can be ignored. The vertical spread of the plume is given by:

$$T = 3\left(\sqrt{2(\alpha_T)\ X}\right) \qquad (12)$$

In a hypothetical situation where a small well were to be located between the fill and the river (30 m or 100 ft from the river), X = 152 m (500 ft) and T = 5 to 50 m (16-160 ft). Compared with the saturated 8 m (25 ft), it is likely that the plume will be well mixed vertically through the full aquifer thickness.

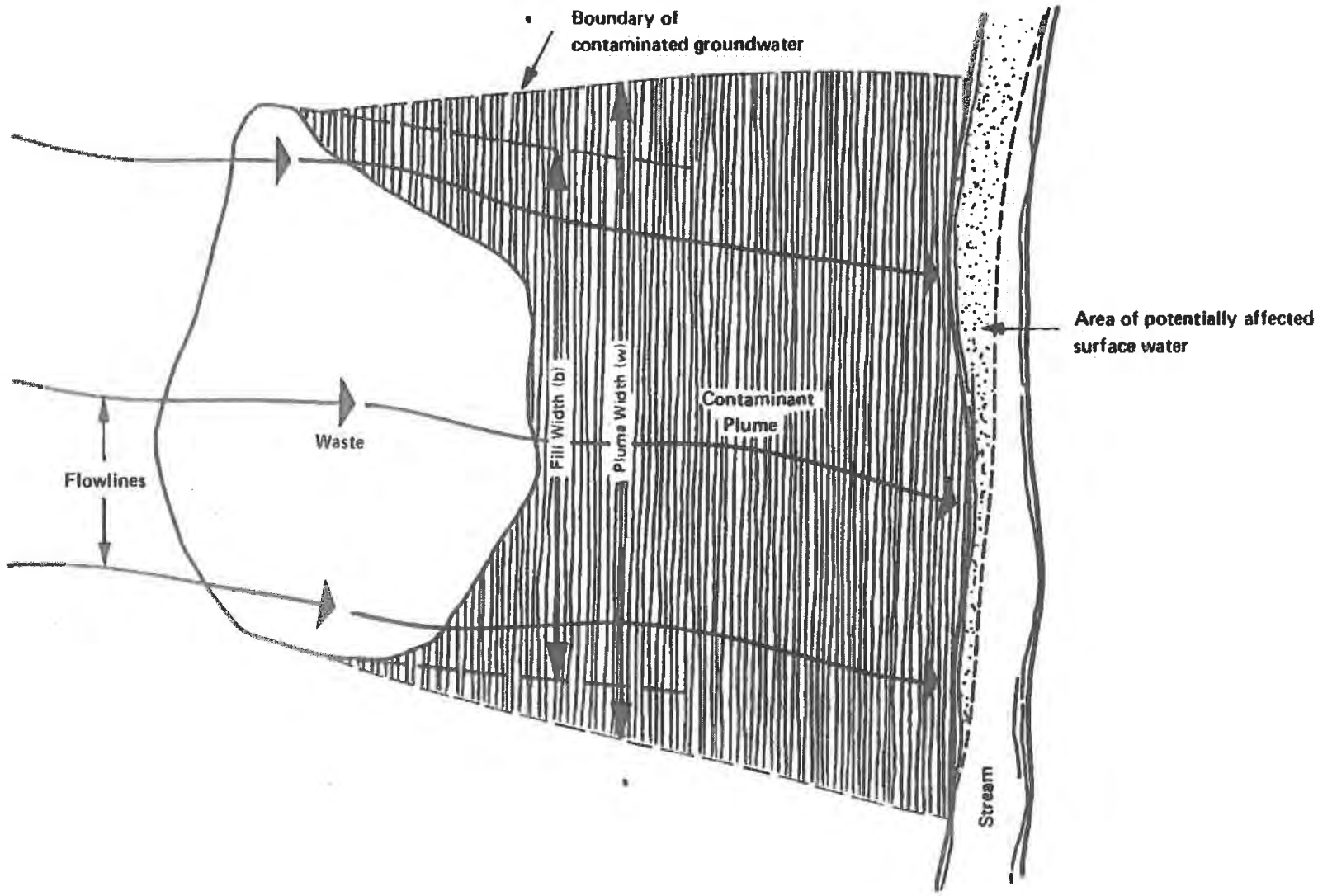

FIGURE 8.10 PLAN VIEW OF GENERALIZED CONTAMINANT PLUME

Once the depth and width of the plume at a sampling location are estimated, the mixing ratios may be determined. The first step is to define the leachate generation rate, Q_l (m^3/yr) (see Section 8.6.2), and the flow in the affected part of an underflowing aquifer, Q_a (m^3/yr). The flow Q_a is through a cross section of width W and thickness T. To estimate Q_a, multiply the Darcy velocity by W and T.

Within approximately a thousand feet of a typical disposal site, lateral dispersion can be neglected. Also, receptors have been identified, such as lakes and streams, large production wells, and wells screened (or otherwise open) over the full saturated thickness, for which limited vertical dispersion need not be considered and T equals the thickness of the saturated zone. In other instances, T can be estimated as:

$$T = 3\left(\sqrt{2\ \alpha_T\ X}\right) \qquad (13)$$

where
T cannot exceed h (the saturated aquifer thickness)

Then, the admixed concentration of any constituent, C is given by:

$$C = \frac{C_l Q_l + C_a Q_a}{Q_l + Q_a} \qquad (14)$$

where
C_l is concentration in leachate
C_a is concentration in background groundwater
Q_l and Q_a are quantities of leachate and groundwater, respectively

The situation is more complex when leachate is a substantial contributor to downgradient flow in the aquifer. This often occurs with unlined disposal ponds, where the downward leachate flow forces contaminated water to greater depth than would occur from dispersion alone. This problem is addressed carefully by McWhorter & Nelson (76) and will not be reviewed here. Given an estimate of vertical and lateral linear flow velocities (V_z and V_l, respectively), a crude estimate of the depth of leachate mixing (T) may be made:

$$T = \left(\frac{V_z}{V_l}\right) X \qquad (15)$$

where

X is distance taken along the flow path

As an example calculation from the studies at the Allen plant (see Section 5.0), V_z is roughly 10^{-6} cm/sec, V_l is roughly 10^{-5} cm/sec and T $\sim$0.1 X. Since the saturated thickness of the aquifer is roughly 18 m (60 ft), the leachate will be well mixed vertically through the full aquifer thickness within 182 m (600 ft) of the pond center (well within the bounds of the pond

itself). In this case, limited vertical dispersion need not be considered. Contaminants will be well mixed through the full aquifer thickness.

8.6.3.2 Admixing in Surface Waters--

Contaminated groundwater usually mixes so rapidly with surface water bodies that no discernible "hot spots" of contamination are expected. Findings at the Powerton site (Section 5.2.5) demonstrate that significantly contaminated groundwater discharging to a very small stream causes only minor observable water quality changes in the stream. Available data, however, cannot discount the possibility of surface water effects from a large, unlined pond discharging to a small stream or to a quiescent body of water such as a small lake or meandering river.

Leachate admixing in streams may be estimated as follows. Vertical mixing is assumed essentially instantaneous; lateral mixing is not. A useful rule-of-thumb (derivable from stream dispersion coefficients) is that if a pollutant is introduced at the shoreline, it will be well mixed across the full width of the stream at a distance $X = 10\ W_s^2/d_s$ downstream from the source, where W_s and d_s are the stream width and average depth, respectively. Downstream of this point, contaminant concentrations in the stream may be estimated as:

$$C = C_{up} + \frac{L}{Qs} \qquad (16)$$

where
C_{up} is the upstream or background concentration (mg/l),
L^{up} is the contaminant loading rate (mg/sec),
Q_s is the stream flow (l/sec).

Upstream of this point, where more acute impacts may be expected, a worst case estimate may be made by assuming the contaminated groundwater discharge is a point source, well mixed vertically. The simplified approximation is:

$$C = C_{up} + \frac{L}{\sqrt{\frac{d_s X}{10 W^2 s}}\ Qs} \qquad (17)$$

This equation yields unnaturally high estimates for very small values of X, because of the unrealistic assumption that the contaminated groundwater discharge is an ideal point source. This may be avoided by ignoring any estimated concentrations that exceed the concentration in the contaminated groundwater. The concentrations estimated by this equation do not apply to the whole stream, but only to a region near the discharge point (shore or stream bed), with approximate lateral dimension given by:

$$\sigma_y = X\left(\sqrt{\frac{d}{10}}\right) \qquad (18)$$

8.6.3.3 Summary--

The methods suggested here are appropriate only under relatively simple and well characterized geohydrologic conditions. Even then they are only reliable to within about an order of magnitude. This level of accuracy, however, may frequently be adequate for an appropriate waste management decision. A really accurate understanding of groundwater flow patterns can only be based on careful field surveys. Simple calculations or sophisticated computerized models cannot compensate for basic deficiencies in the geohydrologic description of a site. Indeed, excessive reliance on models can obscure an often inadequate understanding of site specific geohydrology. However, as mentioned in Section 8.6.3.4, computer modeling may be appropriate in some situations. Several models may be used. Available sources include EPRI, USGS, the Groundwater Model Clearing House (operated by Holcomb Research Institute of Butler University and National Water Well Association), and References 77 and 78.

8.6.3.4 Leachate Admixing Decision-Making Process--

Figure 8.11 shows a methodology for evaluating the effects of leachate admixing with receiving waters. The receiving waters may be surficial (streams, rivers, lakes, estuaries) or subsurface aquifers. In the most general and typical case of disposal near a surface water body, one must consider admixing of leachate with underflowing groundwater, followed by admixing of this contaminated groundwater with the surface water body as the groundwater discharges to it.

The first step is to compare leachate quality with receiving water quality for all constituents of interest. The list of constituents will generally include major ions and heavy metals. Leachate quality may be comparable to or better than receiving water quality for many important constituents in several settings: (a) highly mineralized locations in the arid west, (b) highly acidified locations in the interior, and (c) tidally-influenced coastal settings. Preexisting site contamination is another factor when assessing surface mine disposal operations.

The next step is to review the site water balance and other hydrologic and geohydrologic data to determine the range of flow rates expected in the receiving waters over the life of the facility. Seasonal variability in flows should be considered, as well as the substantial uncertainties inherent in estimating groundwater flow rates. The uncertainty in groundwater flow rates, as estimated either from available data or limited site field survey, may be quite high (as much as an order of magnitude). Estimates are likely to range over a factor of 0.2 to 5.0 times the value. These wide ranges should be accounted for by conducting alternative admixing analyses based on the extremes of the best estimate, if no independent estimate of uncertainty is available.

Seasonal variations in receiving water flows are likely to have a substantial influence on the admixing process in surface waters. Admixing at low flows can be calculated based on the seven-day, ten-year low flows that are available for most major streams and rivers from local, state, or federal water pollution control agencies for the Water Resources Division of the

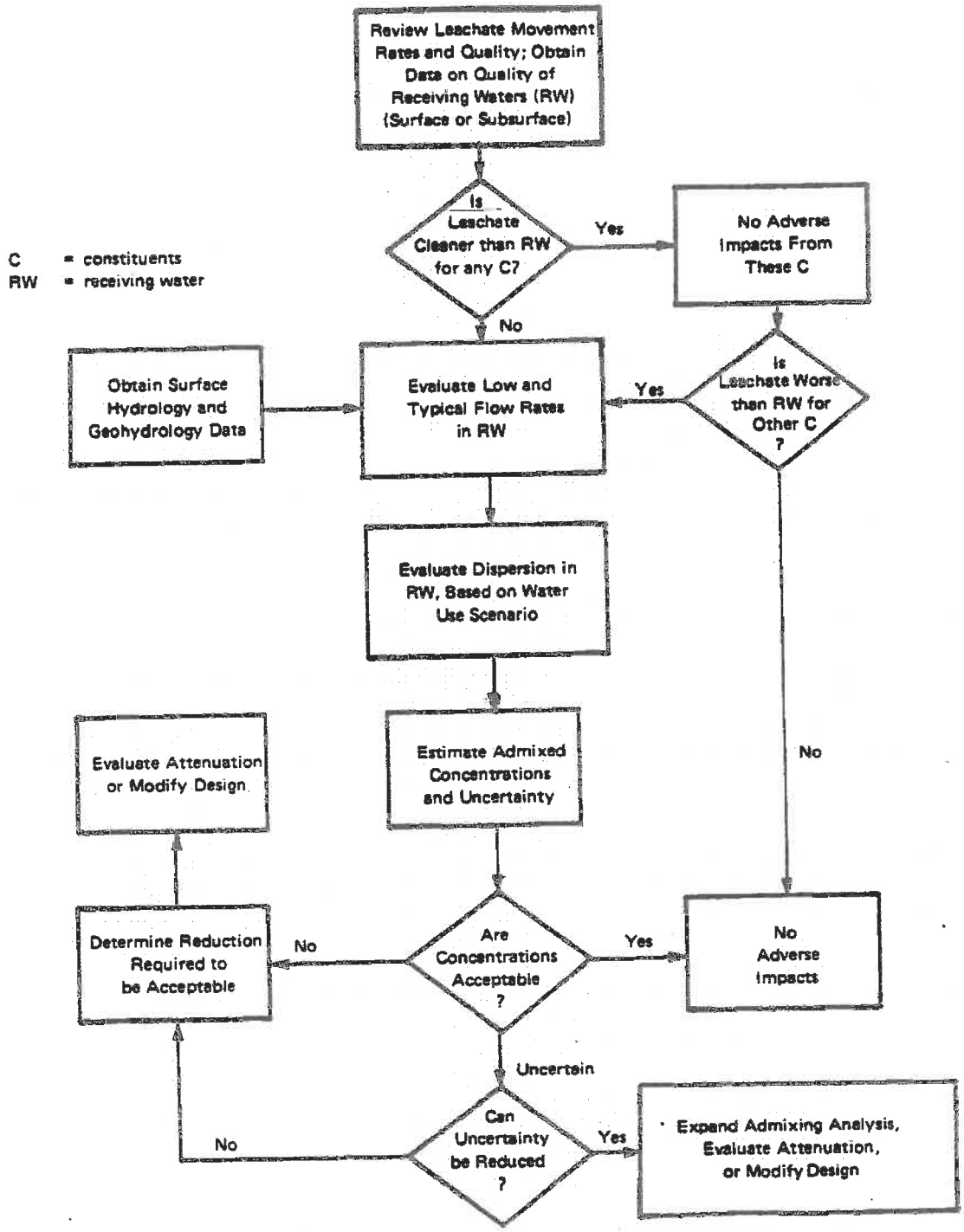

FIGURE 8.11 LEACHATE ADMIXING DECISION-MAKING PROCESS

District Office of the U.S. Geological Survey. If the seven-day, ten-year low flow has not been defined, it can be estimated from a suitable hydrologic time series (79). When suitable data are not available for a direct determination of a seven-day, ten-year low flow for the water body, a variety of indirect methods may be used to define a representative low flow. Low flow can be estimated based on data on the low flow of a nearby stream whose drainage area most nearly corresponds to that of the subject stream in drainage area, climate, and physiography. A reasonable estimate would be that the ratio of the low flows in the two streams equals the ratio of the drainage area. Similarly, if the mean flow of the stream is unknown, the mean flow will be roughly proportional to drainage area, based on other nearby streams whose watersheds are similar in climate and topography.

The effect of seasonal variation in groundwater flow may be accounted for, assuming sufficient data are available. Shallow aquifers affected by surface disposal may show substantial seasonal fluctuations in flow and head. The admixing process, however, may be fairly insensitive to seasonal fluctuations for the following reasons:

- Groundwater admixing is a relatively slow process that occurs over the total travel time from source to receptor; this movement often takes several years and has an averaging impact on seasonal fluctuations.

- At some disposal sites, particularly landfills, fluctuations in the amount and movement of leachate may match those of the groundwater. The resulting concentrations may be relatively insensitive to seasonal variations.

Seasonal fluctuations in groundwater admixing need only be considered when the travel time to significant downgradient receptors is less than one year. In interpreting field data to estimate typical groundwater flow rates, however, it is important to evaluate the degree to which a particular observation period is representative of typical flow rates. If data are available from a limited observation period, geohydrologic/climatic interpretation of the representativeness of the observation period is recommended.

Data characterizing leachate flow rates and quality, receiving water body flow rates and quality should be compiled and compared with leachate and receiving water quality to screen constituents for which leachate quality is better than receiving waters. The final steps of the methodology lead to an estimate of receiving water quality at locations of sensitive water use, assuming that chemical attenuation has not occurred. If the estimated concentrations are within acceptable limits, the chemical attenuation processes would not have to be evaluated, as attenuation would likely reduce concentrations further. With some constituents, however, such as acidic leachates, interaction of the soil with leachate can lead to elevated levels and would thus require attention.

The final steps are the most difficult and controversial in evaluating admixing. Problems arise when data bases and field and theoretical methods

designed for water supply purposes are applied to pollution migration problems at disposal site-scale. For example, small-scale inhomogeneities in properties of the transport medium can control actual pollution migration pathways and apparent dispersion, thus determining whether contaminant will affect a specific well location. Such inhomogeneities are generally not characterized in detail during standard site evaluation field work, nor are models in general use designed to account for their effects on pollution migration pathways. For these and other reasons, it is not possible to predict precisely the contaminant concentration distribution that will result from a specific waste disposal configuration.

Detailed computerized modeling of groundwater contaminant migration at utility disposal sites is not well enough developed to be recommended as standard practice. Use of such models would not substantially reduce uncertainties in predicted groundwater quality, although some exceptions may arise:

- If a calibrated groundwater flow model is already available for the site. (Such a model may have been developed for utility water supply or other purposes). Computerized prediction of contaminant migration patterns may be achieved at small additional cost.

- If noncomputer-based evaluation procedures leave too much uncertainty regarding the seriousness of environmental impacts, and this uncertainty may be reduced computerized models. This case can only be evaluated when the uncertainty of the evaluation procedures is carefully estimated, and the bounds of uncertainty encompass a critical environmental quality objective (such as a drinking water standard).

Computer modeling could be appropriate where the geohydrologic setting is complex or subject to significant future stresses, and where that complexity is well characterized by field data. But models cannot be used to overcome data deficiencies. For example, a potential disposal site is underlain by a sand and gravel aquifer which is separated into two weakly interacting strata by a clay bed. The bed is present in most borings but absent in a few. A municipal production well serving domestic users draws from the lower stratum. Noncomputer-based evaluation procedures are not well suited to this complex configuration, and it is quite uncertain whether leachate constituents will appear in the well water at hazardous concentrations. Computerized modeling may be necessary to evaluate this situation. Other examples include those where future stresses on the hydrogeologic system (a planned production well or substantial additional recharge from a disposal pond) will substantially change groundwater flow processes.

Dispersion phenomena in the receiving waters should next be considered. Specific methods have been presented in the previous section. This step should consider the volume of the receiving water that is actually significant in the context of a specific water use. For example, it is not appropriate to estimate the concentration in a portion of an aquifer one meter cubed in

volume if a municipal well draws from the full aquifer thickness with a cone of influence of one hundred meters cubed in volume.

Once the extent of dispersion is estimated, concentrations may be crudely ascertained by assuming that concentrations are relatively uniform within an affected portion of the receiving waters. Uncertainty in the flow-related parameters must be accounted for, as well as any ambiguities in the water quality of leachate and receiving waters.

The resultant concentrations must be compared with environmental quality objectives. Depending on the level of uncertainty associated with these results, further field investigations or model applications may be necessary. If these measures will not reduce the uncertainty to an acceptable level, the only recourse is to see whether chemical attenuation would lead to a concentration reduction or whether the disposal plan should be modified.

8.6.4 Mechanism of Attenuation by Soils

8.6.4.1 Overview--

As leachate migrates out of the boundary of the waste disposal site, it contacts surrounding soil and moisture present in that soil (whether groundwater or unsaturated soil moisture). During this contact, chemical and physical reactions can occur between leachate chemical species and the soil/water mixture. If these reactions lower concentrations of chemicals in the mobile liquid phase, they are considered capable of attenuating species from the leachate. This section summarizes mechanisms governing leachate attenuation by soil/water mixtures and the properties of each component that may affect the extent of attenuation.

8.6.4.2 General Mechanisms--

The general mechanisms that may reduce soluble component concentrations in leachate include:

- dilution of leachate by existing liquid or moisture in the soil;
- precipitation of species in the leachate by modification of the leachate chemical composition after mixing with solid soil components and with liquid or moisture present in the soil;
- adsorption of chemical species from the leachate/water mixture onto surfaces of soil particles; and
- formation of insoluble complexes between species in the leachate and complexing agents in the soil.

Dilution of the leachate by existing groundwater in the soil (or soil moisture) can cause reductions concentrations observed in the leachate. Where unsaturated soils occur under the waste disposal area, this mechanism may not be significant until the leachate reaches the groundwater level. But if the soils are saturated (i.e., groundwater is directly under the waste or in the waste), it may play a larger role (see Section 8.6.3).

Species can precipitate from the leachate due to changes in leachate pH which occur as it mixes with underlying soil and/or water. Many trace metals are more soluble at lower pH's. An acidic leachate may contain elevated levels of trace elements which will precipitate if the leachate mixes with alkaline water in the soil or with alkaline soil itself. Also, the mixing can cause levels of particular components (i.e., SO_4) to increase in the mixture. This, in turn, can lead to precipitation of soluble cations via the "common ion" effect. A combination of effects due to changes in both pH and chemical composition may cause lower solubilities of various solid phases. Additional reactions (i.e., redox) between soil solids/liquids and leachates can modify speciation to produce less soluble compounds.

Species from the resultant leachate solutions can be adsorped onto soil particles due to ion exchange-type interaction (opposite charges) or simply Vander Waals-type forces. This interaction depends highly on the surface composition of the soil and surface area of the particles. In general, hydrous metal ion hydroxides (Mn, Fe and Al) play a large role in adsorbing trace elements onto the soil. The greater the surface area (greater proportion of small clay type particles), the greater the expected adsorption. Leachate composition is significant in this equilibrium, since the species present in the solution will largely determine the extent of adsorption. All chemical species present in solution which affect speciation of the particular element and those that influence the charge on the soil particles are important.

Formation of insoluble metal complexes between humic acids in the soil and particular trace elements has also been proposed as a mechanism for attenuation. As in adsorption, the composition of the leachate in terms of speciation and modification of charges on soil particles can affect the interaction with complexing agents in the soil. The presence of "free" complexing sites is influenced by leachate pH and the presence of other soluble constituents. The tendency for a trace component to be complexed also depends on its speciation.

Additional information on these mechanisms and a summary of available data are provided in References 80 and 81 and in the results of the soil attenuation experiments conducted in this study (see Appendix F).

8.6.4.3 Properties of Soils Affecting Attenuation Capability--

8.6.4.3.1 Overview -- This section summarizes the properties of soil that affect their attenuative capacity. The important physical and chemical properties are:

Physical Properties

- particle size distribution (% clay, % silt, % sand)
- surface area (measured experimentally or calculated based on particle size distribution)
- moisture content

Chemical Properties

- total organic carbon
- pH of soil/leachate mix (available alkalinity)
- chemical composition of moisture present
- chemical composition of major and trace components

Sorption of a given chemical species various greatly from one soil to another. Similarly, sorption of different species on one particular soil fluctuates widely. However, greater surface areas (smaller particle sizes) generally lead to greater attenuation. Dilution (high moisture content in the soil) provides an initial "attenuation." Greater organic carbon content, higher pH (leachate/soil mixture pH about of 7 to 9), and higher concentrations of hydrous oxides Mn and Fe increase soil capacities for many trace components.

Release of species from the soil into the leachate when the two come into contact is also observed, especially where the leachate/soil mixture is highly acidic (pH 2 to 4) and also where the leachate contains elevated concentrations of species which can displace substances from the soil. Field parameters that affect leachate chemical quality (composition, permeability, moisture content) are also important in determining the extent of attenuation. Adsorption phenomena usually occur in a short time frame (less than 1 day) under good mixing conditions. In field situations where little mixing occurs, adsorption rates may be limited by the slower diffusion of species in aqueous phases. Temperature may also determine the extent of attenuation. Differences between the temperature in the field and the temperature at which laboratory experiments have been performed can lead to erroneous assumptions regarding behavior in the field.

One area that represents a large data gap concerns changes in the chemical composition of the soil/leachate mix. More information is needed on how these changes influence speciation.

8.6.4.4 Properties of Leachate Affecting Attenuation Capacity--

Chemical properties of leachates that can be important in attenuation include:

- concentration (activity) of species of interest in solution,
- speciation of element of interest, and
- concentrations (activities) of other components in solution.

The most obvious leachate property determining soil capacity for a particular species is its concentration in the solution. The capacity of the soil rises as the concentration in solution increases, until the soil is saturated with regard to its capacity. Thus, lower concentrations in solution

would lead to lower capacities. In many cases, plots of log (concentration in the soil - µg/gm) versus log (concentration in solutions - µg/ml) are linear according to the type of relationships derived by Freundlich (14).

Speciation of an element is important in adsorption and precipitation reactions. Speciation includes the oxidation state of the element and its state of complexation. Highly complexing species in solution may associate with the element to form stable complexes with different affinities for the soil than the "uncomplexed" species. Variation in pH can produce stable hydroxy-type complexes (i.e., $H_2AsO_4^-$), which will be attenuated differently from AsO_4^{-3}. A large concentration of Cl^- or SO_4^{-2} can produce ion pairs or complexes in solution ($CaCl^+$, $CaSO_4^\circ$) which may reduce the extent of attenuation. Little experimental data are available on the speciation of substances in actual samples, although many predictive calculations have been made. Current data for speciation of elements in coal ash and FGD waste leachate are limited to some determinations of oxidation states rather than presence of complexes. The presence of 10 to 20 ppb of a strong organic complexing agent in the leachate can complex all of a particular element present at low concentrations (i.e., Cu at 10 to 20 ppb) and prevent any attenuation at that level.

Concentrations of other species in the leachate soil mixture or solution can influence attenuation by: causing changes in the speciation of the element of interest; providing opportunity for precipitation of species with various other ions; and competing for limited adsorption on soils. Other species, as well as pH, can also cause changes in the soil surface charges, thereby affecting adsorption capacity. In some cases, species can be released from the soil.

Most studies of how a given element affects adsorption capacities of various soils have been conducted with relatively "pure" synthetic solutions. In this study, some data has been obtained for actual leachates from FGC disposal sites. Speciation and affects of other species in solution on attenuation have received little attention and represent a significant data gap.

Table 8.4 shows the relative mobility of some trace elements (existing as cations and anions in solution) for a variety of soils.

8.6.4.5 Soil Attenuation Decision-Making Process--

The decision-making process (Figure 8.12) may be undertaken to determine the extent that soil attenuation of leachate species occurs. The path for the most site-specific information assumes that chemical data on interstitial soil pore water directly under the site are available. These data are then adjusted (for mixing with liquids present in the soil or groundwater) and compared to the concentrations in the leachate to determine if the soil has caused changes in concentrations.

If adequate information on the composition of soil water under the site is not available, the composition of the soil solid phase (physical properties such as percent clay, silt, and sand and chemical properties such as total

TABLE 8.4

RELATIVE MOBILITY OF ANIONIC AND CATIONIC METALS IN VARIOUS SOILS

Soil Type	Low	Moderate	High
Clay	Cu,Pb,Be,Zn,Cd,Ni, Se,V,As,Cr		Hg
Silty Clay	Cu,Pb,Be,Zn,Cd, Ni,Se		V,As,Cr
Clay Loam	Cu,Pb,Be,Zn,Cd,Ni	Se,V	As,Cr
Silty Loam	Cu,Pb	Be,Zn,Cd,Ni,Hg	
Silty Clay Loam	Cu,Pb	Be	Zn,Cd,Ni,Hg
Silt	Cu,Pb	Be,Se	Zn,Cd,Ni,Hg,V,As,Cr
Silty Loam	Cu,Pb		Be,Se,V,As,Cr

Note: Se,V,As,Cr are considered to exist as anionic complexes in the solutions used in these experiments.

Source: Reference 12

SECTION 9.0

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16. ABSTRACT

The six-volume report summarizes results of a 3-year study of current coal ash and flue gas desulfurization (FGD) waste disposal practices at coal-fired electric generating plants. The study involved characterization of wastes, environmental data gathering, evaluation of environmental effects, and engineering/cost evaluations of disposal practices at six sites around the country. Study results provide technical background data and information for EPA, state and local permitting officials, and the utility industry for implementing environmentally sound disposal practices. Study data suggest that no environmental effects have occurred at any of the six sites; i.e., data from wells downgradient of the disposal sites indicate that waste leachate has resulted in concentrations of chemicals less than the EPA primary drinking water standards. A generic environmental evaluation--based on a matrix of four waste types, three disposal methods, and five environmental settings--shows that, on balance, technology exists for environmentally sound disposal of coal ash and FGD wastes for ponding, interim ponding/landfilling, and landfilling. For some combinations of waste types, disposal methods, and environmental settings, mitigation methods must be taken to avoid adverse environmental effects. Costs of waste disposal operations are highly system and site specific.

17. KEY WORDS AND DOCUMENT ANALYSIS

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FULL-SCALE FIELD EVALUATION OF WASTE DISPOSAL FROM COAL-FIRED ELECTRIC GENERATING PLANTS

Volume IV. Appendices C Through E

by

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ABSTRACT

This report summarizes results of a 3-year study of current coal ash and flue gas desulfurization (FGD) waste disposal practices at coal-fired electric generating plants. The study was conducted by Arthur D. Little, Inc., under EPA contract 68-02-3167, and involved characterizing wastes, gathering environmental data, assessing environmental effects, and evaluating the engineering/costs of disposal practices at six selected sites in various locations around the country. Results of the study are providing technical background data and information to EPA, State and local permitting officials, and the utility industry for implementing environmentally sound disposal practices.

Data from the study suggest that no major environmental effects have occurred at any of the six sites. For example, data from wells downgradient of the disposal sites indicate that the contribution of waste leachate to the groundwater has generally resulted in concentrations of chemicals less than the primary drinking water standards established by EPA. Although occasional exceedances of the standards were observed, these were not necessarily attributable to coal ash and FGD waste. A generic environmental evaluation based on a matrix of four waste types, three disposal methods, and five environmental settings (based on climate and hydrogeology) shows that technology exists for environmentally sound disposal of coal ash and FGD wastes for ponding, interim ponding/landfilling, and landfilling. For some combinations of waste types, disposal methods, and environmental settings, measures must be taken to avoid adverse environmental effects. However, site-specific application of good engineering design and practices can mitigate most potentially adverse effects of coal ash and FGD waste disposal. Costs of waste disposal operations are highly system- and site-specific.

APPENDIX C

SAMPLING AND ANALYSIS PROCEDURES MANUAL

FULL-SCALE FIELD EVALUATION OF WASTE DISPOSAL FROM COAL-FIRED ELECTRIC GENERATING PLANTS

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EPA Contract 68-02-3167

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PREFACE

This manual establishes administrative and technical pocedures for conducting field sampling and analysis for selected site investigations relating to U.S. Environmental Protection Agency (EPA) Contract No. 68-02-3167, "Characterization and Environmental Monitoring of Full Scale Utility Waste Disposal Sites" with Arthur D. Little, Inc. of Cambridge, Massachusetts.

This manual, entitled, "Sampling and Analysis Procedures Manual," is one of four manuals which will govern and control the various aspects of field and laboratory testing and analysis for evaluating selected utility waste disposal sites.

Preparation of this manual was primarily the responsibility of Arthur D. Little, Inc., under the overall direction of C.J. Santhanam, Arthur D. Little, Inc. Project Director and Julian W. Jones, EPA Project Officer. The responsible personnel, along with other project team members who contributed by direct input, review, and comment, are:

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ABBREVIATIONS

AA	atomic absorption
AE	atomic emission
ASTM	American Society for Testing and Materials
Btu	British thermal unit
cc	cubic centimeter
cm/sec	centimeter per second
°C	degrees Centigrade
°F	degrees Fahrenheit
EPA	Environmental Protection Agency
ESP	electrostatic precipitator
FGC	flue gas cleaning
FGD	flue gas desulfurization
ft	feet
g	gram
IC	ion chromatography
ICAP	inductively coupled argon plasma
in.	inch
kg	kilogram
L	liter
lb	pound
M	molar
min	minute
mL	milliliter
mm	millimeter
mV	millivolt
N	normal
ppm	parts per million
psi	pounds per square inch
QA	quality assurance
QC	quality control
RCRA	Resource Conservation and Recovery Act
sec	second
SPT	standard penetration test
TDS	total dissolved solids
TOS	total oxidizable sulfur

Note: For conversion units, see page C-iv.

CONVERSION FACTORS

English/American Units	Metric Equivalent
Length:	
1 inch	2.540 centimeters
1 foot	0.3048 meters
1 fathom	1.829 meters
1 mile (statute)	1.609 kilometers
1 mile (nautical)	1.852 kilometers
Area:	
1 square foot	0.0929 square meters
1 acre	4,047 square meters
Volume:	
1 cubic foot	28.316 liters
1 cubic yard	0.7646 cubic meters
1 gallon	3.785 liters
1 barrel (42 gals)	0.1589 cubic meters
Weight/Mass:	
1 pound	0.4536 kilograms
1 ton (short)	0.9072 metric tons
Pressure:	
1 atmosphere (normal)	101,325 pascal
1 pound per square inch	0.07031 kilograms per sq. centimeter
1 pound per square inch	6894 pascal
Concentration:	
1 part per million (weight)	1 milligram per 1000 gm
Speed:	
1 knot	1.853 kilometers per hour
Energy/Power:	
1 British thermal unit	1,054.8 joules
1 megawatt	3.600×10^9 joules per hour
1 kilowatt hour	3.60×10^6 joules
Temperature:	
1 degree Fahrenheit	5/9 degree Centigrade

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GLOSSARY

Fixation: The process of putting into a stable or unalterable form.

Impoundment: Reservoir, pond, or area used to retain, confine, or accumulate a fluid material.

Leachate: Soluble constituents removed from a substance by the action of a percolating liquid.

Leaching Agent: A liquid used to percolate through a substance that results in the removal of soluble constituents.

Pozzolan: A siliceous or aluminosiliceous material that in itself possesses little or no cementitious value but that in finely divided form and in the presence of moisture will react with alkali or alkaline earth hydroxide to form compounds possessing cementitious properties.

Pozzolanic Reaction: A reaction producing a pozzolanic product.

Reagent: A substance that takes part in one or more chemical reactions or biological processes and is used to detect other substances.

Stabilization: Making resistant to physical or chemical changes by treatment.

Titer: The strength of a solution or the concentration of a substance in solution as determined by titration.

Titration: A process for determining the strength of a solution or the concentration of a substance in solution in terms of the smallest amount of a reagent of known concentration required to bring about a given effect in reaction with a known volume of the test solution.

1.0 INTRODUCTION

1.1 OVERALL PROGRAM

This Manual is one of the elements of a program undertaken by Arthur D. Little, Inc., as prime contractor for the Environmental Protection Agency (EPA) under EPA Contract No. 68-02-3167 entitled "Characterization and Environmental Monitoring of Full-Scale Utility Waste Disposal Sites." The overall purpose of this program is to obtain data and information concerning the storage, treatment, and disposal of coal ash (fly ash and bottom ash) and FGD waste from coal-fired utility plants. Results of the study will provide the technical background data and information needed to assist the EPA in determining the degree to which the disposal of these wastes needs to be managed in order to protect human health and the environment. The disposal methods examined will include the most prevalent methods used in the industry as well as those that are likely to represent the best control technology for the disposal of coal ash alone, coal ash and FGD waste combined, and, if appropriate, FGD waste alone.

Since this project is undertaken to support the EPA in its regulatory responsibilities under the Resource Conservation and Recovery Act (RCRA) of 1976, concerning utility solid waste disposal, the highest screening priority is given to three subject areas that are both characteristically important for utility solid waste disposal and principal regulatory responsibilities under RCRA. Using this philosophy, the three high priority subject areas are:

1. Impact on Groundwater Quality

   The major impact on groundwater quality is that associated with the movement of leachate from the wastes to the groundwater in the region of disposal. Specifically, this is the highest priority consideration under RCRA. This Sampling and Analysis Procedures Manual is primarily geared to provide information on the physical and chemical nature of the wastes, leachate,

and the surrounding soil such that projections on the movement of leachate from the wastes to the groundwater in the region can be made with a reasonable level of confidence. Physical and engineering characterization and chemical analysis are geared towards this end.

In areas where the groundwater is either non-existent or far too distant for the leachate to have made contact with it, the characterization efforts will be made to determine the extent to which the leachate plume has moved and thereby provide data that can be used in assessing potential impacts.

2. Impact to Surface Water Quality from Non-point Sources

Impact on surface waters in the vicinity of the disposal site from such waste disposal can occur due to two factors:

- Surface runoff originating from or passing over the disposal site and into the surface waters, and
- Leachate from the wastes moving to the groundwater and thereby to the surface waters or alternatively directly moving through the sub-surface to the water body.

It is to be noted that the non-point impact of such solid waste disposal is often more important in those cases where there is no direct effluent overflow from such waste deposits to the surface waters. For example, if an ash pond has a very large overflow to a river, this direct discharge is often much larger in quantity than the total non-point surface runoff and groundwater seepage into the same river. To the extent possible, efforts will be made to determine the impact at non-point sources with the understanding that in some cases it may be difficult, if not impossible, to make a reasonable assessment of non-point impacts.

3. Use of Potentially Mitigative Design, Management, or Control Practices

This is an important part of this project. The

mitigative control approaches could be one of four kinds:

- Mechanical processing so as to provide less hydraulic head on the waste in the disposal site and hence, minimize leachate movement from the site. Dewatering methods, forced oxidation leading to the production of better FGD wastes for filtration, and several others are illustrative examples of this kind of mitigative practice.
- Use of liners. Lining of a disposal site with bentonite, clay, poz-o-pac and other linings are illustrative examples of this kind. It is to be noted that in some site-specific cases, clay might be an existing sub-surface feature. These natural linings also are important mitigative measures and could be part of appropriate site selection as an engineering practice for waste disposal.
- Minimizing water requirements for handling of the wastes will reduce the total movement of dissolved materials into the surrounding areas. While this is not a direct factor, recycle of ash pond water, for example, tends to reduce the total outflow of pollutants from the disposal of ash.
- Use of stabilization processes. Stabilization of FGD wastes by lime and fly ash or other methods provides a waste that could be deposited and compacted so as to reduce the movement of leachate from it.

The above are illustrative examples of the kind of mitigative practices that will be evaluated in this project. It is to be noted that proper site selection is an extremely important mitigative management practice. The selection of preliminary candidate and back-up sites reflects a broad variety so as to take into account the site selection approaches that have been employed and thereby attempt to bracket the environmental impacts of

appropriate site selection.

1.2 PROJECT APPROACH

Functionally, the project has been subdivided into four areas of endeavor:

1. The selection of 12 representative utility waste disposal sites. The selection process will take into account:
   a. Waste type (characteristics) and method of disposal;
   b. Hydrogeologic and geotechnical considerations; and
   c. Environmental considerations.
2. The development of the twelve sites for proper environmental monitoring. This effort will consist of the following:
   a. Hydrogeologic and geotechnical surveys of each site;
   b. Assessment of the environment as it affects waste and host soil sampling-related actions; and
   c. Development of groundwater monitoring wells and field support facilities for sampling and analysis.
3. Sampling and analysis of the waste, groundwater, surface water, and the surrounding soils for the purpose of physical and chemical characterization.
4. Integrated engineering and economic assessment of the various types of waste disposal operations, together with the development of adequate cost data describing a generic variety of waste disposal methods.

The result of these activities will be subject to a fully integrated environmental assessment as well as engineering and economic analysis. The final result will be a set of recommendations on disposal practices.

The project has been divided into three major tasks for obtaining and evaluating information at the sites:

Task I: Preliminary Site Selection and Test Plan

TABLE 1.1

MAJOR PARTICIPANTS: EPA CONTRACT NO. 68-02-3167

Program Area	Principal Participants
Prime Contractor	Arthur D. Little, Inc. Cambridge, MA 02140
Hydrogeologic Activities	Haley & Aldrich, Inc. Cambridge, MA 02142
Geotechnical & Field Drilling	Bowser-Morner Testing Laboratories, Inc. Dayton, OH 45401
Chemical Sampling & Analysis	Arthur D. Little, Inc. Cambridge, MA 02140 and TRW, Inc. Redondo Beach, CA 90278
Physical Sampling & Analysis	University of Louisville Louisville, KY 45208 and Bowser-Morner Testing Laboratories, Inc. Dayton, OH 45401
Engineering/Economic Evaluation	Arthur D. Little, Inc. Cambridge, MA 02140 and Kaiser Engineers Power Corp. Oakland, CA 94623
Quality Assurance/Quality Control	Arthur D. Little, Inc. Cambridge, MA 02140

Source: Arthur D. Little, Inc.

Preparation;

Task II: Site Evaluation and Characterization and Environmental Monitoring; and

Task III: Environmental and Economic Assessments.

The prime contractor for this program is Arthur D. Little, Inc., Cambridge, MA. The principal participants in the overall program and their areas of contribution are listed in Table 1.1.

1.3 PURPOSE OF THIS MANUAL

This Appendix B, "Sampling and Analysis Procedures Manual," for utility waste disposal sites is structured to develop information on the current and potential impact on ground and surface water quality and other environmental impacts in the vicinity of the disposal site. The sampling and analysis phase of the program will provide physical, engineering, and chemical characterization of the waste, surrounding soils, and ground and surface waters to satisfy the overall program objectives.

This manual has been prepared to provide a common methodological approach for the conduct of the sampling and analysis phase of this program. The manual will provide guidelines for a common approach and techniques for sampling and analysis and will thus ensure compatible data gathering from different sites, by different subcontractors. For the sampling of physical and geotechnical properties, the manual will provide uniformity in approach and methodology between Bowser-Morner and other drilling contractors who may be utilized.

This manual is also intended to define standard operating procedures and sampling and analysis techniques for use in, or reference by, the site-specific test plans to be prepared later. Where detailed technical procedures from other sources are to be used without modification, they have been included here only by reference. Other procedures which have been modified for the purposes of this program are covered in detail.

1.4 MANUAL ORGANIZATION

This is one of four basic manuals (Appendix A through Appendix D) that will be produced to maintain a common basis for the conduct of this program and to ensure that the project team members conducting various aspects of the field work will do so in an acceptable and cost-effective manner. The project-related subjects for each manual consist of the following:

Appendix A — Hydrogeologic and Geotechnical Procedures Manual

Appendix B — Sampling and Analysis Procedures Manual

Appendix C — Engineering and Economic Evaluation Procedures Manual

Appendix D — Environmental Assessment Procedures Manual

Details on the engineering practices to develop a site are given in Appendix A, "Hydrogeologic and Geotechnical Procedures Manual." Appendix C, "Engineering and Economic Evaluation Procedures Manual," describes the approach and methodology for performing the engineering and economic assessment of the disposal operation at each site. A later manual, Appendix D, "Environmental Assessment Procedures Manual," will provide the background and approach on how the data gathered by use of procedures described in this manual will be employed for environmental assessment.

This Sampling and Analysis Procedures Manual provides the basis and overall approach for the sampling and analysis tasks in the program. These include:

- Team responsibilities and coordination. Areas of interaction between subcontractors are broadly outlined.
- Preparation of the sampling and analysis sections of the site-specific test plans.
- A generic approach to sampling and analysis of waste sites.
- Procedures for sampling (for chemical and physical tests).
- Procedures for analysis (of chemical and physical properties).
- Procedures for quality assurance and quality control, QA/QC (for physical and chemical sampling and analysis).

2.0 GENERAL CONSIDERATIONS ON SAMPLING AND ANALYSIS

2.1 OVERVIEW

The overall approach to the sampling and analysis portion of the program will involve three major activities:

1. A site-specific detailed test plan will be prepared;
2. Sampling and analysis for physical properties will be performed; and
3. Sampling and analysis for chemical properties will be performed.

As currently envisioned, the site-specific test plans will be prepared as soon as a site is selected and nominated by the Arthur D. Little, Inc. Project Director (after EPA approval). As part of the site selection process, several site visits will have been made, and this information will be included in the test plan. Once the test plan has been accepted by the utility whose site has been selected and EPA, site development will occur. Sampling for physical testing will be done during site development as will any on-site (field) testing for physical properties. Sampling of waste and soils for chemical testing will also occur during site development. Laboratory testing for physical properties will occur during and after site development. Sampling of groundwater, surface waters, runoff, and currently disposed waste for chemical testing will all be done after site development, with sampling extending for a period of about one year. Chemical analysis will be performed shortly after the respective sample has been taken.

2.2 TEST PLANS

Following the nomination of a site by Arthur D. Little, Inc. and approval by EPA, the first task at the site will be the preparation of a site-specific test plan. The test plan will comprise a detailed explanation of all activities to be conducted on a specific site. This will include information on site

development, sampling, analysis, engineering/economics, and schedule and cost. To the extent possible, the test plan will refer to the specific procedures outlined in each of the four procedures manuals. Any new or novel procedures to be used at a site that are not detailed in a manual will be explained in the test plan.

A general outline for the test plan is presented in Table 2.1. Inputs on the sampling and analysis aspects will be received from Arthur D. Little, Inc., and where appropriate from TRW and Bowser-Morner, in Sections 3.2, 3.3, 5, and 6 of the test plan. These sections are outlined in more detail in Table 2.2. The sampling portion of the test plan for soils and wastes is included in Appendix A, "Hydrogeologic and Geotechnical Procedures Manual."

Arthur D. Little, Inc. will have the overall responsibility for compiling the test plans.

2.3 PHYSICAL PROPERTIES

Physical property determinations will be made both for the FGC waste deposit and for the surrounding soil. These properties of the waste and soil are useful in evaluating the potential for groundwater pollution. Such data may also be useful in estimating disposal economics of a particular waste disposal site. Permeability, grain size distribution, natural moisture content, and density (void ratio) are useful parameters in indicating the potential for leachate migration of FGC wastes. Grain size, natural moisture content, and other properties identified by field testing of the soil at each site will aid in assessing the potential for groundwater pollution; these tests will also be used in characterizing the groundwater flow regime.

An important aspect in determining the physical engineering characteristics of a waste deposit is the selection of field or laboratory testing conditions. Field testing provides quantitative information on the type and extent of the deposit and can also provide relative density, strength, permeability,

TABLE 2.1

SITE-SPECIFIC TEST PLAN – GENERAL OUTLINE

1. Objectives

2. Background

   2.1 Power Plant and Location
   2.2 Disposal Operation
   2.3 Geotechnical, Hydrologic, Geologic, and Climatologic Baseline
   2.4 Environmental Information

3. Approach

   3.1 Site Development
   3.2 Sampling/On-site Analysis
   3.3 Off-site Analysis
   3.4 Engineering/Economic Data
   3.5 On-site Environmental Data

4. Potential Problems and Alternative Approaches

5. Cost Estimate

6. Schedule

7. Coordination

8. Data Reporting and Handling

Appendices
Drawings

Source: Arthur D. Little, Inc.

TABLE 2.2

SITE-SPECIFIC TEST PLAN – SAMPLING & ANALYSIS DETAIL

3.2 Sampling/On-site Analysis

3.2.1 Physical Characteristics

1. Background
2. Rationale and Quantities
   - Sampling
   - Field Testing

3.2.2 Chemical Characteristics

1. Background
2. Sampling
   - Waste
   - Soil
   - Groundwater
   - Surface Water Runoff
3. On-site Measurements

3.3 Off-site Analysis

3.3.1 Laboratory Testing – Physical

3.3.2 Laboratory Testing – Chemical

1. Background
2. Sample Preparation
3. Analyses
   - Metals
   - Anions
   - Wet Chemical
   - Organic

Source: Arthur D. Little, Inc.

and compressibility. Laboratory tests performed on disturbed and undisturbed samples are conducted under more controlled conditions and provide more accurate determinations of engineering properties. Since the laboratory tests are performed on relatively small samples, the accuracy of correlating laboratory with field conditions depends on the homogeneity of the waste deposit.

The following field and laboratory tests for physical properties are anticipated for the FGC waste testing program:

Field Tests	Laboratory Tests
Vane Shear	Natural Moisture Content
Standard Penetration	Grain Size
Field Permeability	Specific Gravity
Nuclear Depth-Density	Compaction (Proctor)
	Strength
	Permeability
	Compression

Natural moisture content determinations, grain size analyses, and specific gravity determinations will be made in the laboratory from samples obtained during the standard penetration tests. Strength, permeability, and compression testing will be performed on relatively undisturbed thin-walled Shelby tube samples obtained during the field exploration program. The field tests are described in detail in Appendix A, "Hydrogeologic and Geotechnical Procedures Manual." The laboratory testing procedures are described in Section 5 of this Sampling and Analysis Procedures Manual.

2.4 CHEMICAL PROPERTIES

Chemical characterization will be performed on the following materials:

- Previously and freshly disposed FGC wastes;
- Soils from under and around the disposal site;
- Groundwater from existing and/or newly developed groundwater wells; and

- Runoff and/or surface waters from or near the site.

A summary of the analyses and analytical methods to be used for chemical characterization is given in Table 2.3.

In general, initial screening of samples at a site will be made using pH, conductivity, inductively coupled argon plasma (ICAP) and ion chromatography (IC) for liquids, and ICAP for solids. The extent of further more complete analysis and the number of samples analyzed will depend on site-specific factors. The practice of utilizing screening followed by more comprehensive analyses will be used to maximize the amount of information on the elements and species of interest with regard to definition of environmental impact. EPA Level 1 inorganic and organic protocols will be used at two of the sites (one ash and one FGD-containing material).

Detailed chemical analyses will be used to characterize the solid and liquid phases of the wastes according to the priority listing discussed in Section 7. Analytical methods to be used on wastes include IC for anions, atomic absorption (AA) and atomic emission (AE) (inductively coupled- and dc-plasma) for metals, and other wet chemical instrumental and spectrophotometric techniques.

Analysis of groundwater samples will closely parallel the waste analysis. Depending on the data obtained during the initial months of monitoring, the number of analyses may be reduced and the resulting change in effort diverted to analysis of additional samples. Dissolved oxygen and sulfite measurements will be performed to some extent and on sites where FGD materials are currently being disposed and where the waste liquor analyses show the presence of sulfite.

Analysis of soils from under the site and background soil samples from around the site will be performed at some sites. Interstitial pore water analysis or total analysis of the soil will be done to get an indication of contaminant presence. A two-stage analysis will be used to determine which samples will be analyzed comprehensively (similar to the waste and groundwater situation). Selected species such as anions which can be

TABLE 2.3

PROPOSED ANALYTES AND ANALYTICAL METHODS

Analysis Method	Analytes[1]
ICAP – Inductively Coupled Argon Plasma	Ca, Na, Al, Ba, Be, Cu, Fe, F, Mg, Mn, P, Pb, Sr, Ti, V, Zn, Th, Sn, Ag, Co, Cr, Mo, Ni, Zr
AA – Atomic Absorption	As, Se, Sb, Hg, Cd
AE – Atomic Emission (dc-plasma)	B, Si
IC – Ion Chromatography	F^-, Cl^-, NO_3^-, $PO_4^{\equiv}$, $SO_4^{=}$
Instrumental	pH, Conductivity, Radioactivity
Gravimetry	TDS[2], Acid Insolubles
Wet Chemistry	Alkalinity (OH^-), $CO_3^{=}$, TOS[3], $SO_3^{=}$
Spectrophotometry	Trace $SO_3^{=}$
Level 1 Inorganic[3]	Screening for inorganic components
Level 1 Organic[3]	Screening for organic components
Level 2 Organic[3]	Selected organic species analyses, TOC[2], Acid/Base-Neutral extractables
XRD – X-ray Diffraction	Mineral composition for crystalline phases

1. These analytes were selected from the following lists
   - Possible FGC Tracers – Ca, Na, Cl^-, $SO_4^{=}$, pH, $SO_3^{=}$.
   - Proposed interim primary drinking water standards – Ba, Pb, Ag, Cr, As, Se, Hg, Cd, NO_3^-.
   - Proposed secondary drinking water standards – Cu, Fe, Mn, Zn, $SO_4^{=}$, Cl^-, pH.
2. TDS – Total Dissolved Solids
   TOC – Total Organic Carbon
   TOS – Total Oxidizable Sulfur
3. At two sites only.

Source: Arthur D. Little, Inc.

determined by an ion chromatographic scan (F^-, Cl^-, NO^-_3, $SO^=_4$) or those metals which can be determined by ICAP will be used. Whenever these results indicate the presence of leachate, the remainder of the analyses (TA) will be performed.

Surface/runoff water samples will be analyzed for both suspended and dissolved materials. The analysis of suspended materials will involve determination of the relative amount of fly ash and/or FGD material suspended by selective analysis of the solid for metals by ICAP. A similar analysis including ion chromatography of the dissolved species will be performed.

Additional analyses for species not listed may be required during the course of this program at particular sites. Specific EPA-approved analytical methods will be utilized, or others developed, as needed.

The coordinator will be kept informed of all interactions among subcontractors related to sampling and analysis. Interactions between utility and test program personnel on any aspects of the test plan, schedule, etc., will occur through the site coordinator or with his/her prior knowledge.

A Bowser-Morner site engineer will be responsible for field testing and for obtaining samples of waste and soils during initial development of each site for subsequent physical and chemical tests. Field exploration of the FGC wastes will be performed by either Bowser-Morner personnel or subcontracted personnel under the direction of the Bowser-Morner site engineer. The sampling and analysis program for each site will follow the specific procedure as described in Section 3 of the preliminary test plan. Deviations from the test plan may be necessitated by site-specific conditions and may be made by the site engineer. The Arthur D. Little, Inc. site coordinator and the University of Louisville will review any major changes in the locations or types of samples.

The Bowser-Morner site engineer and project engineer may modify the physical testing program from the preliminary plan if necessitated by site-specific conditions. They will, however, advise University of Louisville personnel of any such proposed changes prior to implementation.

The Bowser-Morner physical testing procedures will be approved by University of Louisville personnel prior to the initiation of the testing program. Approximately 1 in every 20 waste samples will be sent to the University of Louisville for comparative strength and permeability testing.

Sampling of groundwater, surface waters, runoff waters, and freshly produced waste will be performed by the chemical sampling and analysis team (either Arthur D. Little, Inc. or TRW), assigned to the particular site.

3.0 RESPONSIBILITY AND INTERFACING

Sampling and analysis activities will encompass a variety of disciplines and several subcontractors. The major areas of activity will include:

Overall responsibility for sampling and analysis	Arthur D. Little, Inc.
Physical sampling/analysis/QC	Bowser-Morner Testing Laboratories, Inc.
Chemical sampling/analysis/QC	Arthur D. Little, Inc. TRW, Inc.
ICAP analyses	Barringer-Magenta, Ltd.
Advisory QA/QC — physical sampling/analysis	University of Louisville
QA — chemical sampling/analysis	Arthur D. Little, Inc.
Overall QA/QC program	Arthur D. Little, Inc.

The interfacing and coordination of activities among the various subcontractors will be an important aspect of the overall program. Briefly, the major responsibilities for interfacing will be as follows:

- The test plan preparation will be under the overall control of Arthur D. Little, Inc. Input on various aspects will be requested of the subcontractors as appropriate.
- Arthur D. Little, Inc. will be responsible for the overall control and management of the program. Any modifications to the test plan approach must be approved by the Arthur D. Little, Inc. Project Director.
- Authorization to proceed with the sampling and analysis program after acceptance of the test plan at a specific site will be given only by the Arthur D. Little, Inc. Project Director.
- The Arthur D. Little, Inc. Project Director will designate a site coordinator for each site who will be responsible for coordinating activities at that site.

Each sampling team will have a team leader who will be responsible for all aspects of the team's performance while in the field, subject to the overall direction of the site coordinator.

- Samples will be obtained from each site according to protocols set forth in the site test plan. Because of site-specific conditions the sampling team leader may determine that alternate procedures may need to be used. However, any such changes must be approved by the site coordinator and the manager of chemical QA prior to implementation.
- Chemical analyses of samples will be performed by Arthur D. Little, Inc. or TRW, depending on the organization responsible for the site. Analyses for trace metals by ICAP will be performed by Barringer-Magenta, Ltd. Each of these three organizations will designate a laboratory coordinator who will be responsible for all analytical activities which take place in his organization. All analyses will be performed according to the procedures set forth in this manual. From time to time, difficulties may be encountered which necessitate procedural changes. All such changes must be approved by the Arthur D. Little, Inc. laboratory coordinator and the manager of QA for chemical sampling and analysis prior to implementation.
- The overall responsibility for quality assurance (QA) and quality control (QC) rests with the Arthur D. Little Project Director.
- Responsibility for program-wide chemical sampling and analysis QA/QC activities rests with the Arthur D. Little, Inc. manager of chemical QA. University of Louisville personnel as advisors to Arthur D. Little, Inc. will provide QA/QC oversight for physical sampling and testing, and will report their findings and recommendations to the Arthur D. Little, Inc. Project Director.

- QC activities related to field testing or sample acquisition will be the responsibility of the designated site engineer (Bowser-Morner) or field team leader (Arthur D. Little, Inc. or TRW), depending upon the performing organization. These designated individuals will be responsible to the QA manager (physical testing or chemical sampling and analysis).
- QC activities relating to laboratory testing and anlaysis will be the responsibility of the designated laboratory coordinator, and these individuals will be responsible to the cognizant QA manager for chemical or for physical testing.

4.0 SAMPLING METHODOLOGY AND PROCEDURES

4.1 INTRODUCTION

The sampling procedures which are described in this section will be used to obtain representative samples of soils, waste, waste site influents and effluents, groundwater, and surface water for chemical characterization and samples of soils and wastes for physical characterization. Also discussed are many of the procedures which are part of the total sampling process, including field measurements, containers, cleaning of equipment for sampling, field documentation, preservation of samples, and shipment of samples. The selection of detailed procedures which will be used at a particular site and the choice of sampling location will be made during preliminary visits to the site and during the development of detailed test plans.

In obtaining samples for both physical and chemical tests, close attention will be given to maintaining their physical and/or chemical integrity. Many of the laboratory tests for physical properties will require discrete samples which are obtained under undisturbed conditions. For these tests the physical integrity of the sample must be maintained during acquisition and transport. Samples for chemical analysis generally do not need to be physically intact but must remain chemically unmodified.

Samples may be composited to provide a single average value, or discrete samples may be taken to provide a range of compositional values. The latter approach will afford a measure of compositional differences which may occur because of time effects, varying fill composition, and other site variables. Where possible, samples for physical and chemical tests will be taken from locations in close proximity in order to provide for maximum correlation with physical properties.

An effort will be made to minimize contamination in obtaining samples for chemical analysis. For example, fly ash is ubiquitous at most sites and could be introduced into samples and sampling

points (i.e., wells). In addition, where possible, sample modification such as that which may occur when a liquid sample is taken from an anaerobic condition and then exposed to oxygen will be minimized.

The sampling techniques (e.g., pumping and dipping) used for liquids and well-stirred slurries are very different from those used for solids (e.g., coring). Thus, the physical properties of the material being sampled (e.g., liquid, slurry, or solid) determine the techniques to be used at a specific site. The methodology which may be applicable to wet disposal sites (i.e., ponds) discussed in Section 4.2 will be different from that for dry disposal sites (landfills) discussed in Section 4.3. Sampling methods for soil and groundwater are common to both types of disposal sites and are presented in Sections 4.4 and 4.5. Sampling techniques for surface water are discussed in Section. 4.6.

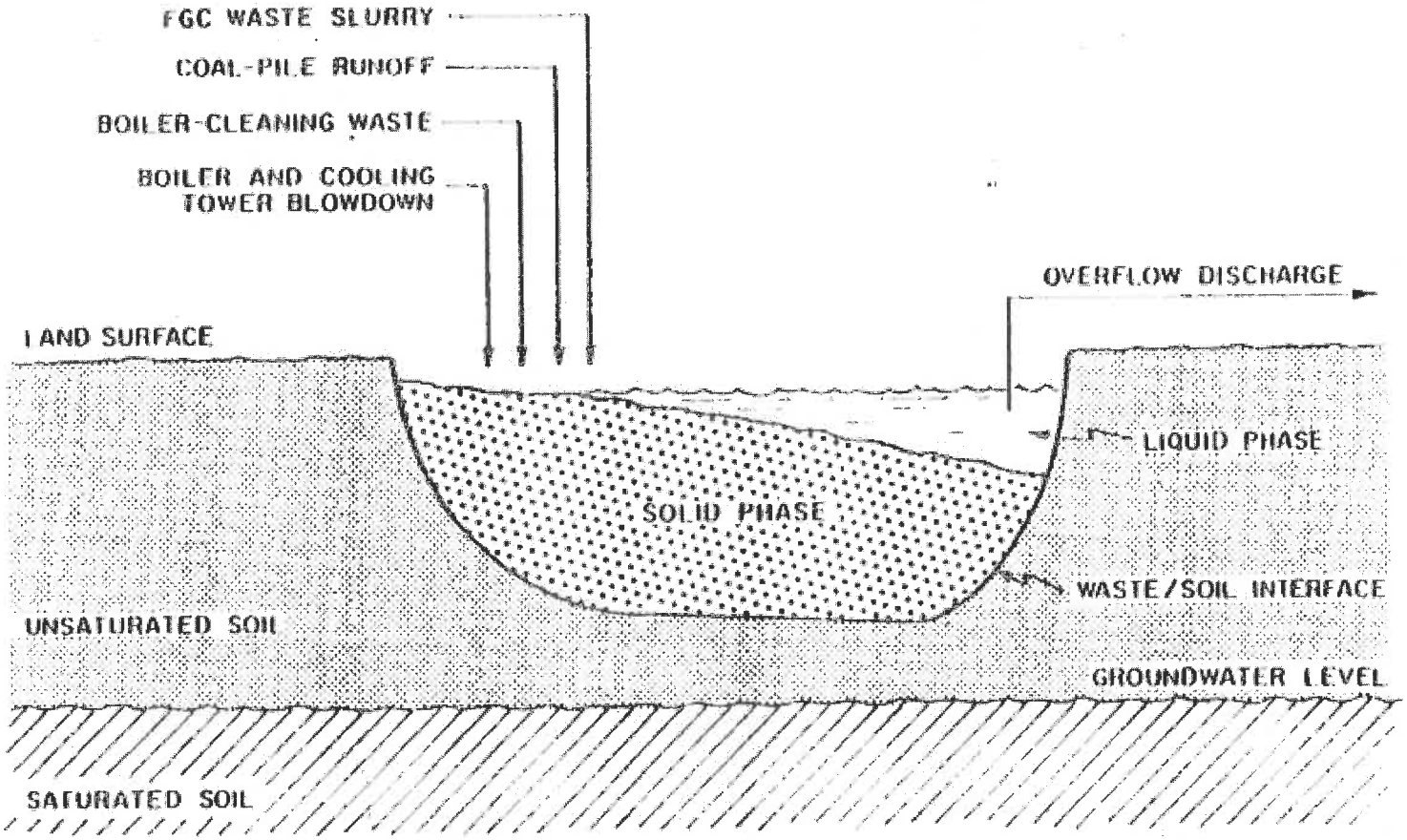
If the utility at the specific site desires to retain a portion of samples obtained, EPA and Arthur D. Little will interact with the utility on the issues to attempt to arrive at solutions.

4.2 WET DISPOSAL (PONDING) SAMPLING APPROACH

4.2.1 Introduction

Information about the various types of influents to, effluents from, and waste present in the pond needs to be obtained in assessing wet disposal (ponding) of FGC wastes. These materials (shown in Figure 4.1) differ in chemical and physical properties as well as in their mode of transport and regularity of flow. (See Table 4.1.) Materials that may enter the pond include slurries of FGC waste (i.e., fly ash, bottom ash, and/or FGD solids) and other wastes that occur from the coal combustion process (e.g., boiler-cleaning wastes, cooling tower blowdown, and runoff from the coal pile).

The chemical and physical properties of these streams may



Source: Arthur D. Little, Inc.

FIGURE 4.1 WET DISPOSAL (PONDING) INFLUENTS AND EFFLUENTS

TABLE 4.1

WET PONDING – TYPICAL WASTES AND RELATED STREAMS[1]

Name	Physical Characteristics (quantity of suspended solids)	Usual Mode of Transport	Flow Characteristics
Influents:			
Coal-Pile Runoff	low	pipe or ditch	sporadic
Boiler-Cleaning Wastes	low	pipe or ditch	sporadic
Cooling Tower Blowdown and Others	low	pipe or ditch	continuous
Miscellaneous Plant Wastewater	low	pipe or ditch	variable
FGC Waste[2]	low to high	pipe or ditch	
Pond Contents:			
Liquid Supernate	very low	N/A	N/A
Settled Solids	very high	N/A	N/A
Effluents:[3]			
Pond Overflow	low	weir/pipe	continuous

N/A = Not Applicable.

1. For illustration purposes only. Not all influents may be present at all wet disposal sites.
2. FGC waste sluice streams may contain FGD material, a variety of ashes (bottom, economizer, air preheater, fly), mill rejects, and soot.
3. Underground effluents (e.g., leachate occurring by infiltration) are not included since these are not directly able to be sampled.

Source: Arthur D. Little, Inc.

also vary substantially with time. Ash sluice lines may contain mixtures of ash and waste from a variety of sources in the combustion process added at different times. These include mill rejects from pulverization of the coal, bottom ash, economizer ash, air preheater ash, soot, and ESP ash (Exhibit A.1.1). The flow of the sluice line may be continuous, but its composition (e.g., suspended solids) may vary a great deal with time.

The flow of coal-pile runoff is related to precipitation or thawing events and thus is non-continuous and sporadic. Boiler-cleaning waste inflow may occur less frequently than coal-pile runoff, but is more predictable because it is a scheduled event. Cooling tower blowdown waste and pond overflow are generally more continuous streams.

The content of the pond varies in composition from a liquid, low in suspended solids, to an inhomogeneous water-saturated solid. The velocity of the liquid phase is generally quite low compared to other streams.

4.2.2 Sampling of the Contents of the Pond

Sampling of the pond contents will be performed to chemically characterize the liquid phase and to physically and chemically characterize the solid phase. These sampling activities will be carried out during site development and in conjunction with performance of field testing for physical properties.

The approach for obtaining samples for chemical and physical properties of the solid phase will involve use of conventional drilling and coring techniques. (See Appendix A, "Hydrogeologic and Geotechnical Procedures Manual.") A rig will be floated on the pond, anchored, and a 10-cm (4-in.) diameter casing will be driven down to the desired depth. Where possible, the liquid layer inside the casing will be pumped out and samples taken with thin-walled Shelby tubes (ASTM D 1587, Ref. 4.1), a piston sampler (ASTM D 1587, Ref. 4.1), or a split-spoon sampler (ASTM D 1586, Ref. 4.2). These samplers will be made of non-corroding steel and cleaned as specified in Section 5. No grease may be

used on any of the samplers used for chemical property samples. Samples at various depths will be obtained by drilling with a side-discharge bit and continually removing the waste to the desired depth, using, where possible, water of known chemical composition or a compressed gas. If appropriate, an inert gas (e.g., nitrogen) will be used to flush the casing prior to sampling material from an environment which is thought to be anaerobic. Where removal of the water from the casing is not feasible, the drilling fluid will be flushed out with pre-analyzed fresh water and samples of waste taken through the standing water.

An average of 18 samples located within the pond is anticipated. These would generally be comprised of six portions obtained at different depths from three boreholes as arbitrarily derived in Appendix A, "Hydrogeologic and Geotechnical Procedures Manual." Deviation from this average number of samples may be made depending on the nature and complexity of the site.

Sampling will occur in conjunction with performance of standard penetration tests (Appendix A). Standard penetration resistance (SPT) tests will be performed on continuous intervals of 0.45 m (1.5 ft) for thin waste deposits of less then 3.05 m (10 ft); on 0.76-m (2.5-ft) intervals for moderately thick waste deposits of 3.05 to 6.1 m (10 to 20 ft); and 1.5-m (5-ft) intervals for thicker deposits.

Piston or Shelby tube samples will generally be used for both physical and chemical laboratory testing and analyses, as they afford minimum disturbance of the sample and minimum exposure to air. Where possible a 3-foot Shelby tube will be obtained for each chemical sample point. A minimum of 0.45 m (1.5 ft) will be obtained for chemical tests. It is anticipated that the number of samples obtained will be proportional to the number of varieties of waste materials encountered. As an example, approximately three to six tube samples or more will be obtained for the physical laboratory testing. The additional Shelby tubes will be obtained for chemical testing and analyses.

Sampling of the liquid phase of the pond will occur during

stream. Horizontal and vertical cross-section samples will be taken during the first time each stream is sampled in order to establish the extent of homogeneity of the cross section. After the level of suspended solids in each sub-sample has been compared, the sub-samples will be composited into a single sample.

When a sampling point is shown to be spatially homogeneous, the number of sub-samples and sampling effort may be reduced.

Automatic samplers may be used for some sites to obtain samples from streams such as ash sluice lines, runoff, or surface waters. However, it will be necessary to prove that the slurry composition is not changed by the delays in transporting the physical sample to the storage containers.

Obtaining representative samples from continuous streams which do not vary greatly in composition or flow rate is easier than sampling sporadic events which vary greatly in both regards. In the former case, a series of grab samples taken at arbitrary times is sufficient to represent the stream. In sporadic situations, modifications may be necessary.

Runoff, as from a coal pile, is one of the least continuous and most unpredictable influents to a pond. Such runoff waters result from precipitation events including both rainstorms and the melting of snow and ice. The composition of runoff liquors, both in terms of suspended and dissolved materials, will be highly dependent on the intensity and duration of the storm event, the nature of the materials which are impacted by these events, and the surface topography of the area itself. The objectives of the runoff sampling program will be to obtain approximate estimates of volume flows and chemical composition of runoff liquors which result from one or more storm events at each site, where such sampling is appropriate. Measurement of volume flows and chemical composition of runoff liquors will lead to very rough estimates since both the flow and composition are extremely variable during the event and are a result of great variability between rain or thaw events. Sampling and analysis at a limited number of events thus can only lead to a limited

and after site development. Conventional dipping samples and/or capped containers (Ref. 4.3) will be used.

4.2.3 Sampling and Flow Measurement for Pond Influents and Non-point Source Effluents

4.2.3.* Sampling

Sampling of liquid and slurry influents (Table 4.1) to the pond will involve obtaining samples for chemical analysis and measurement of the mass flow rate of each stream. The term "slurry" can be used to describe most of the influent streams since they will range from blowdown containing few suspended solids to thickened-FGD underflow with 30-40% suspended solids which is pumped as a mud-like material.

The major consideration in designing sampling and flow measurement procedures for slurries is ensuring that the proportion of solids collected is representative of the total stream. It is expected that heterogeneity develops in these streams due to settlement of solids once the turbulence and mixing in the stream decreases. No general sampling technique can guarantee representativeness for all slurry samples which will be encountered in FGC disposal sites. The detailed methodology and procedures will be established for each site using the guidelines given below.

Slurry sampling will be carried out at a point where mixing (stream turbulence) is maximal in order to afford the best opportunity to obtain a relatively complete representation of the stream composition. In situations where the composition may vary widely because of fluctuations in input streams, samples will be taken at appropriate intervals over the sampling time period. The intervals will vary on a site-specific basis, however, at an average site, slurry streams (ash, FGD) will be sampled at least six times over each single sampling period (day).

Samples will be taken using a dipping sampler or capped container which can be opened under the surface of the slurry

collection or estimates from hydraulic properties (Ref. 4.5). Total collection involves measuring the time required to fill a container of known volume where the entire flow (or an accurately determined fraction of the total) is diverted into the container. Hydraulic property estimates make use of calibrated channels (e.g., flumes and weirs) whose flow properties are known or are accurately predictable from theoretial or empirical relations. Other hydraulic property techniques include measurement of cross-sectional area/depth and linear velocity. Of these approaches, the calibrated flume/weir will afford the most accurate measurements of flow, while the velocity/depth-of-flow approach will provide somewhat less accurate estimates. Field flow measurements may also be made automatically using a continuous automated level recorder in conjunction with a flume or weir. The device can be activated at the onset of precipitation or flow. Use of such a device (for example, the Manning Dipper or Isco Bubbler) together with a flume/weir channel has been found by Arthur D. Little, Inc. to produce acceptable data for measurements in small open channels similar to some which are expected at FGC waste sites.

The number of points at which flow measurement will be required will be determined by the nature of the carrying system (i.e., pipes, open channels, closed culverts) and the complexity of influent streams. For automatic measurements and sampling the devices must be installed or be in place prior to the onset of the event; individual devices will be required for each flow path which is to be monitored. Routine checking or monitoring of the installed flow measurement devices will be performed.

Mathematical estimation involves computation of flow volumes based upon the area of interest. For example, runoff volume may be estimated from the rainfall amounts and known surface dimensions of the waste area. Parameters such as infiltration rate may be subject to uncertainty; however, the precipitation data and area data needed for input into such models can be obtained with a reasonable degree of confidence.

representation of this phenomenon.

The approach which will be taken for runoff sampling and flow measurement will depend greatly on the extent to which runoff waters are diverted and/or channeled at a particular site. At those sites where runoff enters the pond in defined channels, flow measurement and sampling efforts will resemble those employed for streams or ditches. Either manual methods or automated devices will be used for both efforts. Samples obtained manually will be retained separately and composited as necessary. Automatic devices may lead to obtaining a single grab sample or composition of many grab samples.

Manual sampling requires manpower on-site during runoff events and will be generally used only if local utility personnel are willing to help in the effort by obtaining the samples and automatic sampling is not feasible. Runoff can be sampled by using automatic samplers (Ref. 4.4) which collect either discrete or composited samples in proportion to stream flow. Both battery-powered and ac-powered devices are available. Some devices also include automatic sensing mechanisms which activate the device at the onset of precipitation or runoff flow and deactivate when some minimal condition is reached. If runoff is collected in a holding pond and subsequently pumped to the final disposal pond, the holding pond may be manually sampled in the time frame surrounding an event.

In cases where an event (e.g., boiler cleaning) does not occur at all during the sampling period, no samples can be obtained; and estimates of composition and amounts of influent materials will be obtained and calculated from other available data.

4.2.3.2 Flow Estimates

Estimates of flow will be made using manual or automatic field volume measurements and/or mathematical estimation techniques.

Flow measurement by field tests will involve either total

4.3 DRY DISPOSAL (LANDFILLING) SAMPLING APPROACH

4.3.1 Introduction

Similar to a wet disposal operation, assessment of a dry disposal (landfill) operation requires information about surrounding influents to, effluents from, and waste material present in the fill (Figure 4.2). Dry disposal, however, presents a different situation in the physical properties, mode of transport, and flow characteristics of materials (Table 4.2). The disposal site contents are expected to be non-fluid ash and FGD waste solids. The primary surface effluent is runoff waters (managed or unmanaged) from the site which is, as previously discussed, non-continuous and sporadic.

4.3.2 Sampling of the Contents of the Landfill

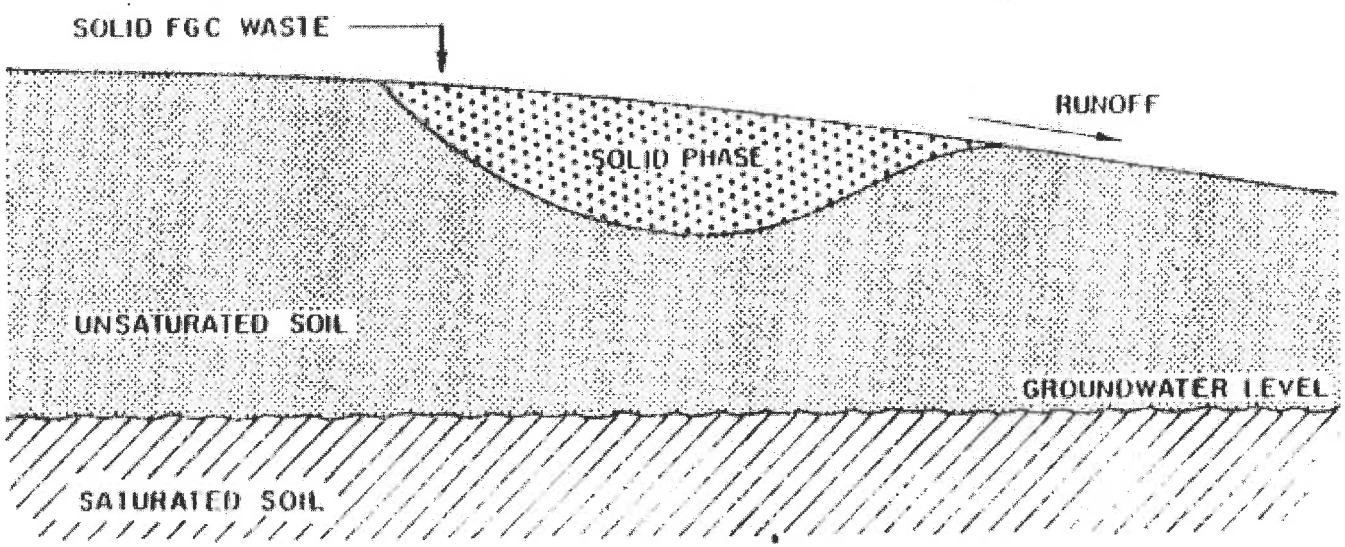
As with sampling of the pond contents, sampling of the landfill will be performed to determine the composition and properties, both physical and chemical, of the materials present in the site.

The approach for obtaining samples will involve the use of conventional drilling and coring techniques. Boreholes will be augered down to the desired sampling point using hollow stem augers, and a core will then be obtained by driving a thin-walled Shelby tube or split-spoon point through the hollow auger. (More details are presented in Appendix A, "Hydrogeologic and Geotechnical Procedures Manual.")

Samples which are not sufficiently cohesive to allow recovery in a thin-wall or split-spoon sampler (e.g., sand, fly ash, certain muds) may be obtained in a disturbed state by dry augering. Samples which are too hard to recover using thin-wall or split-spoon techniques (e.g., some stabilized FGC wastes) will be sampled using rotary rock-coring bits. Since samples for both physical and chemical properties will be taken using these methodologies, appropriate precleaning (Section 5) of all

4.2.4 Sampling of Pond Effluents (Surface Point Source)

Pond effluents such as pond overflows which are point source discharges may be sampled using the sampling methodology and approach (including flow measurements) described in the previous section. These streams are generally continuous and low in suspended solids and thus present little difficulty for designing procedures for sampling and flow measurements. Most effluents go over a weir so flow can be determined hydraulically.



Source: Arthur D. Little, Inc.

FIGURE 4.2 DRY DISPOSAL (LANDFILLING) INFLUENTS AND SURFACE EFFLUENTS

TABLE 4.2

DRY DISPOSAL – TYPICAL WASTES AND RELATED STREAMS[1]

Name	Physical Characteristics	Usual Mode of Transport	Flow Characteristics
Influents:			
Solid Waste	thick sludge or moist solid	conveyor belt or truck	discontinuous
Effluents (Surface)[2]:			
Runoff (liquid)	low suspended solids	surface flow (unmanaged or managed using pipe or ditch)	sporadic
Fill Content:			
Solid FGC Waste	moist solids	N/A	N/A

N/A = Not Applicable.

1. For illustration purposes only.
2. Underground effluents (e.g., infiltration occurring via continuous permeation are not normally included since they are not directly able to be sampled.

Source: Arthur D. Little, Inc.

sampling equipment and other related materials will be required so as to minimize chemical contamination.

For an average site, an arbitrary range of 18 to 30 samples within the site is anticipated. (See Appendix A, "Hydrogeologic Geotechnical Procedures Manual.") These would be generally comprised of about six portions from differing depths from each of three to five borehole locations. Deviations from this average number of samples will be made depending upon the nature of the site. A dry landfill, comprised almost entirely of a treated waste material placed mechanically in a relatively ordered fashion, may require fewer samples for characterization. Decisions and recommendations as to the number of samples to be taken and analyzed for any particular site will be made during preparation of a specific site test plan after review of all site observations and data. The samples will be taken in conjunction with and at intervals described for the standard penetration tests discussed under pond sampling.

The location and number of the test borings will be site-specific; however, a maximum of three to five borings is most probable. The borings will extend to the bottom of the waste pile, and, in selected locations, will extend through the waste into the underlying soil liner and/or natural soil horizon.

4.3.3 Sampling of Landfill Influents

Generally, a portion of material which is representative of the waste being disposed of during each sampling period (i.e., 24 hours) will be obtained. For stabilized materials which require a curing period (generally 28 days) during which major changes in chemical and physical properties occur, samples will be obtained after disposal and/or after these wastes have been allowed to cure such that the sample obtained will represent waste properties that will be close to those obtained at equilibrium. The sample will be obtained as close as possible to the ultimate point of disposal. If the conveyance discharge point cannot be reached, then the next most acceptable sampling point

may be the stockpile formed by the discharge. Sampling location will vary with disposal practice, and will be selected on a site-specific basis. In some cases, and with prior approval of the Project Director (or his designee), samples of wastes which have been aged or emplaced for some time may be taken.

Four samples representing the production during a work day (up to 24 hours) will be obtained over equal time increments (i.e., 2-3 hour intervals). These samples should be representative of production and should contain approximately two kilograms of dry solids. Samples of stabilized wastes will be taken so that they conform to the time criteria (age desired) where possible. Each sample may consist of a number of individual pieces or portions of stabilized waste. In addition, the process operation data (such as filter operating parameters) will be obtained in order to take an appropriate amount of sample for subsequent compositing in the laboratory. Compositing to yield a sample which is representative of the day's production will be done at the analysis laboratory.

If disposal is not occurring during the time of the visit, a decision will be made by consultation with the Project Director (or his designee) as to whether to obtain samples from the most recently disposed waste materials (i.e., materials already emplaced) or to postpone sample acquisition until the next visit.

Procedures for obtaining representative samples of solid materials are given in ASTM procedures (Ref. 4.6). The use of small sampling tools which may discriminate according to the size of pieces in the material in the sample will be avoided. A square shovel will be used for belt, worm screw, or truck conveyors. Ideally, a sample will be taken across the width of the conveyor discharge. This can be accomplished if the conveyor can be stopped momentarily. If such stoppage is impractical then the sampling team will make an effort to obtain material representative of same at the stockpile beneath the discharge.

The stockpile beneath or downstream from the conveyance will be sampled by augering to the bottom at least five points and recovering all material lifted by the flights. Alternatively, if

a shovel is used to sample the pile, a sufficient amount of waste will be moved to obtain a sample representative of the cross section, i.e., not prejudiced to the outside and/or top of the pile. The portion taken will not have been excessively exposed to weathering (rain).

4.3.4 Sampling of Landfill Runoff

Runoff from a landfill may be managed (directed to culverts, ditches, etc.) or may be unmanaged with no direction of flow. In the case of managed runoff, the sampling techniques and flow measurements discussed under wet disposal (Section 4.2) are applicable and will be used. In some instances where runoff is not managed and flow measurement is needed, it may be necessary to create small ditches for sampling purposes.

In cases where ditches are not available or cannot be installed, a runoff plug collector will be used to obtain samples for chemical characterization. The use of plug collectors for obtaining background runoff samples (i.e., water flowing down the side of a hill prior to passing over the landfill) may also be required at some sites. When runoff is not managed, runoff flow rate will be estimated from rainfall, receptor area, and appropriate infiltration factors.

4.4 SOIL SAMPLING APPROACH

Samples of soils around and under landfills and ponds will be taken in conjunction with well placement and waste sampling, as described in Appendix A, "Hydrogeologic and Geotechnical Procedures Manual." The same techniques and approaches described for waste sampling in both ponds and landfills will be used for soils. At sites where coring through the waste/soil interface will be performed, samples of soils will be obtained and analyzed to determine the extent of contamination. Soil samples will also be taken around the site to obtain background samples for both physical and chemical analyses. In some cases artificial liners

(e.g., poz-o-pac material) have been placed in building ponds. These materials which are not considered waste or natural soils around the site will also be sampled concurrent with the waste and soil sampling period. Samples of these liners will be characterized for both chemical and physical properties.

The techniques to be used in soil sampling will depend to a great extent on the location of the samples. For example, soil samples under a dry landfill will be obtained using the methods also used for obtaining samples of the waste. Similarly, samples of soil around the site will be obtained using these methods in conjunction with well placement. For samples of soils under a pond, the techniques for coring through the pond will be used to arrive at the sampling point. Techniques for obtaining solid samples (i.e., Shelby tube, etc.) will then be utilized.

As with waste sampling, soil sampling will be done in conjunction with standard penetration tests. For the control boring (Appendix A), samples will be obtained continuously [e.g., every 0.45 m (1.5 ft)]. For the remainder of the borings (wherever groundwater wells are placed and others as needed), samples will be taken at intervals [e.g., 1.5 m (5 ft)] to the groundwater table and at intervals [e.g., 0.76 m (2.5 ft)] from the groundwater level to the bottom of the well. The exact number and locations will be site-specific.

4.5 GROUNDWATER SAMPLING APPROACH

4.5.1 Introduction

The major objective for groundwater sampling will be the acquisition of portions of the groundwater existing at various points on the site. The choice of the optimal sampling procedure for a particular site and specific wells at a site will be made after a review of all available background hydrogeological and chemical data, including data from other existing groundwater wells, and will be based on the following parameters:

- Well Casing Size. It is anticipated that most of the

wells placed will be 5.1 cm (2 in.) in diameter.

- Recoverable Water Level. Consideration will be given to whether the water level is within suction lift [8.5 m (about 28 ft)] of a vacuum pump (termed a shallow well) or not (termed a deep well).
- Quantity of Standing Water in the Well.
- Recharge Rate of Water. The variation in recharge rate can span times of 0-6 hours ("fast"), 6-30 hours ("moderate"), and greater than 36 hours ("slow") and will affect the generally acceptable practice of removing the quantity of standing water in the well prior to sampling.
- Chemical Composition. Consideration will be given to whether special precautions are needed to minimize alteration of composition.

The categories of alternative sampling methodologies from which a method for obtaining groundwater samples from open monitoring (or observation) wells will be chosen include:

- Manual bailing (i.e., Kemmerer sampler);
- Vacuum pumping or aspiration (i.e., battery-operated peristaltic pump);
- Pressurized pneumatic pumping (i.e., bladder pump); and
- Gas (air) entrainment or lift.

Under each of these categories a number of alternative procedures can be employed. These procedures represent various equipment choices or configurations rather than differences in principle of operation. For a particular well the optimal configuration will be selected. In some situations existing wells may be sampled and existing sampling devices utilized if they are considered to satisfy the needs of the program.

A matrix of sampling approaches and methods for various well parameters is presented in Table 4.3. Additional discussion of groundwater sampling is given in Exhibit A.5-1.

4.5.2 Sampling Methods

TABLE 4.3

SAMPLING APPROACHES AND METHODS FOR VARIOUS WELL PARAMETERS

Water Level in Well	Proposed Sample Recovery and Prebailing Conditions		
	Slow Recharge One Time in More Than 30-36 Hours	Moderate Recharge One Time in 6-30 Hours	Fast Recharge One Time in 0-6 Hours
Distance between groundwater and grade level less than 7 m[1] Any amount of standing water in the well	Vacuum system (peristaltic pump) or pressurization No prebail	Vacuum system (peristaltic pump) or pressurization Prebail 1-3 times[2]	Vacuum system (peristaltic pump) or pressurization Prebail 3-5 times
Distance between groundwater and grade level greater than 7 m[1] Less than 2.25 m standing water	Manual bailing (Kemmerer) or pressurization No prebailing	Manual bailing (Kemmerer) Prebail 1-3 times[2]	Manual bailing (Kemmerer) or pneumatic pump Prebail 3-5 times
More than 2.25 m standing water	Manual bailing, pressurization, or pneumatic pump No prebailing	Manual bailing or pneumatic pump Prebail 1-3 times[2]	Manual bailing or pneumatic pump Prebail 3-5 times

1. Suction lift of 8.5 m minus 1.5 m required for water sample.
2. Lower number of prebailing will be used for the longer recharge rate.

Source: Arthur D. Little, Inc.

It is anticipated that for shallow well sampling a vacuum pumping system or pressurization of the well will be used. Both involve having a sample tube permanently installed in each well. The vacuum pump approach will be applicable to wells in which the requirements for water lift do not exceed 8.5 m (about 28 ft) but it suffers from possible sample alteration because of offgassing when a vacuum is applied. Forcing the sample out by pressurizing the well will eliminate that disadvantage but may cause well water to be forced back into the aquifer if its permeability is sufficiently great.

In practice, shallow wells for vacuum sampling would be equipped with a well cap through which is fed a small diameter tube [0.63 to 0.95 cm, (0.25 to 0.375 in.) inside diameter] made of Teflon or other inert material. The sampling tube will extend approximately 1 m (3.25 ft) away from the PVC well pipe but will still be retained within the outer protective casing. The end of the sampling tube will be equipped with an appropriate fitting to ensure both internal and external cleanliness. The sampling tube will extend below the water surface within the well in order to ensure adequate collection at minimal standing water. A chemically inert weight will be attached to the bottom of the sampling tube in order to hold it down. The well cap will be equipped with a small threaded plug which can be removed at the time of sampling to allow equilibration of the air column in the well with the atmosphere. In addition, a larger 2.5-cm (1-in.) threaded entry port will also be placed in the well cap in order to allow insertion of depth measurement devices without removing the cap.

Manual bailing techniques, well pressurization, and positive pressure pneumatic pumping systems will be used for deep well sampling. Manual bailing may require considerable time and effort if used exclusively for rapidly recharging wells.

The selected techniques will be compared at one or more well locations to determine if significant differences exist between the techniques.

4.5.3 Special Precautions

A key concern in groundwater sampling is to ensure minimal change in the composition of the analytes of interest during collection, preservation, and transport to the laboratory for subsequent analysis.

In addition to the mechanical aspects of sample acquisition the team will consider any need for special precautions in order to preclude changes in groundwater composition because of contact with the surface environment. In particular, if in-situ measurements of parameters such as dissolved oxygen, pH, and conductivity, which will be carried out either during site development or during subsequent sampling visits, indicate the likelihood of anaerobic conditions in the groundwater, it will be necessary to take precautions to exclude atmospheric oxygen from the well column during recharge and prior to acquisition of the analytical sample. Various means of excluding oxygen including flooding with inert gas (if well size and accessibility permit) or use of a small sealable bailing device will be considered.

It is generally accepted in groundwater sampling practice to remove three to five volumes of water from the well prior to actual sampling. This specification may need to be adjusted for each well depending on its recharge rate. For example, if a well recharges only once in 36 hours, only one volume of water can be removed prior to acquisition of the analytical sample within the estimated 36- to 40-hour period that a sampling team will be on the site. In contrast, for a well with a fast recharge rate, it will be possible to remove five volumes of water prior to acquisition of the analytical sample.

At least 1.5 liters of water will be required for chemical analysis purposes, and it is highly desirable that at least two times this quantity be recoverable from any well in order to permit rinsing of sample lines, containers, etc. One and a half liters corresponds to 75 cm (29.5 in.) of well depth for a 5.1-cm (2-in.) well. To obtain twice the desired sample quantity, a recoverable column of water of at least 150 cm (approximately 60

in.) in the well will be desirable.

In situations where only a minimum of standing water is available within a well, the 1.5-liter minimum sample volume requirements may dictate that all of the recoverable water contained within the well may have to be utilized for the actual sample.

In all cases, groundwater samples will be filtered (see Section 4.10) immediately after withdrawal from the well and with minimal contact with air prior to any stabilization.

Manual bailing techniques will be more appropriate for use in conditions of minimum standing water and slow or moderate recharge rates. Manual bailing allows for immediate transport of all of the collected water to the surface. In contrast, pneumatic pressure pumping or pressurization of the well may require staged evacuation of the well if the volume of available water in the well is comparable to the volume of the sample transfer line. This may increase the time required for the sample collection and the possibility of sample quality degradation.

4.6 SURFACE WATERS SAMPLING APPROACH

Available data from the utility and data bases such as STORET will be utilized prior to designing surface water sampling plans. If required, definition of the quality and flow of surface waters (lakes, streams, ponds)* will be made based on analysis of samples obtained at locations where contamination is most likely to be observed (closest to or downgradient from the source) and comparing analysis of these samples to analysis of samples at "background" locations which would be unaffected by the presence of the site. Analysis of these samples will be similar to that for groundwater samples but may not be as comprehensive.

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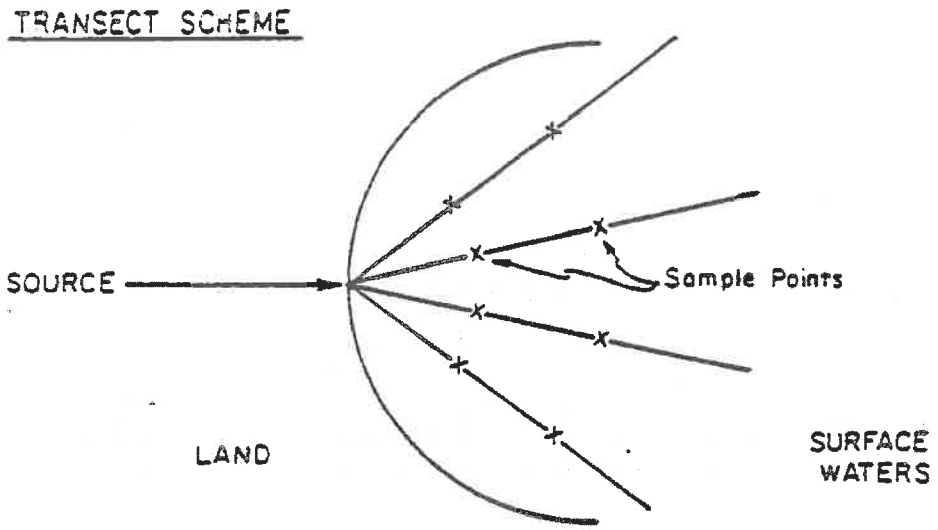
*Surface runoff is discussed in previous sections on influents and effluents to and from the disposal area.

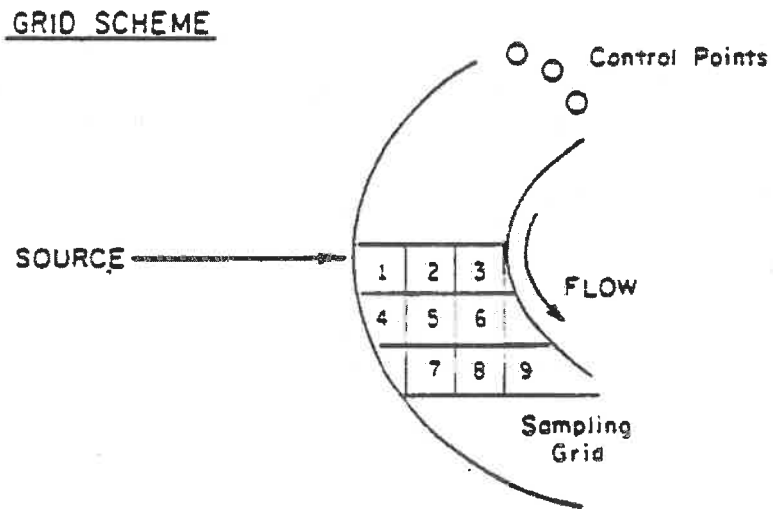
The extent of surface water sampling is expected to be much less than that for groundwater and waste sampling. An average of 12 surface water samples per site is anticipated, although the number and location of sampling points will vary on a site-specific basis. Procedures given in Reference 4.7 will be used.

Definition of the location of sampling points will be made using such approaches as the schemes shown in Figure 4.3. Since the characteristics of particular sites can differ markedly sampling points will be chosen when site specific factors are known. Sampling points will be in locations varying in both width and depth directions. The choice of sampling points and supporting data will be made so that the following criteria will be met:

1. Representative samples of control waters, including the receiving water body upstream of the discharge of interest, will be obtained.
2. Representative samples of the non-point discharge to the receiving water body as close as possible in time to sampling the water body will be obtained.
3. Representative samples of the receiving water body downstream of the waste site will be obtained.
4. In large water bodies where contaminant dilution may limit detection, samples will be obtained as close as possible to the point of contact between groundwater and surface water.
5. Flow measurements of the direct discharge (overflow) and surface water body will be made (if appropriate).

Sampling locations will be chosen based upon estimates of the extent of mixing of the water body at the chosen locations in order to evaluate representativeness of the sample. The extent of uniformity due to mixing at various distances from the site will be initially estimated using the flow of the water body, its physical characteristics (depth/width), and a review of various water quality parameters (pH, dissolved oxygen, conductivity, temperature, and flow) under various surface body flow conditions. Based on these data in three dimensions (vertical,





Source: Arthur D. Little, Inc.

FIGURE 4.3 TRANSECT AND GRID SAMPLING SCHEMES

horizontal, and longitudinal), a determination of the location of sampling points and the number of samples to be composited to yield a representative sample will be made.

Representative samples of the relevant discharges into the water body will be taken at the discharge point or near the intake of the discharge point. Several samples will be taken and composited. The extent of compositing will be determined based upon the quality of the effluent and whether it is expected to change significantly over the sampling period as determined by indicator parameters. This sampling procedure will be repeated several times during the year to permit assessment of variability during the various seasons. Data on the surface body flow, influent flow, and other meteorological data required will be obtained or calculated from plant and available surveys.

In order to more accurately measure the incremental impact of discharges on the surface water body quality, the samples of effluent and those from the water body will be taken within a short period of time (hours) to preclude variations caused by "pulses" of influents.

In cases where the water body is too large to be accurately sampled in the manner described above, sampling using a transect scheme would allow determination of local contamination of the surface water. Mapping the area with data obtained for the water quality parameter given above would allow initial estimates of the homogeneity of the water body near the discharge points.

Flow measurement will be made using velocity methods, level measurement methods, or other techniques as previously discussed.

Sampling methodology equipment such as a Kemmerer or Van Dorn bottle will be used because of their advantages in point sampling.

Sample volume, containers, and preservation will be similar to those used for groundwater sampling. The sample may be filtered in the field.

4.7 FIELD MEASUREMENTS

A variety of field measurements for both physical and chemical properties will be made at each site.

Standard penetration tests, vane shear strength tests, nuclear depth-density determinations, and field permeability tests will be performed on-site as described in Appendix A, "Hydrogeologic and Geotechnical Procedures Manual."

Measurement of the groundwater level in piezometers and wells will be made prior to prebailing or sampling. In addition, measurements will be made to determine and confirm recovery (recharge) of the piezometer and/or well. A battery-operated ohmmeter connected to a cable (which is marked at known increments) or an electrical cable connected to a measuring tape will be used. The tape or cable is weighted at the end with a plastic-coated weight. Detailed procedures are given in Exhibit A.7-1.

Measurement of conductivity, temperature, and pH will also be made where possible in sites in the well prior to withdrawing a well sample and on the withdrawn sample in the field. Obvious chemical changes in the sample during sampling or upon exposure to air (bubbling, precipitation, or rapid conductivity or pH changes) will be noted. Similar measurements will be made for other liquid or slurry samples (surface waters, waste streams) immediately after sample collection. Portable field meters (i.e., YSI Model 33 SCT meter), which are calibrated as per manufacturers' instructions, will be used.

Dissolved oxygen measurements for in-situ well waters and samples will also be made (in particular sites). A portable field meter (such as the YSI Model S-7 DO meter), which is calibrated as per manufacturers' instructions, will be used.

4.8 SAMPLE CONTAINERS

Factors which will be taken into account when choosing containers for the various types of samples discussed are

compatability with the sample (i.e., neither contributing nor removing species of interest), resistance to breakage, and appropriate volume. The containers must have adequate wall thickness to withstand handling during sample collection and transport to the laboratory. Containers with wide mouths are desirable to facilitate transfer of samples from samplers to sample containers. The containers must have tight screw-type, chemically inert lids (i.e., caps and liners of plastic for plastic bottles and Teflon cap liners for glass bottles).

For this program the following containers will be used for the indicated sample/analysis categories:

Sample/Analysis	Container
waters/metals and inorganics	polypropylene or polyethylene
waters/organics	brown screw-cap borosilicate or flint glass, Teflon cap liners
slurries	same as above for water samples for metals and organics
solids	wide-mouth canning (Ball or Mason) jars, Teflon film under jar lid

Regardless of which sample containers are selected, they must be thoroughly cleaned prior to use to remove any contaminants such as oils, greases, dirt, or mold release agents that may be present. The recommended cleaning operation is presented in Exhibit A.8-1 and discussed in Section 4.9.

4.9 EQUIPMENT AND CONTAINER CLEANING

As a major objective of the chemical sampling and analysis activities centers around the measurement of trace-level quantities of metals species as well as some organic materials, it is absolutely essential that the sampling equipment and sample containers which come into contact with the samples be free of any substances which might transfer to the sample material. The cleaning protocol given in Exhibit A.8-1 has been utilized at Arthur D. Little, Inc. to clean glass and plastic sample containers as well as metallic sampling equipment prior to use.

While the quantities of solvents and aqueous solutions to be used in each step are not specified, sufficient volumes should be used in order to thoroughly soak and/or rinse both internal and external surfaces.

All new thin-wall tubing and other metal sampling equipment will be thoroughly degreased with acetone prior to carrying out the cleaning protocol. This degreasing operation should not be necessary once the equipment has been put in use.

To minimize inadvertent contamination of samples by stabilizers used in PVC manufacture, internal surfaces of the PVC well pipe will be cleaned, where possible, by washing with dilute nitric or hydrochloric acid solution and then thoroughly flushing with tap water prior to use.

Sample containers will be cleaned using a hot detergent wash and thorough tap water rinse followed by a nitric acid rinse. They will then be rinsed with tap water and distilled water in succession and finally with high-purity (MilliQ®) water. For those containers which will be used to obtain samples for organic analysis the final rinse will be made with acetone. Final drying of the containers will be done in air. (See Exhibit A.8-1.)

4.10 FILTERING AND PRESERVATION OF SAMPLES

All groundwater, surface waters, slurry samples, and other liquid samples (as from ponds) will be filtered in the field with minimal exposure to air. Equipment for filtration will be composed of a reversible battery-operated peristaltic pump which forces the liquid to be filtered through flexible tubing into a back-flushing plate filter with a 0.45-micron filter (i.e., Leonard Mold and Die Works, Denver, CO.) preceeded by a coarse cellulose ester prefilter.

Preservation of various samples collected at the disposal site will be required to minimize loss of analytes during the storage and transport period prior to sample analysis at the laboratory. Solid samples which have no readily separable liquid will not be preserved. Slurry samples which are separable by

filtration will be separated in the field (as above) and the liquid fraction preserved according to the analyte of interest (see below). The solid fraction will not be preserved. All other liquid samples will be filtered in the field and preserved in the following manner. The filtered sample will be split into two fractions: one fraction (for metals analyses) will be acidified to pH <2 with a fixed volume of concentrated nitric acid (e.g. 5 mL per liter of sample); the second fraction will be shipped in ice and maintained at 4°C in the laboratory until analyses are performed (for anions and other analytes). For samples and analytes which cannot be preserved by cooling or acidification either field analysis or special preservation techniques (e.g., mercury addition for trace sulfite) will be used.

4.11 FIELD DOCUMENTATION

Documentation during field activities will consist of the assignment of unique identifiers to each sample that is collected in the field, the recording and transmittal of all relevant ancillary observations, and the initiation of chain-of-custody procedures for each sample that is collected. A discussion of each of these activities is presented below.

4.11.1 Labels

Labels will be used to identify the origin and purpose of any material that is collected. Information contained on the label will be sufficient to uniquely describe the contents of the container so that misidentification of collected material is minimized. As a minimum, the label will contain the following information:

- Name or initials of the person(s) collecting the sample;
- Time of collection (month, day, year, and time);
- Place of collection; and
- A unique sample code.

An example of the proposed label is presented in Figure 4.4.

FIGURE 4.4

EXAMPLE OF SAMPLE CONTAINER LABEL

Arthur D. Little, Inc.
Acorn Park
Cambridge, Mass. 02140
617-864-5770

Collectors:
Date:
Sample № F 00248

Contractor: ADL TRW OTHER

Site Descriptor: 01 02 03 04 05 06 07 08 09 10 20 30 40

Type of Sample: GW SW SO WA SO OTHER

Location Index: 01 02 03 04 05 06 07 08 09 10 20 30 40

TP A B C D OTHER

Analysis Index: M > AN OR OTHER BLK DUP SPK

Comments:

C-4.31

Each subcontractor will be supplied with a quantity of these pre-printed labels.

4.11.2 Field Notebooks

Two types of field notebooks will be used during the performance of this contract. One will be used to record all pertinent field observations, and the second will be used to produce packing lists for samples returned to the laboratory.

The Observation Notebook will be used to record at least the following information:

- Purpose of sampling;
- Location of sampling site and its address;
- Name of field contact;
- Type of sample collected;
- Numbers and volumes of samples taken;
- Description of sampling site and conditions;
- Date and time of collection;
- References such as maps or photographs taken of all sampling sites;
- Field measurements made; and
- Signature of sampler making entry.

The information recorded should be sufficient so that others may reconstruct the sampling situation without having to refer to the collector's memory.

Because of the complexity of this program, it is suggested that a different Observation Notebook be maintained for each disposal site. In this way it will be possible to accumulate all data about that site over the sampling period in a single location.

The Packing Log will be a separate notebook that contains alternating bound and tear-out pages. As samples are being packaged for shipment, all sample label codes, along with the unique pre-printed label number, will be entered onto a permanent page that is backed by a piece of carbon paper. The tear-out page will serve as the packing list. This task will be performed by

the designated crew chief. The same type of Packing Log should be used by all personnel who take and ship samples. Arthur D. Little, Inc. will acquire a sufficient quantity of log books for all concerned and distribute them as needed.

4.11.3 Chain-of-Custody Procedures

Chain-of-custody procedures will be initiated in the field. They will consist of documentation of all personnel who have handled the samples and sealing of sample bottles and shipping containers to detect any unauthorized opening of same. Detailed procedures are given in Exhibit A.11-1.

4.12 SHIPMENT OF SAMPLES

Shelby tubes will be sealed on each end with microcrystalline non-shrinking wax and capped and taped in preparation for transport. Each sample will be carefully logged with the job number, boring number, depth, and sequential sample number. In addition to Shelby tubes on samples scheduled for chemical analysis, two jar samples will be obtained for each standard penetration test. One jar sample will be sent to Bowser-Morner and the other sample will be sent to either TRW or Arthur D. Little, Inc., depending on the job responsibility.

Shelby tube and SPT jar samples will be boxed and crated for shipment. Samples for physical testing will be hand-carried by the Bowser-Morner site engineer on either the drilling equipment or through commercial airlines. The utmost care will be taken during packaging and shipment to ensure proper sample preservation.

Liquid and slurry samples for chemical analysis will be shipped from the test site to the analysis laboratory by the fastest possible commercial means (generally Air Freight or Courier).

Each sample container will be securely packaged to withstand the rough handling that is expected to be encountered. Each

bottle will be individually cushioned with packing material such as bubble wrap, vermiculite, or styrofoam chips and placed in a shipping crate containing comparable padding. For those samples not requiring refrigeration, a heavy-walled corrugated cardboard, wood, polyethylene, or fiberglass container can be used. If samples are to be shipped in wet ice (see Section 4.10), the ice and samples should be within a plastic bag inside an ice chest. The plastic bag will be sealed to minimize water leakage out of the ice chest. The shipping crate will be securely sealed using nails, fiberglass-reinforced tape, or locks to minimize the chance that it will open during transport. The shipping crate will then be labeled to indicate point of destination and any appropriate handling precautions that should be taken (i.e., This Side Up, Fragile, Contains Glass, etc.). As possible, duplicate labels will be used to emphasize special handling precautions.

4.13 TERMINATION OF THE SAMPLING/ANALYSIS PROGRAM

Upon termination of sampling activities in this program, all non-permanent (mobile) sampling devices which are the property of EPA will be removed from all sites unless requested otherwise by the EPA Project Officer. Wells placed at the site will be turned over to the utility (if they so request) or sealed. If sealing is requested, the top of the well will be cut to ground level, and a sealer (bentonite pellets or cement) will be placed in the well to a minimum of 1.5 m (5 ft) above the uppermost opening of the screen. The remainder will be filled with soil. A similar sealing procedure will be used for any borehole drilled during the program for sampling purposes and which does not subsequently have a monitoring well installed in it.

5.0 PREPARATION OF SAMPLES FOR ANALYSIS

A variety of sample preparation procedures are required before chemical analysis by the various analytical techniques can be performed on samples taken from the field. These sample preparation procedures include compositing of samples, taking representative aliquots from the composites, drying of samples, separation of solid and liquid phases, digestion, and where appropriate extraction of samples.

Sample preparation prior to performance of physical tests is an integral part of the physical testing. However, this preparation is generally more test-specific than that performed for chemical testing and thus is described as part of the physical test procedures given in Section 6.

5.1 ALIQUOTING AND COMPOSITING OF SOLUTIONS, SLURRIES, AND SOLIDS FOR CHEMICAL ANALYSIS

Individual solution, slurry, and solid samples may need to be composited prior to performing chemical analysis. Aliquots of these composites or of individual samples will then be taken for analysis. Table 5.1 summarizes these procedures and a brief description of each procedure follows. Further details are provided in References 5.1, 5.2, and 5.3.

5.1.1 Solutions

Representative portions of solution samples will be obtained by pouring the individual sub-samples into a container, shaking or stirring to ensure that the samples are well mixed, withdrawing a sample volume slightly larger than that required from the vessel using a dry, clean container prerinsed with the sample of interest.

TABLE 5.1

SUMMARY OF ALIQUOTING/COMPOSITING PROCEDURES

Physical Form of Sample	Examples	Aliquoting Method	Compositing Method
Solutions (no suspended solids)	Pond liquor	Shake; pour aliquot	Combine aliquots in container; shake
Slurries (fluid suspensions)	Ash slurry	Continuously mix sample mechanically; use dipper to take three portions	Combine aliquots in container; mix
Solids (non-fluid wet[1] or dry)	Unstabilized FGD Stabilized FGD Ash	Dry to constant weight[1]; grind, if necessary, to reduce particle size using agate or alumina equipment; riffle through steel or aluminum riffler	Combine aliquots; cone-blend three times; roll-blend; cut and quarter

1. In cases where drying of sample may not be performed, the wet solids will be aliquoted using a small angled trier or split-tube sample; and the aliquots will be cue-blended three times, roll-blended, and cut and quartered.
2. Stabilized wastes will be freeze-dried; all others oven-dried. (See Section 5.2.)

Source: Arthur D. Little, Inc. and References 5.1 through 5.4.

5.1.2 Slurries

In this program, "slurries" will refer to any mixture of solids and solution in which the solids can be dispersed by mixing or agitation to yield a uniform suspension with fluid properties. Such suspensions can be handled as if they were a "solution."

If the solid's properties (density, size, etc.) are such that the solids tend to settle out extremely rapidly, the mixture may be more easily handled by allowing the phases to separate and handling them separately as solution and wet solids. (See Section 5.4.) The relative proportions of solution and wet solids resulting from separation would be used in deciding on the amounts of each phase required to give a representative sample. However, where practicable, direct sampling of the slurry is preferable to the separation method since it will afford a sample which is representative of the solid's composition.

In order to obtain an analytical aliquot from a slurry sample which is representative of the field sample it will be necessary to stir or mix the sample well both prior to and during the sampling operation. The ASTM procedure (Ref. 5.1) in which samples for analysis are taken by three successive transfers will be used.

The field sample will be stirred using a non-metallic mechanical agitator or impeller. Vortex formation and consequent air entrainment during stirring will be minimized. The analytical sample will be obtained by quickly dipping three portions approximately equivalent to one-third of the desired sample size, and combining these. Dipping will be done with a precleaned non-metallic dipper of appropriate size. Use of tube thieves or other devices which impede the mixing while the analytical sample is being taken and thus allow segregation during sampling will not be used.

The analytical sample so obtained will approximate the desired sample size and will be used intact for analysis.

5.1.3 Solids

Free-flowing non-conesive solids can be blended and sampled using many of the conventional approaches which are applied to ores, industrial chemicals, etc. On the other hand, wet cohesive solids are much more difficult to blend to yield a material of homogeneous composition from which an analytical sample can be taken. Because of this difficulty in blending, especially where freedom from contamination by trace metals from blending equipment must be assured, all wet cohesive solids will be sub-sampled in the shipping containers by thieving; and a number of these sub-samples will be taken to constitute the analytical sample.

For free-flowing or dry hard materials, the entire field sample (one or multiple containers) will be transferred onto a precleaned sheet of plastic (polyethylene or polypropylene), and quickly examined for apparent homogeneity. The portion to be held in reserve will be immediately transferred to a precleaned container. Samples intended for analysis using an extraction procedure which includes an independent size-reduction technique (such as the EPA "Structural Integrity Test") will be removed at this point. The remainder of the field sample will be subdivided using a sequence of coning three times, roll-blending, and coning and quartering. Samples for determining the moisture content of the field sample will be taken for thieving after the third coning. Sub-sampling and rejection will continue until the sample is reduced to approximately two kilograms. If necessary, the sample may be ground using precleaned agate or alumina equipment to reduce any large-size particles. The sample will then be riffled three times through a laboratory riffler (steel or aluminum), and riffled sub-samples of approximately 7 ounces (200 grams) each will be retained in precleaned containers. Multiple sub-samples may be combined where appropriate.

Wet cohesive solids will be aliquoted using the following protocol. The field sample will be thief-sampled using a small

angled trier or split-tube sampler. The sampling pattern will be such that the analytical samples are representative of the field-sample container geometry, and samples of the entire depth of the container will be obtained. Separate analytical sub-samples will be obtained by combining individual thief samples taken separately from within each of the geometric areas of the container. References 5.2, 5.3, and 5.4 give further details.

5.2 DRYING OF SAMPLES

Prior to analysis and/or compositing, solid samples will be dried to constant weight. Samples which require drying prior to chemical analysis include waste samples (after separation, if possible, from the liquid phase), stabilized FGD materials, and soil samples (after separation, if possible, of pore water). Drying of these samples prior to compositing will be performed to make the compositing process easier. Various drying conditions will be used for the different samples. Unstabilized FGC waste samples will be dried at 60°C for units at least 24 hours and until constant weight is achieved (ASTM D2216-63T, Note 2). Higher drying temperatures may lead to oxidation of calcium sulfite salts and dehydration of various salts. (See Reference 5.5 and Exhibit B.2.1.) Lower drying temperatures may require a longer period of time for drying.

Stabilized FGD materials will be freeze-dried. The use of higher temperatures may lead to further pozzolanic reactions and thus yield erroneous values of alkalinity and other parameters. Soil samples will be dried at 110°C to constant weight (ASTM D2216-63). Air drying to constant weight at a constant humidity at room temperature may be necessary for certain humic solids (ASTM D421-58).

Dried samples will be checked for chemical modifications, such as loss of trace elements during drying, by methods such as spiking with known amounts of trace elements prior to drying and analysis of undried samples for comparison. Samples of FGC wastes

which will be subjected to an extraction procedure will not be dried.

5.3 SEPARATION OF SOLID AND LIQUID PHASES

Separation of solid and liquid phases prior to chemical analysis will be necessary for wet solid samples to obtain samples of both phases, and for liquid samples to remove any suspended solids present. Several separation methods are available including centrifugation, vacuum filtration, and pressure filtration. Of these, pressure filtration appears to be the most generally applicable to the range of sample types and conditions anticipated in this program. With suitable equipment, applied pressures may be varied over a considerable range. Equipment such as that specified in the Federal Register (Ref. 5.6) will be used, where applicable.

In cases where the routine methods above do not yield a volume of liquid sufficient for analysis, high pressure will be applied to the sample to attempt to force additional liquid out. The apparatus used will have a cylindrical body constructed of stainless steel and a Teflon-padded plunger. (See Exhibit 8.3-1 for details.) A 20-ton press will be used to apply pressure on the plunger. For each test the sample will be supported on 325-mesh stainless screen (precleaned with acetone to remove grease) to provide initial filtering of the expressed liquid. The expressed liquor will then be filtered through a 0.45 um filter to remove fine particles prior to analysis.

Filtration of liquids will be carried out using pressure filtration equipment specified by EPA in References 5.6 and 5.7 (i.e., Teflon-coated units such as Millipore TY30-142HW). Filters which will be used in conjunction with the apparatus will be low in trace elements and/or organics depending on the analysis. (See Reference 5.7.)

5.4 DIGESTION AND PREPARATION PROCEDURES

Various digestion and preparation procedures will be used to prepare both solid and liquid samples for analysis. For analytes other than metal ion species, these procedures are individually described in the analytical method given in Section 7. For metal ions analysis, digestion procedures will vary depending on sample type and metals to be analyzed and will range from acid digestion to fusion. A summary of these procedures for liquid samples and solid samples is given in Tables 5.2 and 5.3, respectively. Additional details are given in Exhibit B.4-1 and the appropriate references.

Liquid samples which have been preserved by addition of nitric acid (HNO_3) for analysis of metals by ICAP, plasma emission, and graphite furnace AA (see Table 5.2) will not be further digested. If addition of HNO_3 to filtered samples or dilution of samples results in production of a precipitate, further treatments in the lab to afford dissolution will be required. These will be treated on a case-by-case basis. Samples, if needed, will be diluted using water acidified with HNO_3 to minimize the possibility of precipitation and loss of metals which might otherwise result from the change of pH upon dilution. Specific digestion procedures will be used for As, Se, and Hg because of the nature of the analytical method used subsequent to digestion. Predigestion and preparation prior to some analytical methods (i.e., ICAP) are not needed due to the powerful decomposing properties of the plasma and/or flame.

The first set of solid FGC waste and soil samples from each site will be digested using procedures which afford complete dissolution of the sample at some point during the digestion process (i.e., by addition of HF to dissolve silicates) rather than partial dissolution, which may leave an unattacked residue (Table 5.3) possibly containing some trace elements. After initial screening of these total digestion methods, further tests will be performed to determine if less comprehensive digestion procedures (i.e., those which do not dissolve the sample completely) are as effective as the total digestion and are more cost-effective.

TABLE 5.2

DIGESTION PROCEDURES FOR LIQUID SAMPLES[1] METALS ANALYSIS

Analyte	Analysis Method	Digestion[3]	References
Various Metals[2]	ICAP	None	Ref. 5.8
Various Metals[4]	Flame AA, Graphite Furnace AA and dc Plasma Emission	None or HNO_3	Exhibit B.4 1
As, Se	Hydride Evolution	HNO_3/H_2O_2	Ref. 5.9
As, Se[4]	Graphite Furnace AA	HNO_3/H_2O_2	Ref. 5.9
B, Si	dc Plasma Emission	None	
Hg	Cold Vapor AA	HNO_3/H_2SO_4 in glass reflux to sulfuric fumes, dichromate addition[6]	Ref. 5.10
Hg[4]	Graphite Furnace	None[5]	Ref. 5.11

1. Filtered and preserved (nitric acid) groundwater, FGC liquors, extracts, surface waters, and similar samples.
2. As given in Table 7.5 and Section 7.
3. Prior to analysis method described in appropriate reference.
4. Alternative method.
5. Dichromate addition prior to injection.
6. Oxidation step with $HClO_4$ is omitted.

Source: Arthur D. Little, Inc.

TABLE 5.3

DIGESTION PROCEDURES FOR FGC SOLID AND SOIL SAMPLES
METALS ANALYSIS

Analyte	Sample Description	Analysis Method	Digestion/Preparation	Comments	References
Various Metals[4]	FGC waste and soils (with low organic content)	ICAP	$HF/HClO_4/HNO_3$ to fumes, make up in HCl	1, 2	Exhibit B 4 1
Various Metals[5]	As above	Flame AA	As above	1, 2, 3	--
Various Metals[5]	As above	dc Plasma Emission	As above	1, 2	--
Various Metals	FGC waste and soils (with high organic content)	ICAP	$HClO_4/HNO_3$ reflux to $HClO_4$ fumes HNO_3/HF to $HClO_4$ fumes, make up in HCl	1, 2	Exhibit B.4-1
Various Metals[5]	As above	Flame AA	As above	1, 2, 3	
Various Metals[5]	As above	DC Plasma Emission	As above	1, 2	
Hg	FGC waste and soils (with low organic content)	Cold Vapor AA	HNO_3/H_2SO_4 in glass reflux apparatus, to sulfuric fumes, addition of HF in Teflon to dissolve residue, make up in HNO_3, dichromate addition	2	Exhibit B 4 1 and Refs. 5.10, 5.12
Hg	FGC waste and soils (with high organic content)	Cold Vapor AA	H_2SO_4/HNO_3 in glass reflux apparatus, $HClO_4$ to sulfuric fumes, add HF to dissolve residue, make up in HNO_3, dichromate addition	2	Refs. 5.10, 5.12
Hg[5]	FGC waste and soils	Cold Vapor AA	Aqua Regia, permanganate	6	Refs. 5.11, 5.13
Hg[5]	FGC waste and soils	Graphite Furnace AA	HNO_3/dichromate addition	6	Refs. 5.11, 5.13
As, Se	FGC waste and soils (low organic content)	Hydride Evolution AA	Same as for Hg (low organic content) except make up in HCl		Exhibit B.4 1 and Ref. 5.12

TABLE 5.3 (Continued)

Analyte	Sample Description	Analysis Method	Digestion/Preparation	Comments	References
As, Se	FGC waste and soils (high organic content)	Hydride Evolution AA	Same as for Hg (high organic content) except make up in HCl	6	Ref. 5.12
As, Se[5]	FGC waste and soils	Graphite Furnace AA	HNO_3/H_2O_2, nickel nitrate addition	6	Ref. 5.14
Sb + other metals	FGC waste and soils	Graphite Furnace AA	HNO_3	6	Ref. 5.15
B, Si	FGC waste and soils	dc Plasma Emission	Na_2CO_3 fusion, make up in HCl		Ref. 5.16
Si[5]	FGC waste and soils	dc Plasma Emission	CaO_2 or $LiBO_2$ fusion, make up in HCl		Ref. 5.16
B	FGC waste and soils	dc Plasma Emission	CaO fusion, make up in HCl		Ref. 5.16

Comments:

1. HF leads to loss of volatile fluorides which thus cannot be analyzed in this digest.
2. This digestion provides total dissolution of silicate type materials.
3. The presence of $HClO_4$ cannot be tolerated in graphite furnace AA.
4. The Various Metals are listed in Table 7.5 and Section 7.
5. Alternative Procedure.
6. Partial dissolution of sample if silicates present.

Source: Arthur D. Little, Inc.

For some types of solids (i.e., calcium sulfate, FGD materials, etc.) some reprecipitation of dissolved species following a complete digestion may occur when the samples are diluted prior to analysis. Attempts will be made to avoid formation of precipitates where loss of trace elements can occur because of encapsulation by and/or adsorption on the precipitates formed; however, such losses may be unavoidable in some situations (precipitation of calcium sulfate after fusion). In all tests, quality control procedures including spiking and recovery measurements and standard reference materials will be used to determine and confirm the applicability and reliability of the methods.

For analysis by ICAP, FGC waste solids and most soils will be digested in a mixture of $HF/HClO_4/HNO_3$ acid. This total dissolution procedure will lead to loss of volatile metal fluorides (e.g., Si), and those species cannot be analyzed subsequent to this digestion. For highly organic material a $HNO_3/HClO_4$ digestion prior to addition of HF will be used. These digestions for ICAP analysis, and possibly other analyses by Flame AA dc plasma emission will be carried out by Barringer-Magenta, Ltd. (Toronto, Canada). A portion of this digest will be sent to Arthur D. Little, Inc. or TRW (depending on who is performing the sampling and analysis at the particular site) for analysis of certain metals by Flame AA dc plasma emission as needed. (See Section 7.)

Prior to analysis of mercury by the cold vapor-AA technique, solids will be totally digested in HNO_3/H_2SO_4 in a reflux condenser and HF added to dissolve any residue. Perchloric acid will also be used in this digestion for solids with a high organic content. (Ref. 5.12.) An alternative procedure for mercury sample digestion which does not effect total dissolution of silicate-type materials will also be used and compared to the total digestion procedure. This procedure involves digestion using Aqua Regia followed by stabilization with permanganate (Ref. 5.13) or nitric acid with dichromate addition. These digestates would be used for analysis of mercury by cold vapor AA

and graphite furnace AA, respectively.

Prior to analysis of arsenic and selenium by hydride evolution, solid samples will be digested using the same procedure for total dissolution used for Hg analysis of low or high organic-content samples except that HCl will be used for makeup (after HF addition to dissolve any residue). A digestion method which does not totally dissolve the sample will be compared for cost-effectiveness. This method utilizes a HNO_3, H_2O_2 digestion for analysis of these elements by graphite furnace AA..

In all cases the inability to analyze perchloric acid solution using the graphite furnace AA technique and the possibility of etching of glass or quartz apparatus or instrument components by HF solutions will be considered, in addition to other quality control considerations such as recovery and losses during the digestion process.

Prior to analysis of boron and silicon, solid samples will be fused with sodium carbonate (Ref. 5.16) and the melt dissolved in dilute HCl. Precipitation of calcium sulfate salts may be unavoidable at this point for some FGD samples. Redissolution may be effected by dilution at the expense of sensitivity. The solution could be analyzed by dc plasma emission. If total dissolution is not effected using this approach, alternative fusion (e.g., CaO and $LiBO_2$ for Si) will be used.

6.0 PHYSICAL LABORATORY TESTING PROCEDURES

6.1 INTRODUCTION

Physical characteristics of FGC wastes must be known to properly evaluate the potential for environmental impact via leaching; further, knowledge of physical properties is of value in determining the disposal economics of a particular waste-generating methodology and deposit. An important aspect in determining the physical engineering characteristics of a waste deposit is the selection of field or laboratory testing conditions. Field testing provides quantitative information on the type and extent of the deposit and also provides relative density, strength, permeability, and compressibility data. Laboratory tests performed on disturbed and undisturbed samples are conducted under more controlled conditions and provide more precise determinations of some engineering properties.

The following field and laboratory tests are planned for the FGC waste testing program:

Field Tests	Laboratory Tests
Vane Shear Strength	Natural Moisture Content
Standard Penetration	Grain Size
Field Permeability	Specific Gravity
Nuclear Density	Compaction (Proctor)
	Compressive Strength
	Permeability/Consolidation

It is not intended that all of the above tests will be performed at every site or on every sample. The type and quantity of physical tests performed at a given site generally will depend on the type of waste disposal (wet or dry). Test requirements (type and quantity) will be site-specific and will be described in the site-specific test plans. Typical laboratory and field tests to be performed at a landfill disposal site and a wet-pond disposal site are given in Tables 6.1 and 5.2, respectively.

ASTM standards will be followed during the physical

TABLE 6.1

DRY LANDFILL MODEL SITE:
TYPICAL PHYSICAL TESTING QUANTITIES

Quantity/Site[1]	Item
Laboratory Testing (Number of Tests)	
5	Extended Permeability/Consolidation Tests (Solids Content vs. Permeability)
6	Grain-Size Determinations
6	Specific Gravity Determinations
20	Moisture-Content Determinations
1	Consolidated-Undrained Triaxial Compression Test with Pore Pressure Measurements (TCTWPPM) (3-point envelope)
6	Standard Proctor Tests
Drilling, Field Testing, and Sampling[2]	
33 meters (100 feet)	Drilling length
20	Standard Penetration Test or Vane Shear Tests
10	Shelby Tube Samples or Stationary Piston Samples (3-inch, thin-wall)
25	Nuclear Density Tests

1. The exact quantity of borings and tests will be site-specific.
2. In borings where considerable sampling and testing is involved, auxiliary borings will be installed at 1.5-meter (5-foot) offsets to obtain additional samples.

Source: Bowser-Morner Testing Laboratories, Inc.

TABLE 6.2

WET POND MODEL SITE: TYPICAL
PHYSICAL TESTING QUANTITIES

Quantity/Site[1]	
Laboratory Testing (Number of Tests)	
6	Field Permeability Tests
15	Grain-Size Analyses
15	Specific Gravity Determinations
40	Moisture Content Determinations
Drilling and Field Testing	
33 m (100 ft)	Drilling length
40	Standard Penetration Tests or Vane Shear Tests

1. To be modified at time of compilation of Site Development Plan.

Source: Bowser-Morner Testing Laboratories, Inc.

laboratory testing program. Bowser-Morner standards will be used for tests not covered by ASTM. The tests and applicable standards will be used as shown below. Detailed procedures are given in References 6.1 through 6.7.

Physical Laboratory Tests	Specifications	References
Natural Moisture Content	ASTM D 2216-71	6.1
Index Tests	ASTM D 854-58	6.2
	ASTM D 424-59	6.3
Compaction Tests	ASTM D 698-78	6.4
Strength Tests	ASTM D 2166-66	6.5
	ASTM D 2250-70	6.6
	ASTM D 2434-68	6.7
	Bowser-Morner	Exhibit C.2-1
Permeability/Consol-idation Tests	ASTM D 2434-68	6.7
	Bowser-Morner	Exhibit C.2-2

Unstabilized and stabilized FGC materials and pozzolanic materials will generally be tested similarly in physical testing procedures. It is anticipated that most stabilized waste samples taken will have been "placed" in the field under normal operating conditions and will have been naturally cured so that minimal changes in properties will occur with time after sampling. In some cases, uncured stabilized samples may be taken for comparison purposes.

6.2 PHYSICAL LABORATORY TESTING PROCEDURES

6.2.1 Natural Moisture Content Determinations

The moisture content is defined as the weight of water divided by the weight of solids and will be determined for all recovered samples in accordance with ASTM D 2216-71 (Ref. 6.1). Note 2 of the ASTM D 2216-71 specification will apply for

oven-drying FGC waste materials. A drying temperature of 60°C is recommended because sulfate-rich FGD sludges break down to anhydrite at higher temperatures, thus, the 60°C temperature will be maintained for all moisture content and related determinations.

6.2.2 Index Tests

Grain size analyses, Atterberg limits tests, and specific-gravity determinations will be performed to determine index properties of the waste materials. ASTM standards will apply for all index testing. The specific gravity is defined as the ratio of the weight in air of a given volume of material to the weight in air of an equal volume of distilled water at a temperature of 4°C. The specific gravity is used in weight-volume calculations. ASTM D 854-58 (Ref. 6.2) standards will be used for specific-gravity determinations.

Grain-size analyses include sieve and hydrometer analyses for determining the percentage (by weight) of particles with a given effective diameter in a sample of solid waste particles.

Atterberg liquid and plastic limits are defined as the moisture contents corresponding to arbitrarily defined liquid and plastic consistencies. Since most of the wastes involved in this program are anticipated to be non-plastic, Atterberg limits probably will not be relevant. If cohesive wastes are encountered, Atterberg limits will apply. Actual engineering properties of cohesive soils have been correlated to Atterberg limits, and these tests are important soil index tests for this reason. The ASTM D 424-59 (Ref. 6.3) standard will apply for the liquid and plastic limits.

These tests (index and specific gravity) will be performed on the waste materials to determine whether correlations with measured engineering properties exist.

6.2.3 Compaction Tests

The standard Proctor laboratory compaction test will be used as a standard to evaluate the field placement techniques at the dry and landfill disposal sites. The percentage of compaction being obtained in the field as compared to the standard Proctor maximum dry unit weight can be obtained by determining field densities of the waste materials. This information will be valuable in determining whether additional compactive effort or better moisture content control is effective in increasing field density. If field and laboratory testing indicate that the engineering properties can be improved by increasing the waste density, then the Proctor data will indicate to what extent the density can be increased. ASTM specification D 698-78 (Ref. 6.4) will apply for all standard Proctor compaction tests.

6.2.4 Strength Tests

Knowledge of the shear strength of the wastes is necessary in determining stability of fill and retaining structures. The majority of the wastes are anticipated to be cohesionless materials. In most instances, consolidated-undrained triaxial compression tests with pore pressure measurements will be performed to determine effective strength parameters of the cohesionless wastes amd soils. Wastes that have been treated with lime and fly ash to form pozzolanic bonds could also be subjected to unconfined (uniaxial) compression or unconsolidated-undrained triaxial compression testing. Since ASTM procedures do not cover consolidated-undrained triaxial compression tests, the tests will be performed according to Bowser-Morner specifications as described in Exhibit C.2-1. Unconfined compression and unconsolidated-undrained triaxial compression tests of cohesive wastes will be performed according to ASTM specifications D 2166-66 (Ref. 6.5) and ASTM D 2250-70 (Ref. 6.6), respectively.

6.2.5 Permeability Tests

Permeability is an engineering property which indicates the ease with which a fluid flows through a particulate substance. Since the coefficient of permeability of a waste material will influence the rate of flow through the material and to groundwater resources, the permeability testing program is considered the most important physical laboratory test for this project. Also, the relation of coefficient of permeability to waste solids content is important in evaluating whether or not permeability of dry fills can be decreased by increasing density through increasing compaction effort or by better controlling field moisture content. Extended laboratory permeability tests will be performed on undisturbed samples so that coefficients of permeability can be related to solids content.

Solids content for samples subjected to the extended permeability/consolidation tests will be increased by consolidation in a triaxial compression chamber. Compressibility characteristics of the waste also will be determined from the extended permeability tests by measuring the volume change-time relationships during consolidation. The initial permeability testing procedure will follow general guidelines of ASTM D 2434-68 (Ref. 6.7). Adaptation to the triaxial compression chamber will be performed according to Bowser-Morner specifications as described in Exhibit C.2-2.

7.0 CHEMICAL LABORATORY TESTS

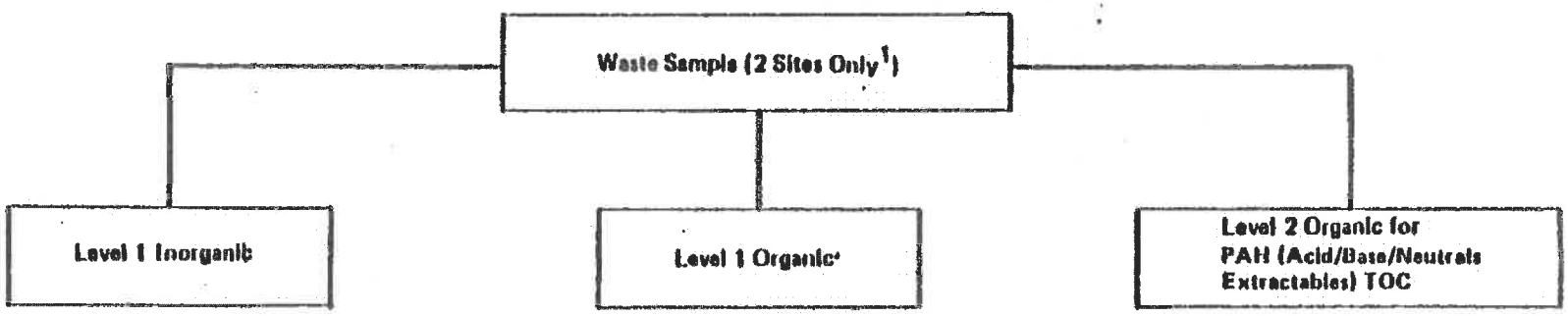
7.1 INTRODUCTION

Chemical analysis of the FGC waste samples obtained at each of the sites will be performed in two stages. The first stage will involve screening of selected samples at two sites using the methodology shown in Figure 7.1. The results of these screening tests and other chemical data which will be gathered from existing studies will be used to further define the extent of more complete analyses of various samples. Analysis schemes for ash, slurry, wet FGC waste, dry FGC waste, stabilized FGC waste, groundwater, or surface water and soil samples are presented in Figures 7.2 through 7.7. The particular analysis scheme for samples from a site will be tailored to the samples involved. The distribution of effort between analysis of more samples versus a more complete analysis of fewer samples will be made using factors such as waste properties, numbers of wells, and previous available data. If the option of taking more samples is used, the number of analyses performed on a particular sample will be limited, based on a priority ranking given in Tables 7.1 through 7.3.

In general, multi-element analysis techniques (ICAP, IC) and pH and conductivity analyses will be performed (where applicable) on most samples. The number of other types of analyses will generally be lower than that of the techniques mentioned above. The ranking with regard to choice of the type of sample to be analyzed (Table 7.3) emphasizes the liquid rather than solid phases because of the mobility requirement for environmental contamination which liquids provide.

The extent of chemical characterization of some samples may be reduced for particular species if these species are found to be below predetermined concentration limits (e.g., analysis detection limits) during analysis of initial samples.

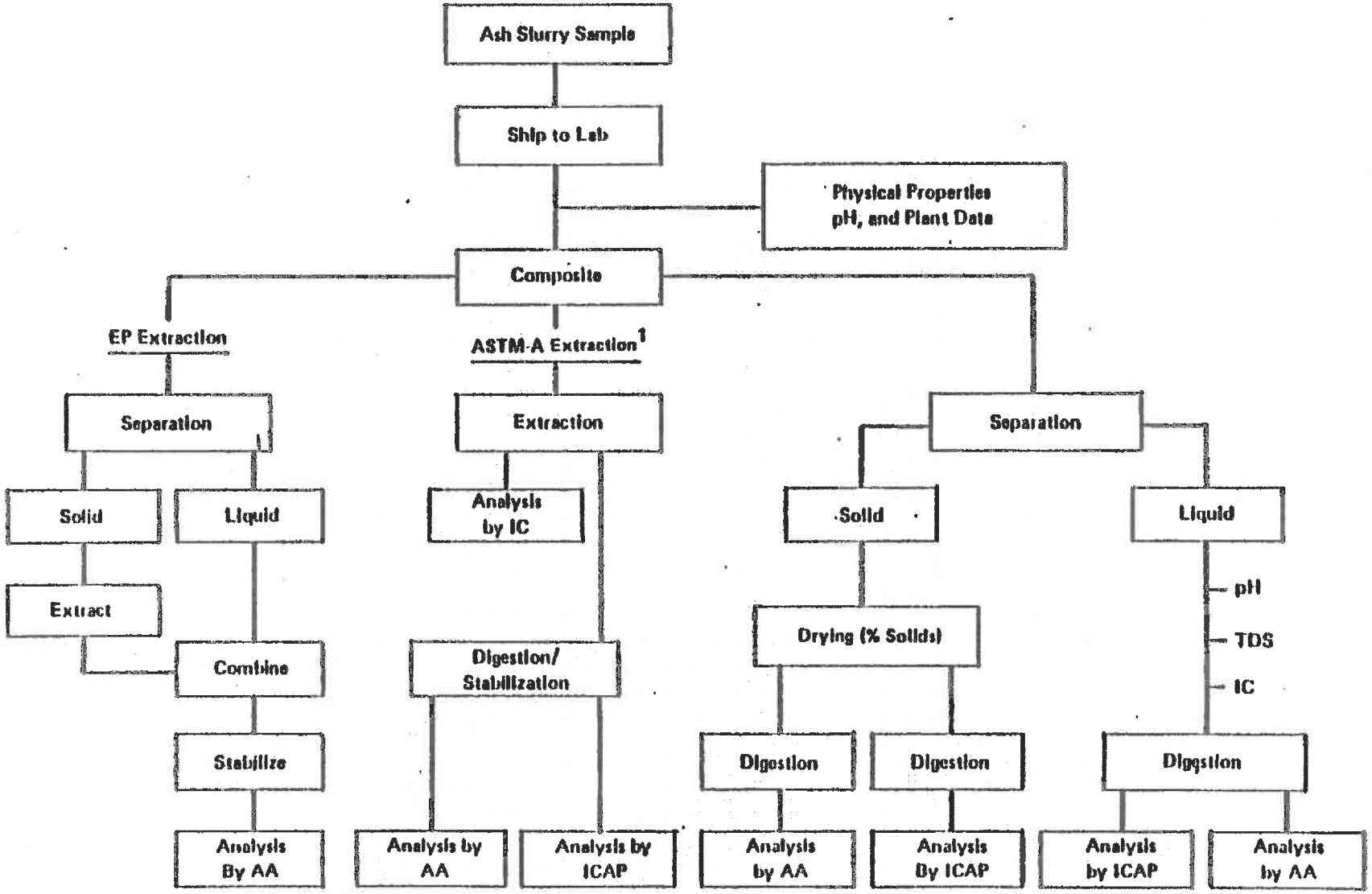
For wastes which do not yield a sufficient volume of liquid phase for analysis by laboratory separation techniques (Section



1. One FGD-containing waste, and one ash-only waste.

Source: Arthur D. Little, Inc.

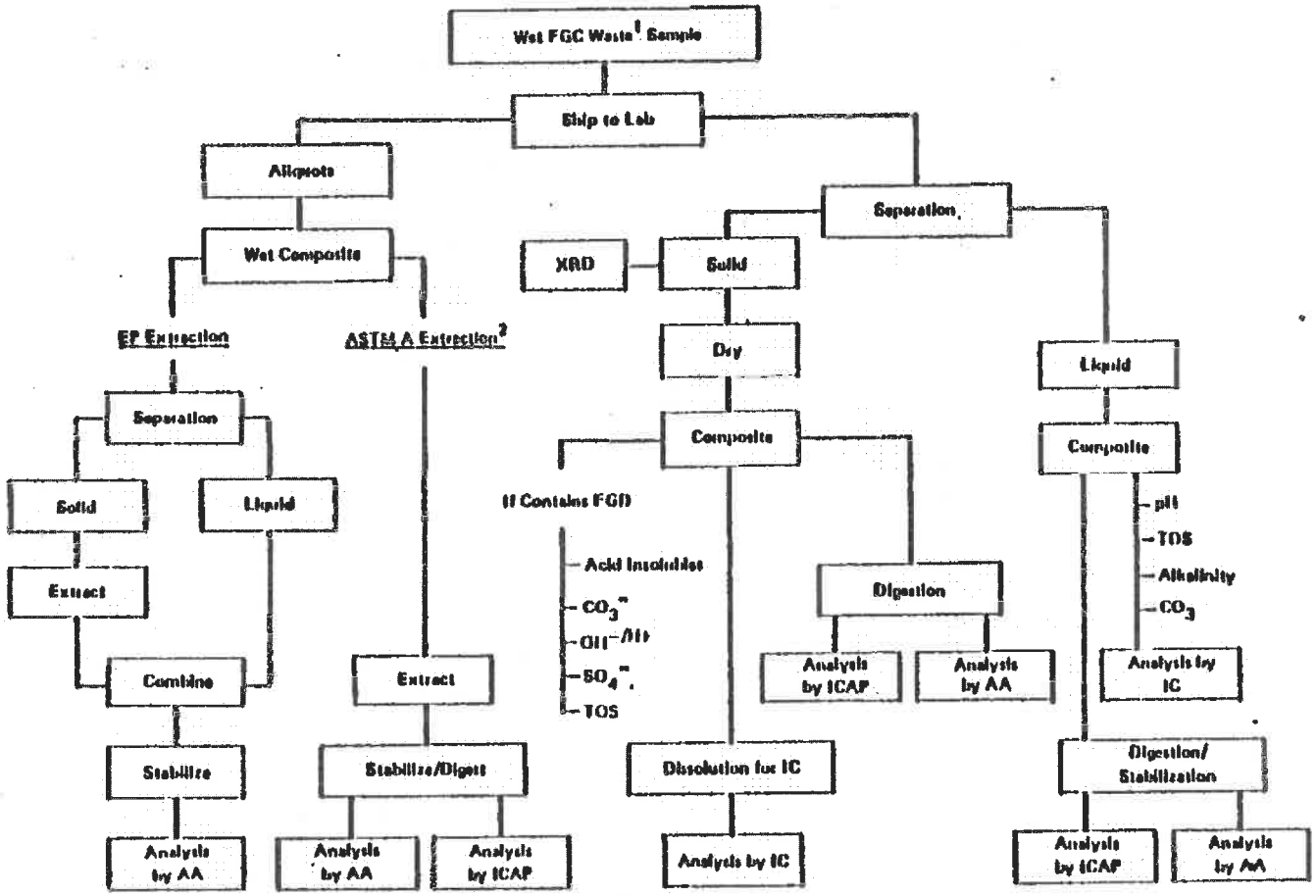
FIGURE 7.1 : INITIAL SCREENING ANALYSES OF WASTE SAMPLES



1. ASTM-A extraction only if liquid phase cannot be obtained.

Source: Arthur D. Little, Inc.

FIGURE 7.2 ASH SLURRY SAMPLE ANALYSIS SCHEME



1. FGC Waste = Ash + FGD
2. ASTM A extraction only if liquid phase cannot be obtained.

Source: Arthur D. Little, Inc.

FIGURE 7.3 WET FGC WASTE SAMPLE ANALYSIS SCHEME

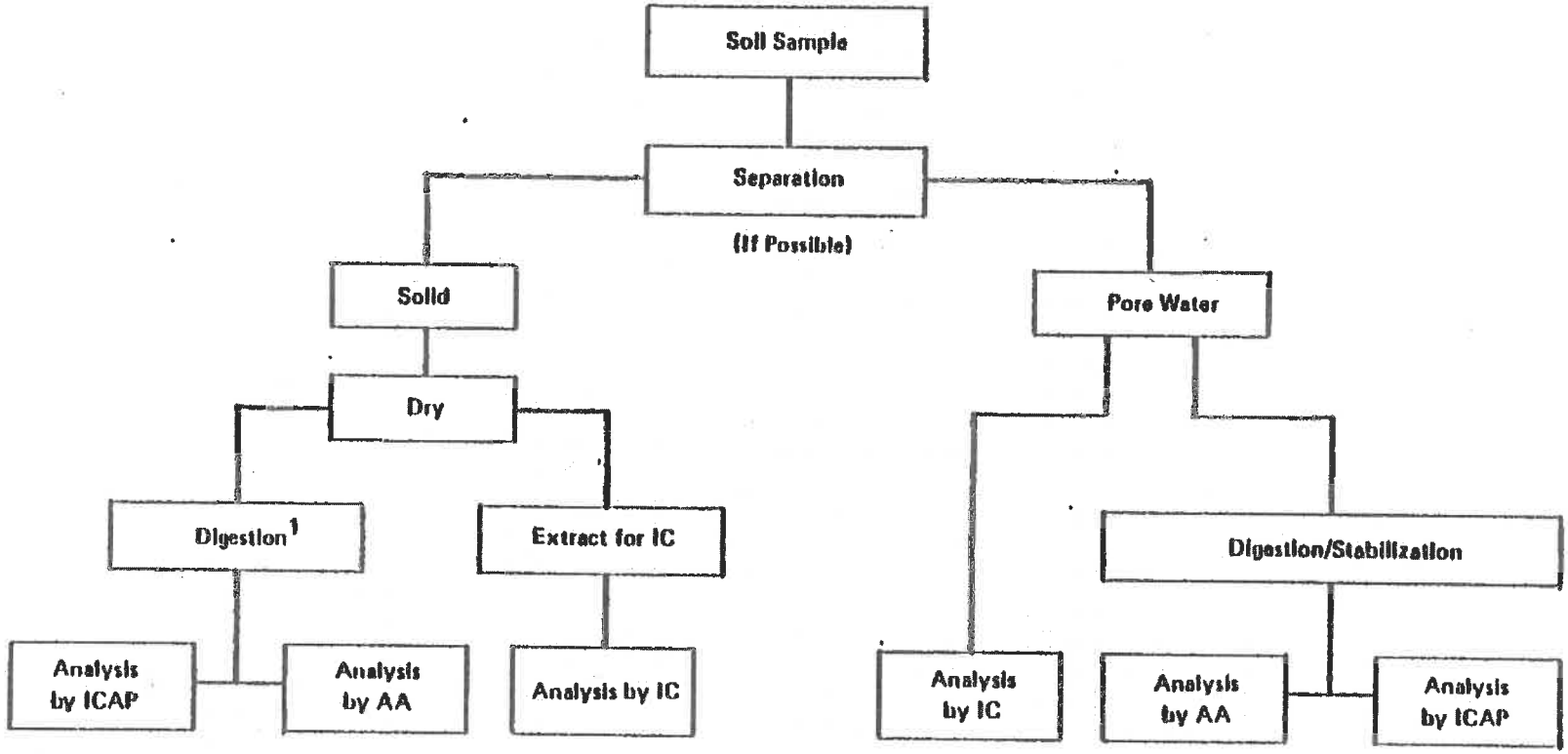
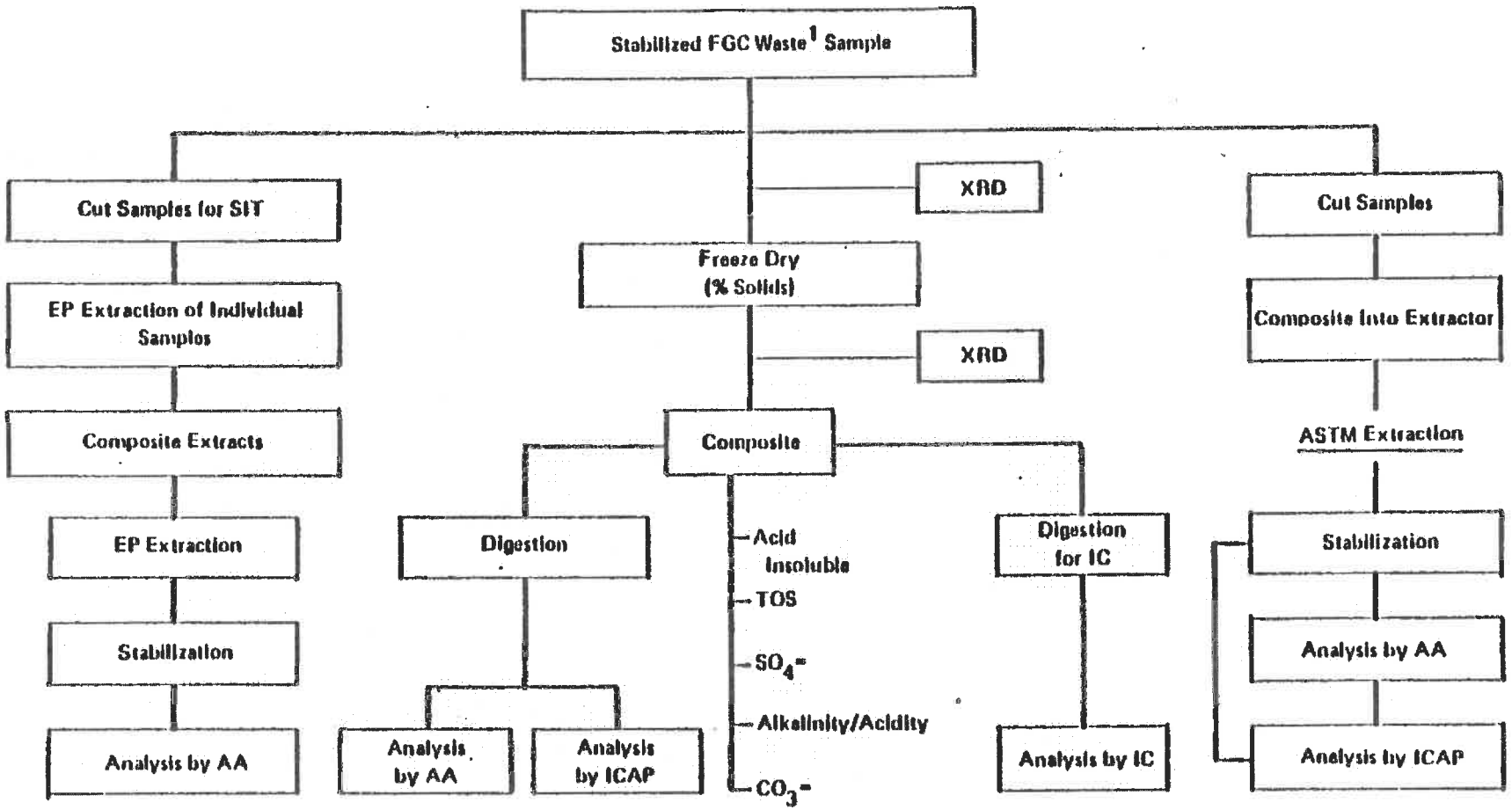


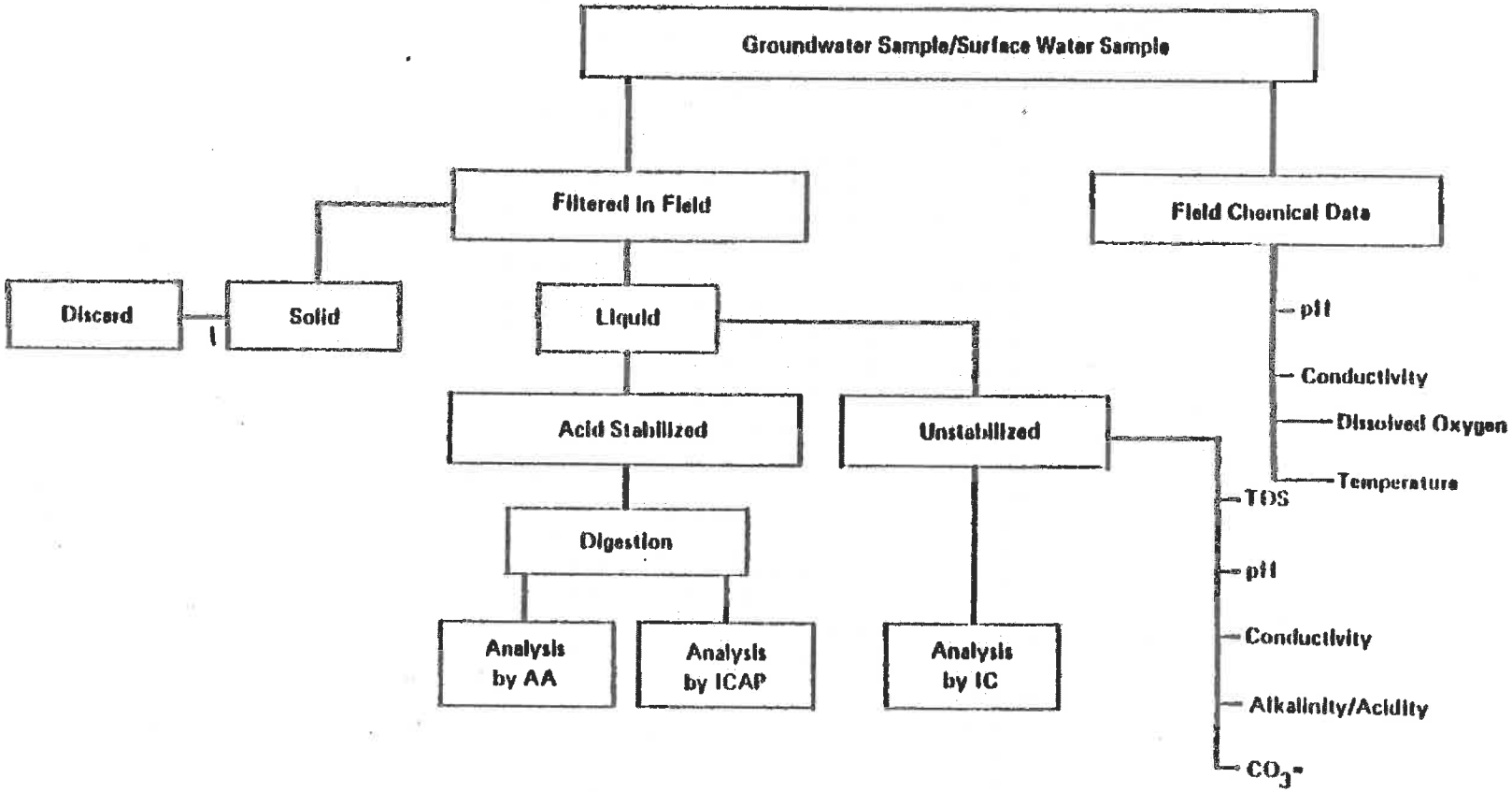
FIGURE 7.4 SOIL SAMPLE ANALYSIS SCHEME



1. FGC Waste = Ash + FGD.

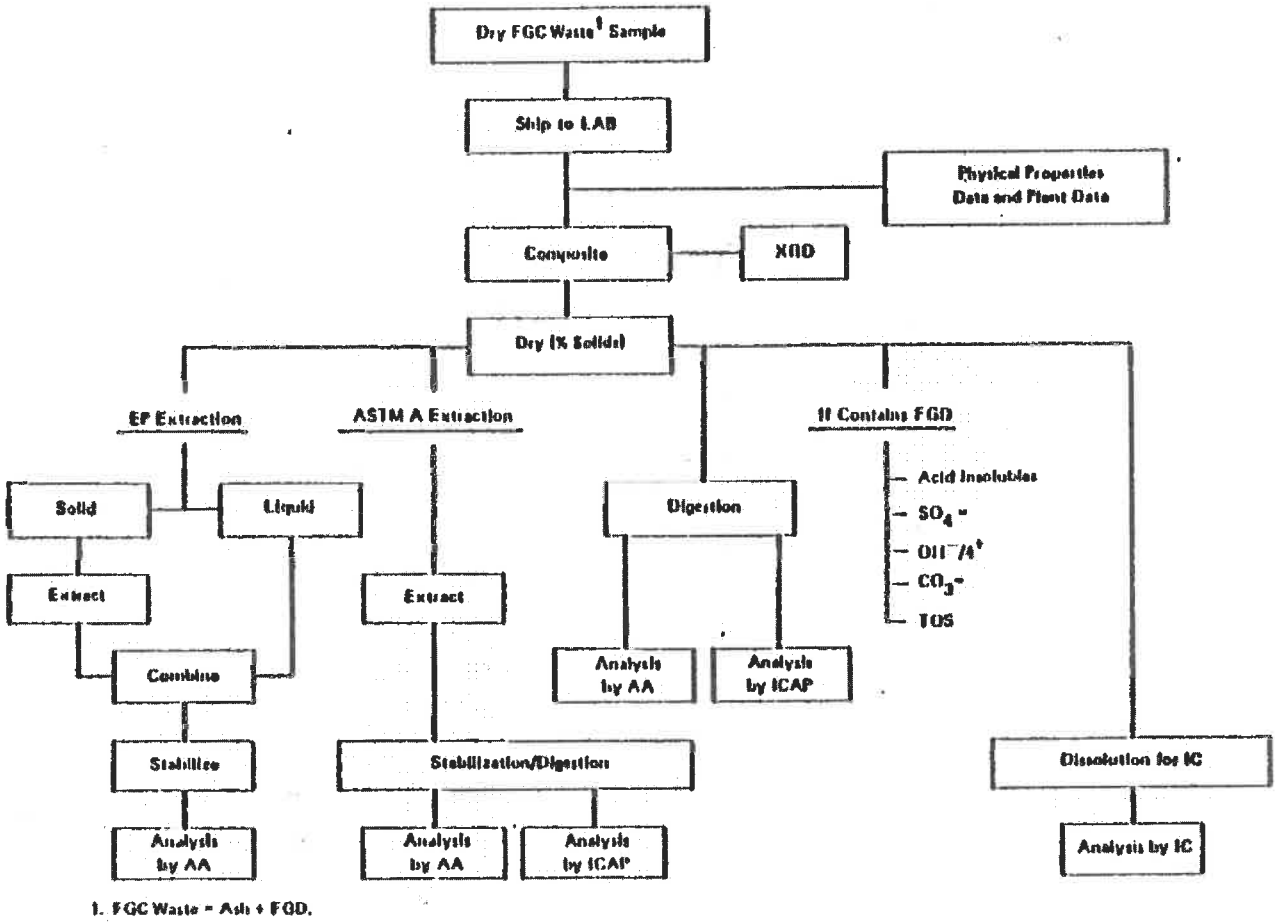
Source: Arthur D. Little, Inc.

FIGURE 7.5 STABILIZED FGC WASTE SAMPLE ANALYSIS SCHEME



Source: Arthur D. Little, Inc.

FIGURE 7.8 GROUNDWATER AND/OR SURFACE WATER SAMPLE ANALYSIS SCHEME



Source: Arthur D. Little, Inc.

FIGURE 7.7 DRY FGC WASTE SAMPLE ANALYSIS SCHEME

C-5.8

TABLE 7.1

PRIORITY RANKING OF CHEMICAL ANALYSES FOR LIQUIDS

Rank	Method	Analytes/Reason
1	Instrumental	pH, conductivity/low cost, good overview of sample
2	Inductively Coupled Argon Plasma – (ICAP) (24 metals)	Ba, Ag, Cr, Pb (primary drinking water)[1] Ca, Fe, Mn, Zn (secondary drinking water)[1] Ca, Na (good FGC tracers) Al, Be, Cd, Co, Cr, K, Mg, Mo, Ni, P, Sr, Th, Ti, V, Zr/low cost multi-element analysis for many species of interest (analyzed simultaneously with above species)
3	Ion Chromatography (IC)	F^-, NO_3^- (primary drinking water) Cl^-, $SO_4^=$ (secondary drinking water, good FGC traces) Br^-, $PO_4^{\equiv}$, NO_2^-/low-cost multi-species analysis for species of high interest (separated during analysis of other species)
4	Atomic Absorption – (AA)	Se, As, Cd, Hg (primary drinking water, good FGC traces) higher-cost individual analysis of very important species
5	Atomic Absorption – (AA)	Sb / high-cost individual analysis of metal not specified in proposed drinking water criteria
6	Atomic Emission – (AE)	Si, B / same as above.
7	Gravimetry	TDS, / high-cost individual analyses of parameters not of great importance
8	Wet Chemical	CO_3^{2-}, alkalinity, acidity / mass balance, high-cost individual analyses. Some idea of alkalinity and acidity is also obtained from pH values.
9	Spectrophotometry/IC	SO_3^{2-} (importance may be higher in sulfite-rich wastes) / high-cost, low probability of detection due to ease of oxidation. IC may be used to analyze for low levels of sulfite if appropriate preservation techniques appear consistent with the analysis method.

1. Reference 7.1

Source: Arthur D. Little, Inc.

TABLE 7.2

PRIORITY RANKING OF CHEMICAL ANALYSES FOR SOLIDS

Rank	Method[1]	Analytes/Reason
1	ICAP (24 metals)	(see liquids)
2	AA	Se, As, Cd, Hg / (see liquids)
3	Wet Chemical	Alkalinity, acidity/pH in secondary water standards
4	Wet Chemical	$SO_4^{=}$ / in secondary drinking water Interim Standards
5	Wet Chemical	Total Oxidizable Sulfur (TOS)[2]; Acid Insolubles / characterization of waste
6	AA	Sb / lower-importance metal
7	AE	B / lower-importance species
8	AE	Si / mass-balance data
9	Wet Chemical	CO_3^{2-} / mass-balance data, waste characterization
10	X-Ray Diffraction — XRD	Confirmation or identification of bulk solid phases

1. See Table 7.1 for abbreviation meaning.
2. May be ranked same as 3 for sulfite-rich wastes.

Source: Arthur D. Little, Inc.

TABLE 7.3

RANKING OF SAMPLES WITH REGARD TO IMPORTANCE OF CHEMICAL ANALYSIS

WASTE CHARACTERIZATION:

Rank	Item/Sample	Reason
1	Liquids	Greatest environmental impact route and interest
2	Solids	Reservoir of pollutants, waste site characterization

OVERALL SAMPLES:

Rank	Sample	Reason
1	Groundwater	Determination of impact
2	Waste	Reservoir (liquid first, then solid) of potential impact
3	Non-Point Discharge (runoff)	Impact related
4	Surface Waters (lakes, streams)	Impact related (non-point discharge receptor)
5	Soils[1]	Attenuation and future impact related

1. May be ranked higher (3) for regions where groundwater contamination is expected to be less important or as yet undetectable.

Source: Arthur D. Little, Inc.

TABLE 7.4

SAMPLE SAMPLING AND ANALYSIS CHEMICAL MATRIX
(For a Typical Site for a Twelve-Month Monitoring Period)

Sample Type	Analysis Type[1] (No. of Samples)
Waste (previously disposed)	ICAP (18), IC + other (18), AA + other (6)
Waste (currently disposed)	ICAP (4), IC (4), + AA (4), EP (1), ASTM (1)
Groundwater	ICAP (90), IC (90), AA + other (30)
Soils	ICAP (30), IC (30), AA (selected number)
Surface Waters	ICAP (12), IC (12), AA + others (6)

1. A complete description of analytes is given in Sections 7.2 to 7.7. The abbreviations refer to the following Analyses: ICAP – Inductively Coupled Argon Plasma Emission, IC – ion chromatography, AA – atomic absorption, EP – EPA extraction procedure, ASTM – ASTM extraction method, others – other analytical techniques including atomic emission, gravimetric, wet chemical. See Tables 7.1 and 7.2.

Source: Arthur D. Little, Inc.

6), a water extraction (e.g., ASTM Method A, Ref. 7.2) will be carried out. Water was selected as the extraction fluid because it resembles more closely the properties of the natural leaching media which may occur at the dry disposal sites (e.g., rain water). The EPA Extraction Procedure will be applied to waste grab samples prior to the initiation of full-scale sampling and analysis.

An example matrix of samples and number of samples to be analyzed by various analysis methods for a given site are given in Table 7.4. A specific matrix will be generated for each site.

All of the analytical methods proposed in this section will be checked during a method qualification period to determine their applicability for the various samples in this program.

7.2 INDUCTIVELY COUPLED ARGON PLASMA (ICAP)

Multi-element analysis of a variety of samples will be performed using ICAP analysis. Although ICAP has not as yet been referenced by EPA as a standard analysis technique, EPA has recently proposed its use for analysis of trace elements in water and wastes (Ref. 7.3).

In this study the following types of samples will be analyzed by ICAP for the elements listed in Table 7.5:

- Filtered groundwater samples;
- Liquid phase of disposed FGC wastes obtained by various separation techniques;
- Liquid phase of soil samples obtained by pressure filtration;
- Digest samples of solid phases of FGC waste samples;
- Digest samples of soils;
- EP (Acetic acid) extract of FGC waste samples;
- ASTM-A (water extract) of FGC waste samples; and
- Filtered surface water samples.

ICAP analysis will be performed by Barringer-Magenta, Ltd. (Toronto, Canada), who operate a large-scale ICAP testing service laboratory.

TABLE 7.5

ICAP DETECTION COMPARED WITH SAMPLE CONCENTRATIONS AND OTHER CONCENTRATIONS OF INTEREST

No.	Element	ICAP Detection in Solution[1] (ppm)	Groundwater Quality Criteria[2] (ppm)	FGC Waste Liquors[3] (ppm)	ICAP Detection in Solids[4] (ppm)	FGC Waste Solids (ppm)	Comment: Likely to Need Supplemental Analysis
1	Ag	0.05	0.05	ppb	5	1-50	yes
2	Al	0.5		—	50	major comp.	no
3	B	0.05		ppb-ppm	5	10-1000	yes, lost in digestion
4	Ba	0.05	1.0	ppb ppm	5	10-1000	no
5	Be	0.005		0.0005 0.05	0.5	1 50	possibly
6	Ca	0.5		100-3000	50	major comp.	no
7	Cd	< 0.07	0.01	0.004-0.1	100	0.5 10	yes
8	Co	0.5		0.002-0.1	50	2-400	possibly, not major interest
9	Cr	< 0.008	0.05	0.001-0.5	10	20-400	no, AA detection similar
10	Cu	0.05	1.0	0.002-0.4	5	4-1000	no, AA detection similar
11	Fe	< 0.2	0.3	0.02-0.1	10	major comp.	no
12	K	10.0		0-200	1000	major comp.	possibly for solids
13	Mg	0.1		0 3000	10	major comp.	no
14	Mn	< 0.01	0.05	< 0.01-0.0	10	5-1000	no, AA detection similar
15	Mo	0.3		0.0-5	200	1-10	yes, if of sufficient interest
16	Na	20.0		10-30000	2000	major comp.	possibly for solids
17	Ni	0.5		0.03-0.9	50	3-500	yes
18	P	5.0		—	500	—	no, not major interest
19	Pb[5]	< 0.05	0.05	0.002-0.5	200(2)	5-1000	no
20	Sl	0.5		—	50	major comp.	yes, lost in digestion
21	Sr	0.01		—	1	5-10,000	no
22	Th	0.1		—	10	2-20	no, not major interest
23	Tl	0.05		—	5	major comp.	no
24	V	0.05		ppb-ppm	5	2-800	possibly
25	Zn	< 0.02	5.0	0.01-27	5	2-1000	possibly
26	Zr	0.2		—	20	20-1500	no

1. Ten times detection limits quoted by vendor (Barringer-Magenta).
2. *Federal Register*, December 18, 1978.
3. "Assessment of Technology for Control of Waste and Water Pollution from Combustion Sources," Arthur D. Little, Inc., report to EPA, Volume III, Generation and Characterization of FGC Wastes, Contract No. 68-02-2654, August 1979. (Ref. 7.4)
4. 100 times solution detection limits for digestion of 1 g in 100 mL.
5. ICAP analysis includes AA analyses for these elements (AA detection l[illegible]re given in parenthesis).

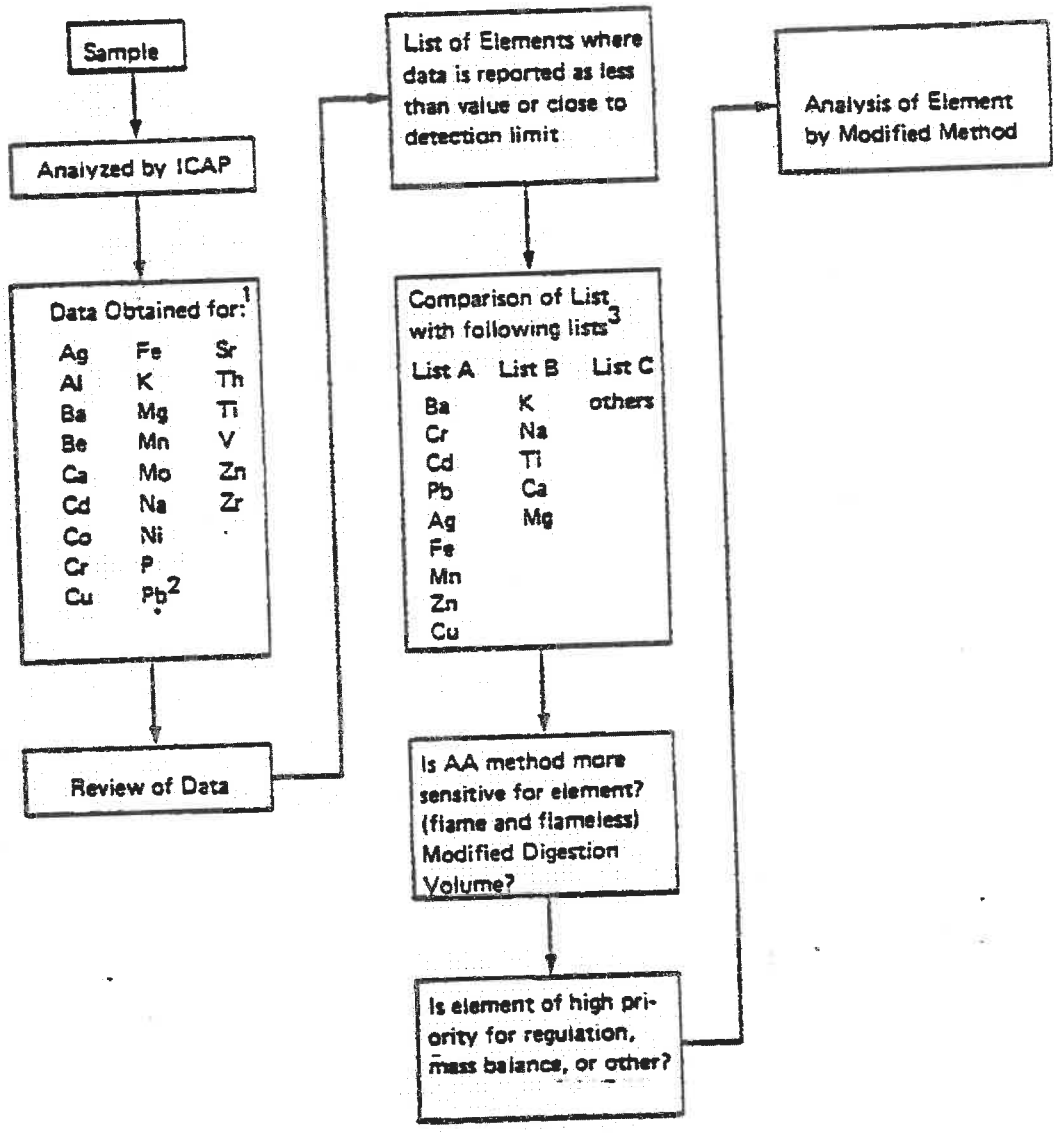
A comparison of the ICAP detection limits (defined as ten times detection limits reported by the ICAP laboratory to account for possible matrix problems) for 26 elements versus reported concentration ranges of these elements in some FGC liquors, FGC solids, and proposed groundwater quality criteria are also given in Table 7.5. Detectability in solids has been defined for the purpose of this table as 100 times that in solution because of the digestion step which produces a 100-fold dilution. ICAP detection limits for most elements are lower than the anticipated concentration ranges in the corresponding sample types. This fact demonstrates that ICAP is suitable for analysis of many elements at the desired range for many of the samples. However, this is not universally true. For this reason, and also because the relative cost of ICAP is significantly lower than individual analyses of elements by AA or other techniques, the following approach will be used. ICAP will be used as a screening method. Where the data obtained by ICAP analysis is close to or below the ICAP detection limit and the element is of sufficient importance (see Figure 7.8), the analysis will be repeated using atomic absorption spectroscopy or another appropriate technique. This approach is illustrated schematically in Figure 7.8.

A summary of the elements which, because of the anticipated concentration range in most samples, are considered likely to be analyzed only by the ICAP vendor and elements which for the same reasons are likely to require analysis by AA or other methods is given in Table 7.6.

On at least two waste samples the level 1 Inorganic Protocol which includes SSMS will be performed to provide data on elements not included in the above techniques.

7.3 METALS BY ATOMIC ABSORPTION (AA)

This section describes procedures which may be used to analyze trace metals in digests of FGC waste solids, interstitial liquors, and samples of surface water or groundwater. Atomic absorption methods are anticipated to be required for arsenic,



1. B and Si require a different digestion and thus will be analyzed separately.
2. Analysis by vendor using AA methods provided simultaneously.
3. List A – Proposed Groundwater Quality Criteria metals.
   List B – Important for mass balance.
   List C – Site specific (e.g., aquatic toxicity for Cu).

Source: Arthur D. Little, Inc.

FIGURE 7.8 DECISION PROCESS FOR USING ICAP AND/OR FLAME OR FLAMELESS AA

TABLE 7.6

POSSIBLE ELEMENTS DISTRIBUTION BY ANALYSIS

ICAP Vendor (Includes Pb by AA) Elements Likely to be Analyzed by ICAP	Element Likely to Need AA Back-up Method	Elements Possibly But Not Likely to be Analyzed by Back-up AA Method	Elements Anticipated to Require AA or Other Method
Al	Ag	Be	Cd
Ba	Ni	Co	B (plasma emission)
Ca	Cd	K	Si (plasma emission)
Cd		Mo	Hg, Se, As, Sb (volatile species)
Cr		Na	
Cu		V	
Fe		Zn	
Mg			
Mn			
P			
Pb			
Sr			
Th			
Ti			
Zr			

Source: Arthur D. Little, Inc.

selenium, antimony, mercury, and other elements listed in Table 7.6.

Cadmium will need to be determined by AA because it is very likely to be found at levels which may be of concern but which are below ICAP detection limits. It is also likely that silver and nickel may be present at levels of concern which are also below ICAP detectability. A comparison of AA detection limits for these and other elements with Proposed Groundwater Quality Criteria (Ref. 7.1) and the range of levels which have been observed in FGC samples is shown in Table 7.7.

7.3.1 Arsenic (Hydride Evolution or Graphite Furnace)

The generally accepted high-sensitivity method for determining arsenic involves converting the arsenic to arsine (AsH_3) by first reducing all arsenic to As (III) with NaI and then converting it to AsH3 with $NaBH_4$. Immediately upon formation, the AsH_3 is sparged from the reaction solution by a stream of argon which sweeps it into the air-hydrogen flame of an atomic absorption spectrometer. A detailed procedure for this determination is included in Exhibit D.3-1.

Recent advances in AA technology have produced a graphite furnace procedure for measuring arsenic that appears to rival the hydride evolution method in sensitivity while offering definite advantages in analytical throughput. Nickel nitrate is added to the sample to produce a nickel arsenide which is sufficiently non-volatile to permit furnace measurement. The sample is placed in the graphite furnace which is electrically heated first at low temperature to dry and ash the sample, and then heated to 2900°C to atomize the sample for AA measurement. A detailed procedure for this EPA analysis method is given in Reference 7.4.

During method qualification, these two methods will be compared using various FGC and other samples.

7.3.2 Selenium (Hydride Evolution and Graphite Furnace)

TABLE 7.7

DATA FOR METALS THAT MAY REQUIRE ANALYSIS BY A METHOD OTHER THAN ICAP
(For Elements of Sufficient Importance)[1]

Element	AA Detection[2] In Solution (ppm)	Proposed Groundwater[8] Quality Criteria (ppm)	Concentrations In[9] FGC Liquors (ppm)	ICAP Detection[3] In Solids (ppm)	Concentrations In[9] FGC Solids (ppm)	Comment on Overall Detection
B[4]	0.02 (dc plasma)	–	ppb-ppm	2	10-1000	OK
As[4]	0.02 (hydride, furnace)	0.05	< 0.004-1.8	2	0.6-63	Borderline
Se[4]	0.01 (hydride, furnace)	0.01	< 0.001-2.7	1	0.2-19	Borderline
Hg[4]	0.01 (cold vapor)	0.002	< 0.001-0.07	1	0.001-6	Borderline
Sb[4]	(graphite furnace)					
Ag[5]	0.01 (graphite furnace)	0.05	ppb-ppm	1	1-50	Probably OK
Cr[6]	0.1 (flame)	0.05	< 0.001-0.6	10	3-250	Borderline
Cu[5]	0.04 (flame)	1	< 0.002-0.6	4	1-76	OK
Mn[5]	0.08 (flame)	0.05	< 0.01-90	8	11-120	Borderline
Fe[5]	0.05 (flame)	0.3	0.3-10	5	major comp.	OK
Zn[4]	0.06 (flame)	5	< 0.01-27	6	10-430	OK
Cd[6]	0.01 (furnace)	0.01	0.004-0.1	1	0.5-10	Borderline
Pb[6,7]	0.05 (flame)	0.05	0.002-0.5	5	5-1000	Borderline

1. See Tables 7.5 and 7.6 for background.
2. Ten times detection limit (Arthur D. Little data), includes a dc plasma method.
3. 100 x solution detection limit. Barringer-Magenta, Ltd. data.
4. Definitely requires AA.
5. Possibly requires AA.
6. Not likely.
7. AA performed by ICAP vendor.
8. *Federal Register*, Dec. 18, 1978.
9. Note 3, Table 7.5 (Ref. 7.4).

Source: Arthur D. Little, Inc.

The state of the art of trace selenium analyses is analogous to that of arsenic which was described above. A method involving the formation of gaseous H_2Se has been the generally accepted method. A graphite furnace procedure may supplant the hydride evolution technique. Procedures based on hydride evolution are given in Exhibit D.3-2. The EPA graphite furnace procedures are given in Reference 7.5.

7.3.3 Antimony (Graphite Furnace)

Antimony can be determined by AA with the graphite furnace using the EPA procedure given in Reference 7.6. The addition of a reagent to reduce antimony volatility is not necessary.

7.3.4 Mercury (Cold Vapor)

"Cold vapor" techniques for ultra-trace determinations of mercury have been used for many years. In one such technique a reaction vessel fitted with a sparger is connected to an optical cell placed in the measurement beam of an AA spectrometer with Tygon tubing. The exit port of the cell is connected back to the sparger inlet of the reaction vessel via a peristaltic pump to form a closed system. A sample of the solution to be analyzed is placed in the reaction vessel and the mercury is reduced to highly volatile elemental mercury by adding stannous chloride. The peristaltic pump circulates the mercury vapor from the vessel to the AA measurement cell. The details of this procedure are presented in Reference 7.7. A graphite furnace technique will be compared for cost-effectiveness and applicability (Ref. 7.8).

7.3.5 Other Metals By AA

Silver, nickel, and cadmium will also be analyzed by graphite furnace techniques analogous to the procedure for antimony. The EPA methods which will be used are given in References 7.9 through 7.11.

Further discussion of the relative applicability of the various hydride and graphite furnace methods for As, Se, Hg, and Sb is given in Exhibit D.3-3.

7.4 ION CHROMATOGRAPHY (IC)

Ion chromatography is a relatively new instrumental technique for measuring a number of commonly occurring anions in solution at sub-ppm levels. A small (generally 100 uL) sample of the solution to be measured is injected into an aqueous carrier stream containing a dilute sodium carbonate/bicarbonate mixture. The anions in the sample are carried through an anion exchange column where separation occurs. After the conductivity of the carbonate/bicarbonate in the carrier is "suppressed" by converting it into carbonic acid, the anions are quantified using an electrical conductivity detector.

In this program IC will be used to measure fluoride, chloride, nitrate, and sulfate in liquid samples.

In instances where fluoride or chloride is the only substance of interest, it may be more cost-effective to measure it using the fluoride or chloride ion-specific electrode. (See Section 7.5.10.)

Anions in the following types of samples will be measured during the program:

- Liquid phase of waste materials;
- Interstitial water in soils;
- Groundwater;
- Water extracts of soils and waste samples; and
- Surface water samples.

Detailed procedures on using an ion chromatograph (DIONEX Model 14) are given in Exhibit D.4-1. A comparison of IC detection limits and concentration of the listed anions in various samples of interest and proposed standards is given in Table 7.8 and illustrates the applicability of this technique for analysis of the various samples of interest in the program.

TABLE 7.8

COMPARISON OF IC DETECTION LIMITS WITH SOME RANGES OF INTEREST
(all values in ppm)

Species	Limit IC	Proposed Drinking Water Standards	Typical Concentrations in FGD Liquors	FGC Waste[1]
F^-	0.05	1.4-2.4	0.7-70	1-20
NO_3^-	0.3	10*	—	2
Cl^-	0.07	250	470-43,000	1-10
$SO_4^=$	0.1	250	100-30,000	10-400

*as N, 44 ppm as NO_3^-.

1. Provided for comparison only. For 1-g sample dissolved in 100 mL of solvent.

Source: References 7.1, 7.12, and 7.13.

7.5 MISCELLANEOUS ANALYSES BY WET CHEMICAL AND OTHER METHODS

This section summarizes a variety of wet chemical and other procedures which will be used to analyze various species in FGC waste solids and liquors, groundwater, and surface water samples.

Detailed procedures are given in the following references and and exhibits:

Sample	Analyte	References
Ash slurry liquor	pH	Exhibit D.5-1
	Total Dissolved Solids (TDS)	Exhibit D.5-2
Ash/FGD waste liquor	pH	Exhibit D.5-1
	Total Oxidizable Sulfur (TOS)	Exhibit D.5-3
	Hydroxide (alkalinity or acidity)	Exhibit D.5-4
	Carbonate (alkalinity)	Exhibit D.5-5
Ash/FGD solids	Acid Insolubles	Exhibit D.5-6
	Total Oxidizable Sulfur (TOS)	Exhibit D.5-3
	Sulfate ($SO_4^=$)	Exhibit D.5-7
	Hydroxide (alkalinity)	Exhibit D.5-4
	Carbonate ($CO_3^=$)	Exhibit D.5-5
Groundwater/surface water	Sulfite (SO_3)	Exhibit D.5-3
	pH	Exhibit D.5-1
Groundwater/surface water	Total Dissolved Solids (TDS)	Exhibit D.5-2
	Conductivity	Reference 7.14
	Carbonate ($CO_3^=$)	Exhibit D.5-5
	Hydroxide (alkalinity, acidity)	Exhibit D.5-4

Procedures for measurement of boron and silicon using dc plasma emission (Ref. 7.15) and fluoride/chloride using ion selective electrode are also included. (Ref. 7.16 and 7.17.)

7.5.1 Total Oxidizable Sulfur (TOS)

Measurement of TOS at high concentration in solid and liquid samples will be made by reaction with iodine and titration of excess iodine with thiosulfate. Trace levels of sulfite will be measured using a modified West-Gaeke (colorimetric) procedure. These procedures are detailed in Exhibit D.5-3.

A newly developed technique using ion chromatography will be evaluated to determine comparability with the above techniques.

7.5.2 Sulfate ($SO_4^=$)

Sulfate in solid samples (FGD) will be determined by addition of excess lead to the solubilized sample and determination of the excess lead using a back-titration with sulfate or by ion chromatography. Measurement of sulfate in liquid FGC wastes will be made by oxidation of all sulfur species with H_2O_2 and determination of total sulfate by IC. Sulfate will then be determined by difference of any sulfite (TOS) originally present. These procedures are detailed in Exhibit D.5-7.

7.5.3 Carbonate ($CO_3^=$)

Carbonate in FGD solids will be measured by evolution as CO_2 (after oxidation of $SO_3^=$ to $SO_4^=$) and collection in an impinger filled with NaOH solution. Carbonate in the solution is then determined by titration. The procedure is detailed in Exhibit D.5-5.

7.5.4 Alkalinity/Acidity

Alkalinity or acidity of various solid and liquid samples will be determined by titration with acid or base using various indicator solutions. The procedures are detailed in Exhibit D.5-5.

7.5.5 Total Dissolved Solids (TDS)

Total dissolved solids in various liquid samples will be determined by drying an aliquot to constant weight at 120°C. The procedure is detailed in Exhibit D.5-2.

7.5.6 Acid Insolubles

This procedure will be used to determine an approximate ratio of ash to FGD material present in a mixture of the two. The procedure determines the amount of sample which is insoluble in 1 N HCl. The procedure is detailed in Exhibit D.5-6.

7.5.7 pH

Measurement of pH will be made on liquid and slurry samples using glass and reference electrodes. This method is detailed in Exhibit D.5-1.

7.5.8 Conductivity

Measurement of conductivity will be made using commercially available instruments (i.e., YSI Model 33 SCT meter). The procedure which will be utilized is detailed in Reference 7.14.

7.5.9 Boron/Silicon

Analysis of boron and silicon in solids will be performed directly or after fusion with Na_2CO_3. Dissolved solid and/or liquid samples will be analyzed directly by emission. The recommended procedure for fusing solids is 0.1 g with 1 g Na_2CO_3 and dissolution in 1 N HCl. (This procedure needs to be tested for FGC materials.) Alternate fusion techniques will be used as discussed in Section 5 in conjunction with the dc plasma emission technique. An alternate colorimetric analysis using curcumin reagent will be used if samples cannot be analyzed by emission. Details are given in Reference 7.15.

7.5.10 Fluoride and Chloride

For solid samples such as ash and FGD materials, measurement of fluoride and chloride may be made after total dissolution of the sample and using an ion selective electrode. For fluoride, the sample will be analyzed by HF evolution and measurement of the collected fluoride measured by ion selective electrode as in Reference 7.17. Altenatively the fluoride collected can be analyzed by ion chromatography. Chloride analyses for solids will be performed as in Reference 7.16.

7.6 RADIOACTIVITY

The disposal area will be sampled and analyzed for active nuclides in several areas in order to assist in evaluation of the potential environmental impact of disposal of FGC waste with regard to off-site transport of radioactive substances. These areas may include (in order of priority),

a) Waste samples,

b) Liquors and leachates, and

c) Radon emanation from area.

Samples associated with these areas include:

- Waste — ash and FGD solids,
- Liquors — sluice liquors accompanying waste,
- Leachates — extract samples from solids, groundwater, and surface runoff (background and downgradient), and
- Emanation — radon gas emanation from the site and off-site as background.

Initially, it is proposed to sample and characterize the radioactive nuclide content of samples of the solid phase from the site and currently disposed influent solid materials as a first step to assessing if further analysis is required. Performance of additional tests is contingent upon determination of the need to do so, which will be based on assessment of previous results.

The discussion and methodology described below covers procedures which can be employed if necessary for analysis of all of the listed samples. Materials will be sampled and analyzed according to the following typical matrix:

Sample	Number	Analyte
Influent Solid	3	^{226}Ra
Solid in Site	9	^{226}Ra
Influent Liquor	to be determined	^{226}Ra, ^{228}Ra, total a, total B
Liquor Phase in Site	to be determined	^{226}Ra, ^{228}Ra, total a, total B
Extract of Waste	to be determined	^{226}Ra, ^{228}Ra, total a, total B
Groundwater/Surface Water	to be determined	^{226}Ra, ^{228}Ra, total a, total B

Radon Flux from Site to be determined ^{222}Rn (gas)

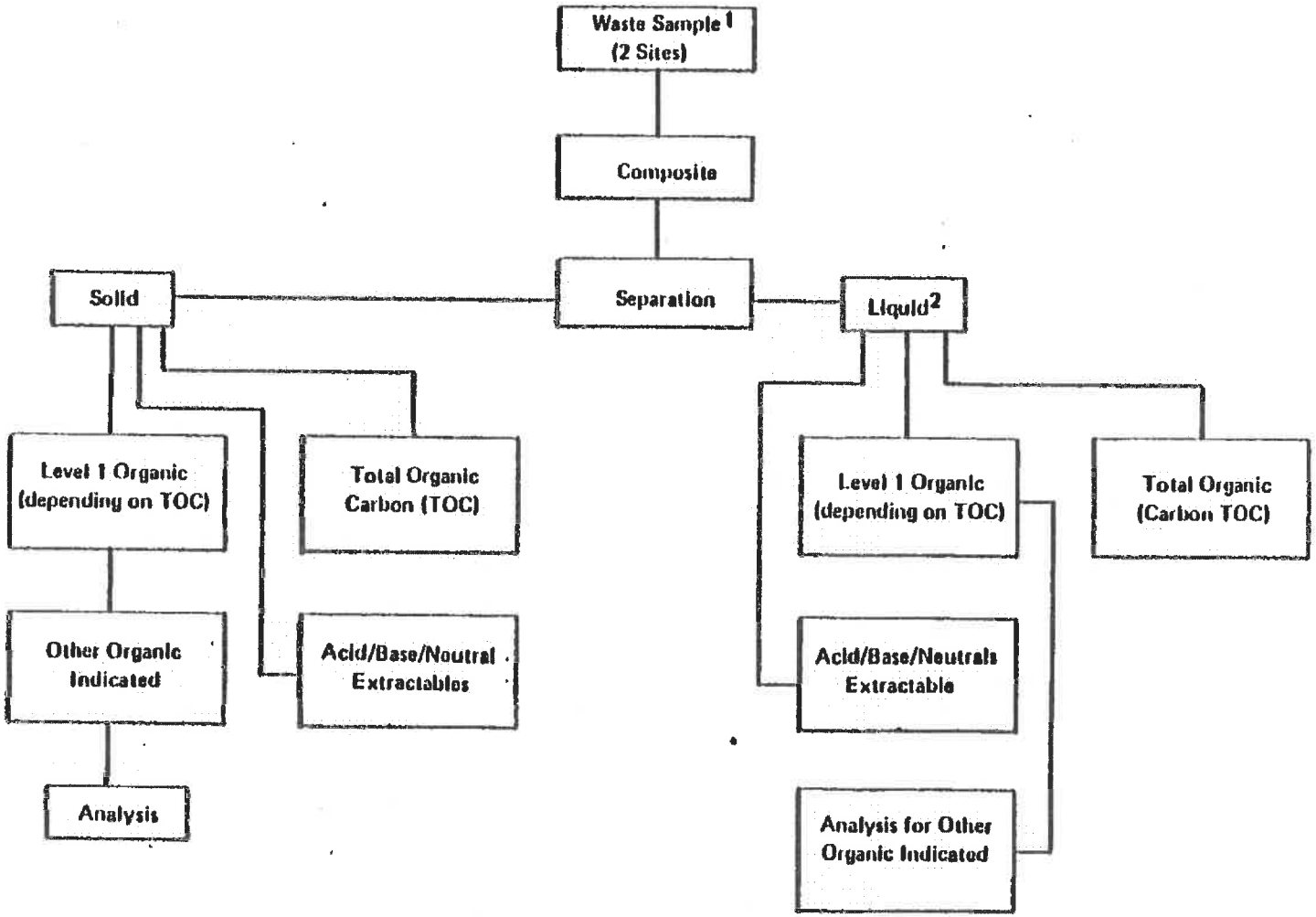
The methods to be used to characterize the radioactivity in the listed samples are given in References 7.20 through 7.24 and briefly described in Exhibit D.6-1.

Radioactivity in the solid samples will be characterized by the ^{226}-Ra concentration using either the Radon Emanation technique (Ref. 7.20) or Gamma Ray Spectroscopy (Ref. 7.21). Radioactivity in liquid samples will be characterized by analysis of ^{226}Ra, ^{228}Ra, total alpha, and total beta. Radium 228 will be determined by barium coprecipitation and beta particle counting (Ref. 7.22). Radium 226 will be determined by barium coprecipitation and alpha particle correcting. Total gross alpha and beta will be determined by drying the liquid samples and using gas flow through proportional alpha and beta counters (Ref. 7.23). Rn^{222} flux at and off the site will be measured using canisters filled with activated charcoal and measuring the accumulated gamma ray activity in the canister using a detector (Ref. 7.24).

7.7 ORGANIC ANALYSIS OF FGC WASTES

A limited number of organic analyses will be performed on FGC waste samples as an initial screening, and if the presence of organic substances of interest is indicated in the waste solids or liquors, the extent of organic analyses will be expanded and will also include some groundwater and/or surface water samples. A summary of the initial organic sampling and analysis approach is given in Figure 7.9. Performance of additional tests will be contingent on the need to do so based on these results.

The Level 1 Organic procedures and the priority pollutant analysis approach (Acid/Base/Neutrals Extractables) are given in References 7.23, and 7.24. Some investigators have indicated the possible presence of dimethyl and monomethyl sulfate in FGC wastes. If possible a few samples will be screened for these substances. As part of this screening approach a Level 1 Inorganic scan will also be performed (Ref. 7.25). Procedures for total Organic Carbon Analysis are given in Reference 7.26.



1. FGC waste samples do not contain any pesticides or herbicides, thus these are not analyzed.
2. Applicable also to groundwater samples (excluding Level 1 Organic).

Source: Arthur D. Little, Inc.

FIGURE 7.9 SUMMARY OF ORGANIC ANALYSIS APPROACH[1]

7.8 DOCUMENTATION OF LABORATORY ACTIVITIES

7.8.1 Laboratory Chain-of-Custody Procedures

At the laboratory, all samples will be received by the laboratory custodian, or a specifically designated trained alternate. The custodian will sign and date the shipment waybill, inspect the packages for evidence of tampering, and then open the packages to examine the contents. The custodian will first verify that the information on the sample labels matches that on the packing list enclosed with the samples. Then the custodian will log in all samples by assigning laboratory identification numbers in ascending sequence, every sample having a unique, non-recurring laboratory number. The Laboratory Log Notebook will include the field number, date of receipt, condition of sample when received, a qualitative description, the assigned laboratory number, sample preparation required (spiking, etc.), sample distribution, and any other information deemed appropriate. The sample custodian will be responsible for preparing and introducing control samples, blanks, and check standards.

Samples will be kept in a locked container (refrigerated, if necessary, for sample preservation) when not being analyzed. Sample distribution sheets (e.g., one per lot of ten samples) will accompany the samples as they progress through analytical procedures. These sheets will supplement the data given in Laboratory Log Notebooks.

7.8.2 Laboratory Log Notebook

In keeping with good scientific laboratory practice, each analyst will keep a Laboratory Log Notebook in which all procedures performed and results obtained are recorded. Standard procedures may be indicated by reference to the appropriate document; however, any deviations will be recorded in detail. For experimental results which will be calculated from raw data, the

raw data, means of calculation, and final calculated results will be recorded in the notebook. The analyst will review, sign, and date each page of the notebook daily.

Information will be recorded in the Laboratory Log Notebook so as to permit the analyst to reconstruct at a later time exactly what procedures were followed. The project analytical supervisor will review each analyst's notebook with him/her weekly to ensure completeness, clarity, and verification of procedures.

8.0 QUALITY ASSURANCE/QUALITY CONTROL

The sampling and analysis Quality Assurance/Quality Control (QA/QC) program for this project will ensure that all sampling and analysis information collected and reported is valid and complete, and sufficiently precise and accurate to meet end-use requirements. The QA/QC program will verify that the data generated by project personnel meet all the established criteria. As applied to the sampling and analysis portion of the project, the QA/QC program will include in-house Arthur D. Little, Inc. activities and the activities of associated subcontractors. The program will cover site development, sampling, analysis, data processing and handling, and all supporting activities in these areas.

The QA/QC program will be integrated and will ensure that all procedures will include provisions delineating the practices, requirements, and procedures which are to be implemented at each phase of the program for all participants and subcontractors.

The QA/QC program will be implemented at two levels:

1. Quality Assurance Level

   Activities at this level monitor the development of experimental data goals and the design and implementation of QC procedures. QA personnel determine that QC procedures are being followed and that corrective action is being taken when necessary. Finally, the QA function ensures that the level of uncertainty inherent in the experimental data is communicated to the ultimate recipients of the data.

2. Quality Control Level

   This level includes all activities carried out by program technical personnel to determine data precision and accuracy, comparison with previously defined goals, and taking corrective action if goals are not being met.

The fundamental components of the QA program will be common to chemical sampling, analysis, hydrologic exploration, and physical testing. The QC procedures which are used to track

performance will differ depending on the sort of sampling, analysis, or testing which is being performed. Chemical analyses will rely heavily on the use of calibration standards and experimental determinations of instrument response characteristics. For physical testing, the QC procedures will be based on careful adherence to established, well-characterized protocols and on careful calibrations of fundamental measurements of mass, pressure, displacement, and volume.

The Arthur D. Little, Inc. Project Director, Mr. C.J. Santhanam, has overall responsibility for QA/QC activities associated with this project. Oversight and advice with regard to QA/QC of physical sampling and analysis will be provided by Dr. D. Joseph Hagerty of the University of Louisville. Dr. James E. Oberholtzer of Arthur D. Little, Inc. will be responsible for QA/QC relating to all chemical sampling and analysis activities. Dr. Hagerty and Dr. Oberholtzer will report to Mr. Santhanam on their respective areas in this project.

The following two sections present a general discussion on the QA and QC activities which will be carried out in this program. Detailed recommendations for physical and chemical sampling and analysis are contained in the two final sections.

8.1 OVERVIEW OF QUALITY ASSURANCE/QUALITY CONTROL ACTIVITIES

8.1.1 Quality Assurance

8.1.1.1 Personnel Training

In a general sense, QA for the sampling and analysis program will be provided by evaluating the possible options and selecting the optimum procedure early in the sampling and analysis program. Preferred practices will be emphasized in training sessions, provided in procedures and instructions, and ensured by the establishment of minimum standards for facilities and equipment operation, procurement and control of supplied data, and sample/data accountability. Training will be oriented to a

critical view of all procedural steps, including data recording and transmittal which are necessary to obtain the desired quality.

Administrative QA investigations will include determinations of whether or not subcontractor project personnel are fully cognizant of the provisions of this manual. Additionally, administrative QA activities will be designed to determine whether or not supervisors have ascertained that all personnel are qualified for the field exploration, field testing, and laboratory testing activities to which they have been assigned.

Quality Assurance managers and advisors have assumed that all personnel employed in field and laboratory activities are qualified by experience and education to undertake and complete the work that is assigned to them by their respective project managers. The technical personnel assigned to field exploration activities or laboratory testing activities should receive intensive and extensive training in the sampling and testing procedures described in this manual. Additionally, supervisory and administrative personnel assigned by the subcontractor to work on this project must be familiar with the provisions of this manual with regard to QA and QC, and they must make every effort to comply with these provisions during the entire progress of the study. Further education and indoctrination of subcontractor personnel with regard to QA and QC for physical testing activities may be required. This indoctrination could take the form of periodic lectures, discussions, and seminars conducted by personnel of the subcontractors, as well as by externally originated consultants and experts.

8.1.1.2 Review of Procedures and Their Documentation

A careful review of all field and laboratory procedures being considered for the program will be performed prior to their implementation. This review will ensure that the methods chosen are appropriate for the program needs, ensure that descriptions are sufficiently complete and unambiguous so that they can be

carried out consistently and uniformly, and ensure that adequate QC procedures are written into the methods so that reliability of the analytical results can be tracked.

8.1.1.3 Sample Identification and Traceability

Because of the size and complexity of this program, the volume of data points generated, and the test duration, a sample identification system will be established to provide traceability of all data. A tentative system is discussed in Section 4.11.

8.1.1.4 Review of Quality Control Procedures

Continued QC is essential to the success of this program. The adequacy of the QC program will be regularly reviewed; QA will subsequently verify the continued effectiveness of QC in these areas.

8.1.1.5 Auditing

Audits will be performed by the apropriate QA personnel responsible for either physical or chemical S/A on all aspects of the program, including field testing, sampling, and analysis. The audit effort will include random audits, suspect item audits, and problem audits within the constraints of the program. The auditing effort can consist of unannounced visits by QA personnel to inspect field or laboratory operations in progress or possibly involve scheduled discussions of planned procedures prior to implementation or of experimental results after they have been generated.

8.1.1.6 Review of Final Results and Conclusions

As the program progresses and conclusions are being drawn, QA personnel will endeavor to see that the uncertainties inherent in the experimental data are understood and taken into account.

8.1.2 Quality Control

Quality Control, as discussed in this section, is that part of the quality program which is internally applied to program activities. "Internally" means that the quality controls are implemented within the performing organization. However, the quality control guidelines, rules, methods, inspections, and limits of acceptability used in the program will be approved by QA personnel and audited as part of the QA function.

The manual is to be followed explicitly. If deviations are required, these must be documented and reported. Any changes will be approved by the QA officer and distributed to all parties concerned as addenda to this manual. Through study and demonstrated appropriateness, acceptable revisions to procedures can be developed, which in turn will represent a new set of controlled conditions. The guidelines to be used in the sampling and analysis program training, manual, facilities, etc., are provided below.

8.1.2.1 Facilities, Equipment, and Supplies

All equipment will be calibrated on a regular basis as per protocol for the individual instruments. The laboratories will be neat and orderly, within appropriate limits imposed by the nature of the operation. Laboratory benches, particularly areas where critical operations such as weighing or transfer are carried out, will be kept clear of all but necessary tools, glassware, and other equipment.

Well-defined and documented purchasing guidelines for all equipment and reagents having an effect on data quality will be used. Only chemicals and solvents of known purity with certified analyses will be used. Each procedure will dictate the purity level of special solvents as required. Performance specifications for all critical items of equipment will be reviewed initially to assure that the equipment is satisfactory for the purpose intended.

Materials of construction and cleaning procedures for sampling apparatus, sample containers, and laboratory apparatus will be specified to minimize contamination.

8.1.2.2 Documentation Control

Any procedural changes will be documented and a clear, defined method for document revisions will be established. A revision will be prepared by the appropriate technical coordinator, e.g., chemical sampling or physical testing and submitted to the QA officer for approval and distribution. This will include informing all involved personnel of the updated procedures and distributing copies of updated procedures to each person on the program, thus assuring that the change is implemented and permanent. It should be understood that revised procedures supersede previous ones, unless specific alternative choices are specified.

8.1.2.3 Calibration Procedures

The quality of any data is no better than the accuracy of the calibration of the instrument or apparatus. For instruments or apparatus which are empirically calibrated, every calibration curve should have at least three points, one of which is higher and one of which is lower than that of the sample. A calibration curve with only one or two data points is valid only if it has been verified that the calibration is intimately associated with the nature of the test and accuracy requirements, and should be presented as part of the procedure. In general, calibration should be made at a sufficiently frequent interval so that zero drift, gain changes, reagent degradation, or other time-associated changes do not contribute significantly to the overall variation of the method.

Detailed calibration procedures for each method to be used are being developed in conjunction with method qualification studies and will be issued as addenda to this manual.

8.1.2.4 Monitoring Precision and Accuracy

To document that reproducible results are being obtained (i.e., precision of the method), duplicate samples will be run. Although the frequency of such check analyses is, by nature, dependent on such factors as the original precision of the method, the reliability of the instrumentation involved, and the experience of the analyst, good laboratory technique is to run duplicate analyses a minimum of ten percent of the time. In this program, at least one sample in ten analyzed will be either a field or lab duplicate. The resulting data should agree favorably with the known precision of the method. Otherwise, the analyst will troubleshoot the system to determine the discrepancies. The QA coordinator will specify which specific samples are to be run in duplicate by the various analysts.

Concurrently, QC also monitors the accuracy of the measurement method. It is preferable to obtain values compared to known standards; however, a measurement of the response of a chemical analysis method to additive known amounts of the species is also very valuable. As a matter of routine practice, spiked samples will be used as a quality measurement. Appropriate spiking frequency is dependent on the analytical procedure and the nature of the sample matrix. It is not appropriate to specify an exact spiking frequency at this time; however, it is envisioned that about 10% of all samples will be spiked. Spiked samples will be run on samples specified by QA personnel.

In the area of physical testing, it is difficult to assess accuracy based on measurements of standards. In this area, accuracy is more often determined by fundamental metrological calibrations, e.g., mass or displacement, and by careful adherence to standard procedures.

8.1.2.5 Feedback and Corrective Action

Of utmost importance is the mechanism for reviewing data, problem detection, reporting, and corrective action. The

responsibility shall lie essentially with each analyst and the respective analytical coordinator to review the data and decide which data may be suspect. The field sampling coordinator will play a similar role in the sampling area. The QA officer will meet regularly with each coordinator to review and approve any suggested corrective actions.

8.2 QUALITY ASSURANCE AND QUALITY CONTROL ACTIVITIES FOR PHYSICAL TESTING

8.2.1 Introduction and Summary

The quality assurance/quality control (QA/QC) activities related to physical testing shall consist primarily of:

- Activities which are essentially internal to each of the organizations performing field and laboratory physical testing and evaluation, and
- Activities which are external to the two subcontractors performing the actual work.

QC will be the responsibility of subcontractor project managers subject to overall QC by Arthur D. Little, Inc. Project engineers and geologists who will directly supervise laboratory testing, field sampling, and exploration activities have a major role in implementing QC. QA advice and oversight will be provided by University of Louisville personnel, organized to report to the Project Director, C.J. Santhanam.

In general, QC activities will be based on a heavy reliance on standardized testing procedures for the most part contained in applicable standards of the American Society for Testing and Materials (ASTM). Additionally, quality control for laboratory testing will be supplemented with a monitoring program in which samples of wastes and natural soil materials will be selected for testing at the University of Louisville, as well as at Bowser-Morner Laboratories. In essence, one of every 20 samples taken will be split with a portion retained by Bowser-Morner to be subjected to the entire suite of tests and a portion sent to the University of Louisville for check testing with respect to strength and permeability.

QA activities will extend into two primary areas, administrative QA and technical QA. Administrative QA activities will ensure that the physical testing work is done in an efficient and accurate manner with regard to the overall organization of the work, the allocation of responsibilities for

the work, the procurement of supplies and services, and the meeting of schedules for various activities. Technical QA activities will be directed towards overall evaluation, monitoring and, if needed, remedial measures applicable to various technical activities such as sub-surface exploration, field sampling, field groundwater monitoring, calculations associated with field and laboratory procedures, laboratory testing methods, etc. Additionally, technical QA will involve the monitoring and evaluation of all test plans and reports drawn up under this project. Finally, procurement activities related to physical testing in this project will be evaluated in terms of the administrative quality assurance procedures mentioned previously.

8.2.2 Responsibilities

With regard to the laboratory testing, sub-surface exploration, field monitoring and evaluation, and other physical activities undertaken by the subcontractors, Bowser-Morner or Haley & Aldrich, the project managers for those subcontractors shall be considered the individuals responsible for implementation of QC measures for the various activities assigned to them. With regard to the particular operations carried out at a given power plant waste disposal site, the project manager for each of the subcontractors shall designate an individual who is a member of the field party at that site as the official QC supervisor for all activities by that subcontractor at that site. With respect to laboratory testing work, the project manager for Bowser-Morner shall delegate an individual to be responsible for QC of the laboratory testing associated with this project. These specific individuals in the subcontractor organizations shall be responsible for the control and management of field investigations, field testing, laboratory testing activities, procurement of supplies and equipment associated with these activities, and the reporting and analysis of data gathered during these activities. Additionally, these QC managers, along

with the chief cost management officer for this project for each of the subcontractors, shall track and account for project costs. Finally, the QC personnel for each of the field investigation efforts and for the laboratory testing activities shall be responsible for maintaining communication with the QA advisor at the University of Louisville, the project managers at each of the subcontractors, and the Arthur D. Little, Inc. Project Director.

8.2.3 Administrative QA Activities

The administrative QA activities carried out with regard to physical testing for this project will be intended primarily to evaluate the degree of proper implementation of QC procedures by the subcontractor organizations employed in physical testing work. In other words, the administrative QA audits and investigations described herein will be designed primarily to evaluate administrative procedures for implementing QC rather than to discover technical inadequacies or deficiencies. The primary emphasis will be placed upon scrutiny of organizational methodology including the maintenance of a schedule for the work, the control and organization of all documentation associated with the work, and the plans for QC activities.

With respect to QA audits and visits directed towards investigations of administrative procedures, the appropriate personnel at the subcontractor organizations will be informed of the proposed date of an audit prior to the conduct of that audit. An audit report will be prepared by the QA advisor and circulated to all appropriate personnel. After the audit is completed and prior to the preparation of an audit report, a post-audit conference will be held with subcontractor personnel by the QA advisor. With regard to any deviations in procedures or deficiencies in physical activities, the subcontractor project manager will be required to interact with the QA advisor subject to the overall directives of the Arthur D. Little, Inc. Project Director, to identify the causes of the deficiencies or deviations, and to ensure that the deviations and/or deficiencies

are properly corrected.

8.2.3.1 Liaison and Communications

Administrative QA efforts will be directed toward maintaining easy and adequate communications between subcontractors engaged in physical testing, the QA advisor, and the Arthur D. Little, Inc. Project Director for this work. Significant attention will be devoted to the control of project documents such as job specifications; descriptions of testing procedures; copies of reports, calculations and drawings; site visit reports; preliminary test plans; final test plans; and other documents associated with the physical testing work for this project.

All documents associated with this project should be clearly identified with a special code designation for this project. A document log should be maintained by the contractors engaged in physical testing to monitor the distribution and transfer of all documents associated with this project. Documents related to this project should be routed through a single individual designated for this duty by each of the subcontractor organizations. All project documents should not be released to other subcontractor organizations or to any other individuals without prior approval of the Arthur D. Little, Inc. Project Director. This restriction does not apply to informal communications such as memoranda and personal notes of an unrestricted nature; nor does it apply to records of telephone conversations, unless the subject matter of the informal communications is liable to misinterpretation or other undesirable usage after distribution to personnel outside Arthur D. Little, the University of Louisville, Bowser-Morner Laboratories, or Haley & Aldrich.

8.2.3.2 Procurement of Services, Equipment, and Supplies

In order to assure accuracy and quality in the physical testing activities carried out on this project, administrative QA restrictions must also extend to procurement of services and

equipment, as well as supplies, by the subcontractors engaged in physical testing. The Arthur D. Little, Inc. Project Director assisted by the QA advisor will endeavor to establish the capability and the availability of any consultants or service organizations desired by the subcontractor before granting approval for such employment. Approval of all consultants and other contracted individuals must be obtained from the Arthur D. Little, Inc. Project Director before they are assigned work on this project.

These provisions for procurement of services shall include procurement of all contract drilling and exploration services, whether such contract drilling is procured by Bowser-Morner or by Haley & Aldrich. Before such contract drilling services are procured, a contractual statement of scope of work, schedule for work, and project responsibilities to be applied to the contract drillers would be reviewed by the QA advisor on such decisions by Arthur D. Little, Inc. Prior to the granting of approval for such work, the contract drillers' specifications for services including sub-surface explorations will be reviewed. Other items concerned with contract provisions such as insurance requirements, warranties, bonding, terms of payment, and other information will be required prior to the approval of the use of contract drillers in this project. Final approval will be granted by the Arthur D. Little, Inc. Project Director.

With respect to equipment and supplies purchased by the subcontractors for this project, the routine purchase of supplies and testing equipment for the geophysical investigations and the groundwater monitoring activities included in the scope of this project will be the responsibility, as far as QC and QA are concerned, of the project managers for the individual subcontractors for physical testing. However, the equipment and supplies used and purchased for this project, both for field testing and exploration, and laboratory testing and evaluation will be evaluated by the QA advisor as required and directed by the Arthur D. Little, Inc. Project Director.

8.2.4 Technical QA Activities

8.2.4.1 Review of Test Plans

In order to assure quality in the conduct of the physical testing associated with this study, it will be necessary in advance of any physical testing work to develop a complete plan for field exploration, field testing, and laboratory testing for each of the sites investigated. Obviously, this testing plan can be modified to suit conditions discovered on-site, but the test plan must be developed prior to the commencement of work at a particular site and must be approved by the Arthur D. Little, Inc. Project Director. Any changes to the test plan shall be reviewed by the QA advisor.

Prior to the beginning of laboratory testing work and prior to the commencement of the initial field exploration activities, scheduled audit visits to the physical testing laboratory and to at least one power plant waste disposal site will be arranged by the QA advisor. These scheduled audit visits will be designed to eliminate sources of inaccuracies or deviations from accepted procedures prior to the commencement of any physical testing activities.

8.2.4.2 Review of Field Operations

QA activities related to field operations will include attention to such matters as use of proper forms for reporting sub-surface information and the results of field tests, the submittal of daily reports from field project managers, complete and accurate compilation of drilling logs (and review of drilling logs by the Arthur D. Little, Inc. Project Director), and prompt submittal of all field documents to the subcontractor office and forwarding of such documents for review, as appropriate, by the QA advisor.

Various activities also will be evaluated such as: the classification of waste specimens and soil specimens from each

8.2.4.3 Review of Laboratory Operations

With respect to laboratory work associated with this project, technical QA will include an investigation of the qualifications of the personnel engaged in testing activities. Also, the provisions for receiving and storage of samples will be evaluated. Samples must be received and stored in organized fashion, and complete and accurate documentation on all samples must be maintained at all times. With regard to laboratory testing equipment, technical QA investigations will be directed towards monitoring technical QC activities such as calibration and checking of instruments, documentation of such calibration, remedial measures for equipment out of calibration, etc. Furthermore, complete records of all testing procedures (data sheets, test reports, plots of test data, etc.), must be maintained and will be subject to scrutiny by unannounced audit test visits to the subcontractor laboratory by the QA advisor. If any non-conformances are observed in laboratory testing procedures, the subcontractor project manager will be expected to assist the QA advisor in identifying the cause of the non-conformance, evaluating the effects of the errors made as a result of the non-conformance, and carrying out proper action to remedy the non-conformance.

8.2.4.4 Review of Calculations and Data Presentation

Calculations for analyses and for interpretation of laboratory tests will be reviewed by the coordinator for physical testing with the individuals performing such calculations to make sure that the calculations are performed accurately and that they are subject to independent checking by competent individuals. Similarly, use of computer programs in data reduction and in the interpretation of field data will be evaluated to ascertain that all such programs have been checked by the use of sample problems, that the accuracy and reliability of the programs have been verified by subcontractor personnel, that the programs are

site; the accurate location of all sampling sites; the sealing and labeling as well as storage of all samples taken from each site; careful handling of undisturbed samples where appropriate; proper packaging of all samples for shipment and shipment at the earliest possible date; and the submittal of a separate packing list for each shipment of samples to the subcontractor office, the QA advisor, and the Arthur D. Little, Inc. Project Director.

With regard to contract drilling operations, technical QA investigations will be directed toward ascertaining whether such contract drilling operations are being carried out in compliance with the sampling and analysis procedures contained in this manual and the site development procedures contained in Appendix A, "Hydrogeologic and Geotechnical Procedures Manual." The drilling operations and the sampling activities carried out by the subcontractors as well as by any contract drillers will be subject to continued scrutiny in areas such as the competency of personnel, the maintenance of drilling and sampling equipment, and the calibration of all field testing equipment.

With respect to groundwater monitoring and sampling, the QA advisor will, as and when directed by the Arthur D. Little Inc. Project Director, review plans for and provide advice on the installation and evaluation of groundwater wells and piezometers. Additionally, the manner of data collection and the frequency of data collection from wells and piezometers will be evaluated.

For all of these field operations, the subcontractor project manager will be expected to assist the QA advisor for this project to determine the causes of any deviation from accepted procedures or deficiencies in testing results identified. After the cause of such deviations or deficiencies has been identified, the effect of the identified errors will be evaluated, and appropriate corrective action will be undertaken by the subcontractor project manager with the assistance, where appropriate, of the QA advisor. Every effort will be made to identify any administrative or procedural problems which could hamper the performance of field exploration and testing operations and the assurance of quality in those operations.

sufficiently well-documented to provide easy and accurate use, and that evaluations obtained by the use of computer programs can be redone at a later date on the basis of existing project data contained in subcontractor files. With regard to calculations, all mathematical formulas and symbols should be referenced as to source and such symbols and formulas should be checked to see that they are applied properly. Units used in calculations must be consistent with the units given in the sources for the formulae and calculations. The arithmetic in calculations must be checked for accuracy. If any deficiencies or discrepancies are encountered in checking calculations, the cause of such discrepancies must be identified and the effects of such errors must be evaluated. When the results of literature searches, site visits, design calculations, or laboratory experiments are reported, every effort must be made to make sure that figures, data plots, summaries, and tables are correct as well as complete. Any changes or revisions made in original documents must be transferred to copies and must be checked for accuracy. All interpretations and recommendations must be checked with applicable codes of practice for consistency.

8.2.5 QC Activities

QC on this project with regard to physical testing and field exploration will be accomplished primarily through reliance on standard procedures and methods widely accepted in geotechnical engineering practice. Primary emphasis will be placed on compliance with the provisions of ASTM Standards as described in Appendix A, "Hydrogeologic and Geotechnical Procedures Manual," and in other sections of this sampling and analysis manual. If a situation arises in which one of the procedures outlined in either of these manuals is considered by a subcontractor organization to be inappropriate or not strictly applicable, acceptable state-of-the-art methods may be substituted as appropriate for the listed procedure, but only after appropriate consultation with the QA advisor for physical testing for this

project and approval by the Arthur D. Little, Inc. Project Director. Reliance will be placed on the manuals for laboratory procedures and field procedures which have been developed by Bowser-Morner and Haley & Aldrich, and which are used by personnel of those organizations to maintain routine QC on projects.

In addition to the activities mentioned above, a further effort at QC will be made through check testing of samples at the University of Louisville Civil Engineering Laboratories. One sample in every 20 samples of FGC wastes and natural soil material will be selected by the testing personnel to be split, with a portion of the sample forwarded to the University of Louisville and a portion of the sample retained for routine testing by the subcontractor organization. The split sample will furnish a basis for evaluation of testing techniques carried out by the subcontractor. The testing activities of greatest concern in this monitoring effort will be the determination of material permeability and strength.

8.3 QUALITY ASSURANCE AND QUALITY CONTROL ACTIVITIES FOR CHEMICAL SAMPLING AND ANALYSIS

8.3.1 Introduction and Summary

Quality control (QC) in the area of chemical sampling and analysis will involve a number of activities which will be carried out by technical personnel directly responsible for field and laboratory activities. Control of quality will be maintained by first demonstrating the precision and accuracy of candidate techniques before they are applied to the analysis of real samples. Blanks, duplicates, standards, and spikes will be introduced into the sample stream throughout the duration of the program to provide a continuing measure of precision and accuracy.

Quality Assurance (QA), both administrative and technical, will be provided by personnel not directly connected with the day-to-day activities of the ongoing program. Administrative QA activities will seek to assure that the work is carried out efficiently, cost-effectively, and on schedule. Technical QA activities will include evaluations of sampling and analysis methods, test plans, the QC protocol, and the data analyses and reports generated as a result of chemical sampling and analysis activities. In addition to reviewing procedures, plans, and reports and to seeing that they also receive peer review, the individual responsible for QA/QC of chemical sampling and analysis will make unannounced audit visits to field sampling locations and to the laboratories carrying out analytical work.

8.3.2 Responsibilities

With regard to the field activities carried out to obtain samples for chemical analysis by Arthur D. Little, Inc. and its subcontractor, TRW, Inc., the responsibility for QC implementation will rest with the coordinator of field sampling in each of those organizations. For any particular sampling visit

to a given power plant waste disposal site, the field sampling coordinator will designate an individual to be the field sampling team leader. The team leader will be responsible for carrying out QC activities during that visit.

Quality control of chemical analysis in the laboratories of Arthur D. Little, Inc. and the subcontractors, TRW, Inc. and Barringer-Magenta, Ltd., will be the responsibility of the analytical laboratory supervisor who will be designated at each facility.

Quality assurance related to chemical sampling and analysis will be the responsibility of Dr. James E. Oberholtzer of Arthur D. Little, Inc., reporting to the Arthur D. Little, Inc. Project Director. Subject to the direction of Dr. Oberholtzer, Mr. Ed Moon of TRW, Inc. will provide QA oversight over activities in that organization.

8.3.3 Administrative QA Activities

Administrative QA activities carried out in connection with chemical sampling and analysis will seek to ensure that the organizational structure and administrative procedures of each of the performing organizations are appropriate for carrying out the overall chemical sampling and analysis program in an accurate, timely, and cost-effective manner. Of major importance will be a determination that the chain of command set up within each of the organizations performing chemical sampling and analysis will be effective in assuring that QC activities are carried out. Quality assurance oversight over administrative activities will be exercised by conducting audit visits to the performing organizations prior to the start of work.

Another important area of administrative QA effort will involve ensuring that good communications are maintained between laboratories performing chemical sampling and analysis activities, the Arthur D. Little, Inc. Project Director, and as appropriate, individuals of other disciplines who are involved in the program. Quality assurance personnel will seek to ensure that

any difficulties encountered during field sampling or laboratory analysis are communicated to the appropriate, cognizant individuals promptly. They will also ensure that procedural modifications necessary to circumvent field or laboratory difficulties are communicated to and implemented by the performing organizations on a timely basis.

To facilitate the process of transmitting analytical data from one laboratory to another and to ensure that only results whose quality has been determined are transmitted, a data manager, who shall be responsible for all transmissions, shall be designated within each of the performing organizations. Data developed during the course of this program by the contract laboratory Barringer-Magenta Ltd., shall be released to Arthur D. Little, Inc. and TRW as follows:

- In all cases, the data will be given to Arthur D. Little, Inc. directly, and
- In those cases where samples were sent to them by TRW, TRW will receive copies of data at the same time as Arthur D. Little, Inc.

Data developed by or supplied to TRW in conjunction with this program shall be submitted only to Arthur D. Little, Inc.

8.3.4 Technical QA Activities

8.3.4.1 Review of Test Plans

The test plans developed for each power plant waste disposal site to be studied will be scrutinized by QA personnel to ensure that the proposed procedures for carrying out chemical sampling and analysis are appropriate for the studies to be conducted at that site. Quality assurance evaluations will ensure that all sampling and analysis methodology has been appropriately qualified prior to its application to real samples and that an appropriate QC plan has been included in the test plan.

It is expected that difficulties will be encountered during field sampling and laboratory analysis operations from time to

time. Procedures will need to be modified to circumvent such problems. Quality assurance should be notified of such problems as soon as possible after they are encountered. Proposed solutions should be reviewed with QA prior to their implementation. Clearly, there may be instances in which immediate modification is necessary to permit the continuation of sampling and analysis activities. Such changes may be made on a one-time basis; however, the QA officer should be notified as soon as possible by telephone and a formal review will be conducted before the procedural change is made permanent for future work.

8.3.4.2 Review of Field Activities

All aspects of field sampling and field measurements will be reviewed by QA on a continuing basis. Field sampling notebooks and the contents of sample shipments will be examined to ensure that data recording and documentation procedures are being followed. Unscheduled field audit visits will be made by QA personnel to view the conduct of field measurements and acquisition of samples.

8.3.4.3 Review of Laboratory Activities

All laboratory activities in the three performing organizations will be reviewed and evaluated periodically by means of unannounced audit visits. Of primary interest during laboratory visits will be a determination that prescribed QC procedures are in place and being practiced faithfully. Procedures for receiving samples, ensuring their security, and maintaining a chain of custody will be evaluated. Analysts will be observed as they perform their work, and their supervisors will be expected to review laboratory notebooks and other records with QA personnel.

8.3.4.4 Review of Data Presentation

All data, both from the analysis of unknown and QC check samples inserted by the laboratory sample custodian, will be reviewed by QA personnel to ensure that appropriate QC was practiced and that the precision and accuracy inherent in the experimental results is clearly indicated and understood by those receiving the experimental data for further interpretation. The laboratory data manager at each of the performing organizations will be expected to interact with QA personnel on an ongoing basis to facilitate this review.

8.3.5 Quality Control Activities

Program personnel involved in almost every area of sampling and analytical activities will need to concern themselves with one or another aspect of QC. Areas of activities which involve QC include:

- Analytical methods qualification;
- Acquisition of field samples;
- Compositing of samples;
- Sample digestion or other pretreatment; and
- Final analytical measurement procedures.

Recommendations for QC checks in each of the above areas are discussed in the separate subsections which follow.

The major focus of a QA/QC program is to track the precision and accuracy of the experimental data being produced throughout the program. Initial estimates of precision and accuracy for each analytical method will be obtained by analyzing replicate check samples during the method qualification phase of the program. The continuing performance of each method will be monitored by analyzing some of the same check samples and field duplicates from time to time as the program proceeds. Ideally, check samples should be similar in composition to the unknowns being analyzed, and the concentrations of the constituents of interest should have been determined by a number of analytical procedures to verify their accuracy. Standard reference materials available from NBS, EPA, and other sources are well-characterized; however, their gross compositions sometimes do not match those of the unknown samples very well. In such cases, a single pooled check sample can be analyzed repeatedly throughout the program to provide a measure of analytical precision with a realistic sample matrix.

In this program we propose to use both standard reference materials and pooled samples for QC purposes. During method qualification both types of samples will be analyzed -- standard reference materials to check accuracy and pooled samples to check precision with more realistic matrices. Subsequently, when

unknown field samples are being analyzed, pooled check samples will be reanalyzed periodically to ensure that method performance does not change.

Standard reference materials which are recommended for use in this program include NBS fly ash, NBS trace mercury in water, EPA trace metals in water, and perhaps NBS river sediment. Since a realistic pooled sample would not be available until after a number of sites have been sampled, Arthur D. Little, Inc. will prepare synthetic "pooled" check samples for use by both TRW and Arthur D. Little, Inc., as well as for submission to Barringer-Magenta. Arthur D. Little, Inc. will prepare a representative FGC waste check sample from a quantity of high-sulfite, FGC sludge solids which contain fly ash. Pooled groundwater samples will be prepared by combining several samples of groundwater available to Arthur D. Little, Inc. into a single sample. The sample will be spiked at low levels with the substances of interest in the groundwater measurement protocol to ensure that they are present at detectable concentrations. One portion of that material will be acidified to stabilize the trace metal content, one portion will be left unchanged for anion and wet chemical parameters, and a third portion will be packaged separately for use as a trace mercury check.

8.3.5.1 Procedures for Qualifying Analytical Methods

Method qualification is actually the last step in the process of bringing a new analytical method on-line. Since the results of the qualification analyses provide the point of departure for tracking the performance of the methods during the ongoing program, the qualification analyses of check samples should be performed only after the analysts are thoroughly familiar with the methods and have practiced them on samples of known composition and have found them to be working well.

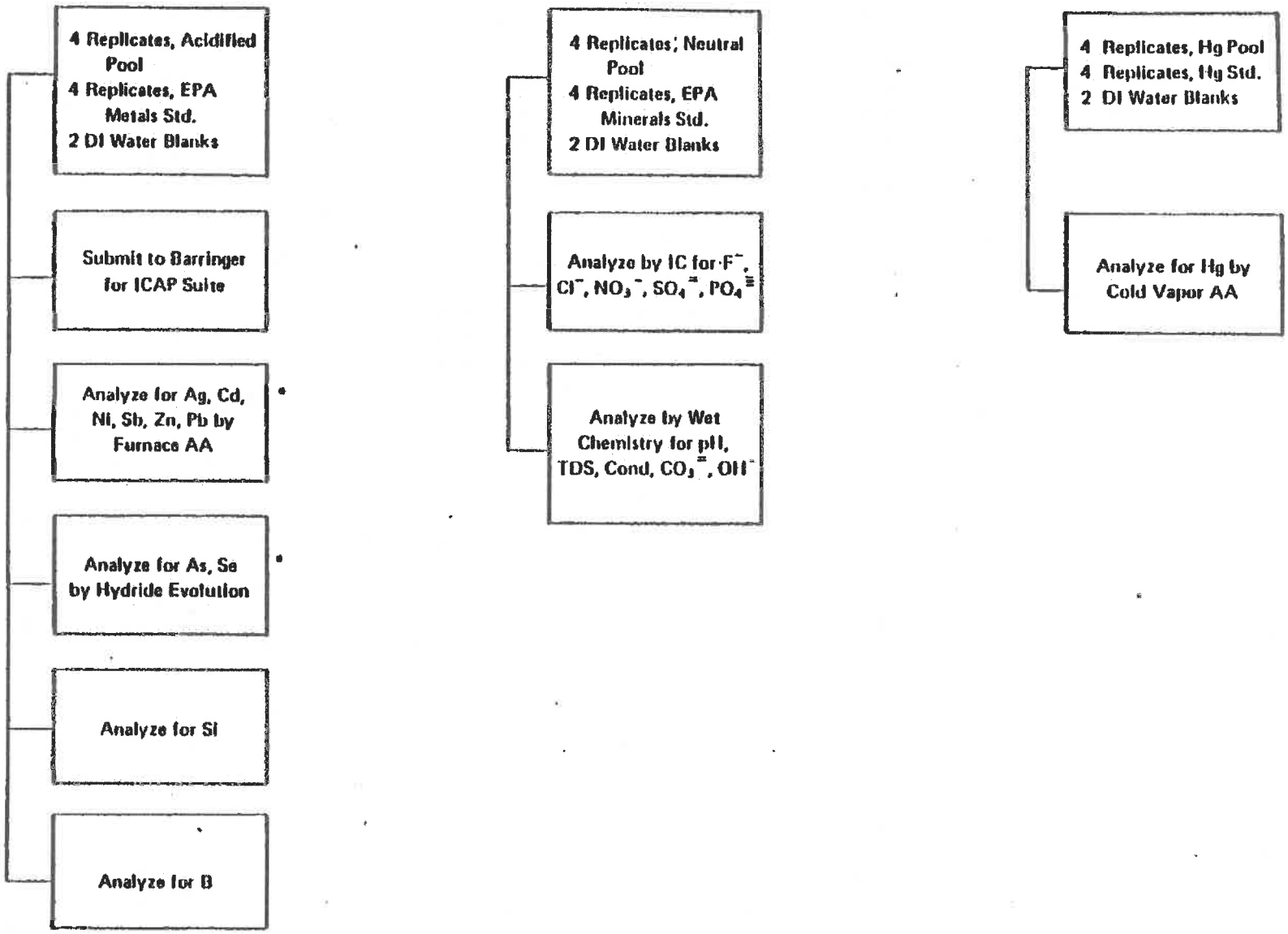
The general procedure which is suggested for method qualification involves analyzing a standard reference material and a pooled check sample, each in quadruplicate. Detailed

procedures have been developed for the several sample types of most importance to this program -- groundwater FGC wastes (solid phase) and FGC wastes (interstitial liquors). The same final analysis method (e.g., ICAP, IC, furnace AA) will be used for samples of all three types. It is recommended that for the check samples of all three types, the final solutions which are to be analyzed for a certain parameter be brought together and analyzed as a single batch to eliminate temporal variations. The sample set should be randomized so that all four replicates of one sample are not analyzed in immediate succession. If subgroups are analyzed on different days or by different analysts, that fact should be noted.

The qualification analyses for groundwater procedures is outlined in Figure 8.1. It should be noted that one of the four acidified pooled replicates should be spiked with Ni, Sb, Zn, Pb, As, and Se at at least three different levels and the initial concentration determined by the method of standard additions to check for matrix effects in these methods. Arthur D. Little, Inc. will spike one of the pooled samples submitted to Barringer-Magenta to check for ICAP matrix effects.

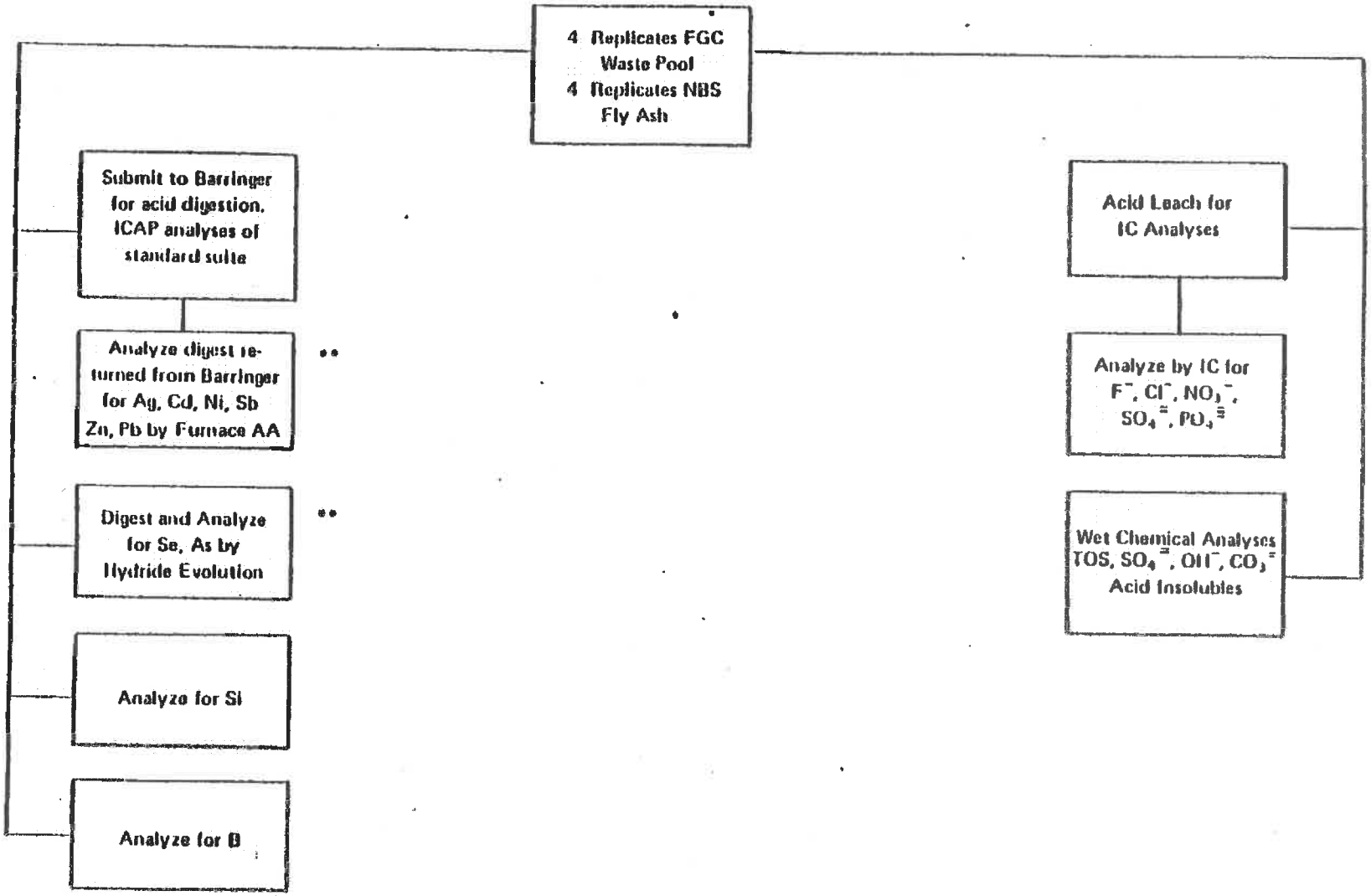
Procedures for dealing with FGC waste solids are shown in Figure 8.2. Barringer-Magenta will digest the samples sent by both TRW and Arthur D. Little, Inc. They will return a portion of the digest to each laboratory for analyses of the indicated metals by AA. Barringer-Magenta should be requested to return a portion of the digestion reagent blank as well. The levels of each of the six elements should be measured in the blank solution. As in the case of groundwater samples, AA matrix effects are to be checked by performing standard additions to one digest solution. For all parameters involving pretreatment (e.g., acid leaching) for selenium digestion, one of the final solutions to be analyzed should be split and analyzed in quadruplicate.

As shown in Figure 8.3, a surrogate FGC waste interstitial liquor is to be prepared by leaching a quantity of the FGC waste solids in twice its weight of water for 48 hours. The leaching should be done at room temperature, with stirring in a tightly



*One of the pool replicates shall be analyzed for all eight elements by three standard additions.

FIGURE 8.1 PROCEDURE FOR QUALIFYING GROUNDWATER ANALYTICAL PROCEDURES



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*For each analytical finish, one of the pool replicate solutions shall be split and analyzed in quadruplicate.
**One of the pool replicates shall be analyzed for all eight elements by three standard additions.

FIGURE 8.2 PROCEDURE FOR QUALIFYING FGC WASTE ANALYTICAL PROCEDURES* (Solid Phase)

closed vessel.

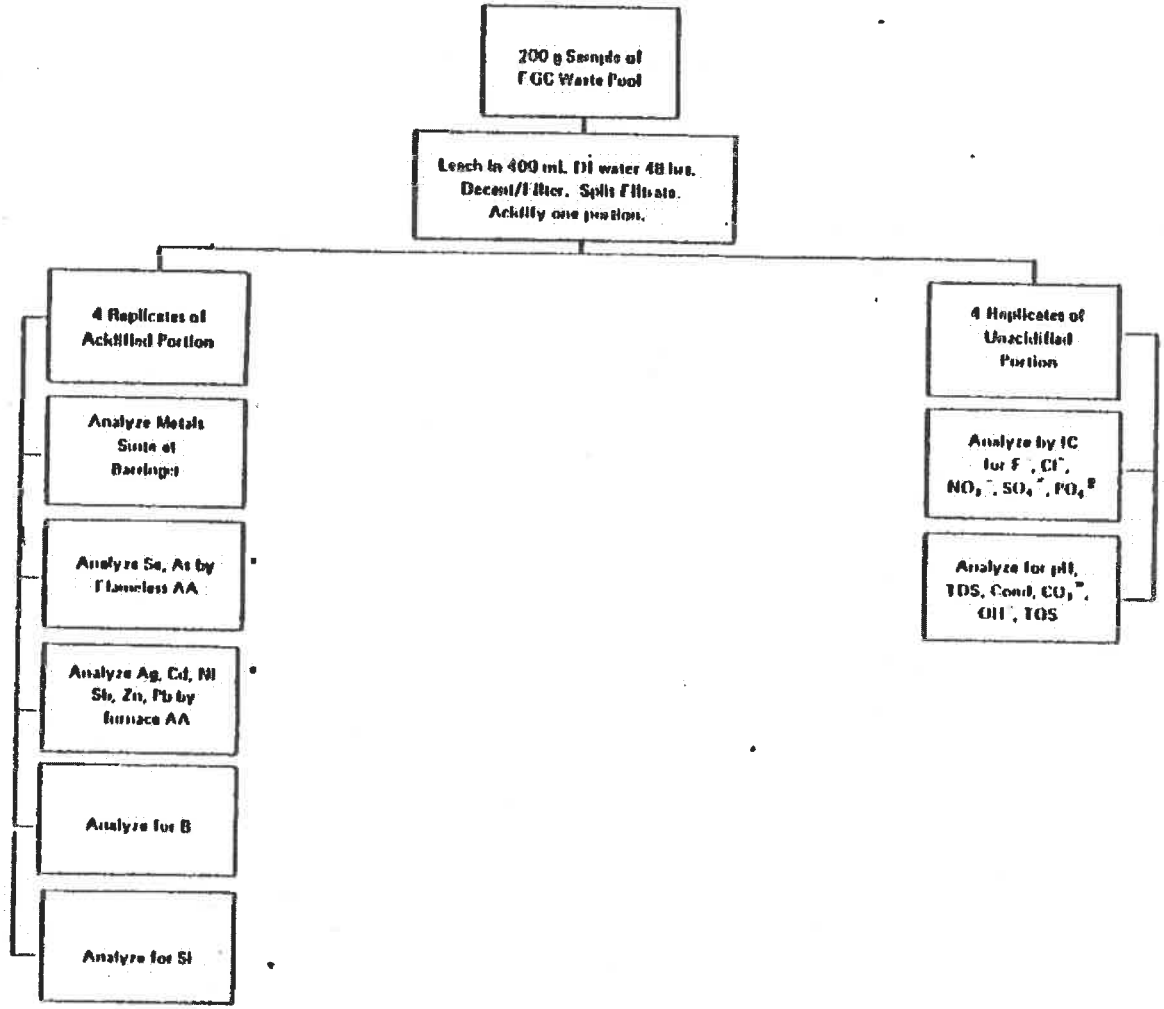
For each set of four replicate results -- standard reference material, pooled sample, and replicate final measurement, when performed -- compute the mean result and the standard deviation of the mean. For the standard reference materials, compute the individual percentages recovered, the mean recovery, and the standard deviation. All individual analytical results along with the computed statistics should be submitted to the QA represenative.

8.3.5.2 Quality Control Checks During Field Sampling

Duplicates of certain of the field samples will be obtained and sent through each analytical procedure in order to track the overall precision of the analytical results produced during the sampling and analysis program. Blank samples will also be obtained and analyzed to verify that contamination of the field samples did not occur. We will aim to analyze one duplicate and one blank for about every ten samples brought from the field.

A suggested protocol for obtaining QC check samples during field sampling is shown in Table 8.1. Since each sample of groundwater or surface water will be shipped as two sub-samples -- one acidified and one unpreserved -- both of those sub-samples will be duplicated. On average, one set of duplicates per sampling visit should be sufficient. The duplicates should be taken from a different well each visit to ensure that as many as possible of the wells are duplicated during the program.

One set of blank samples should also be taken on each visit. Insofar as possible, the blank should have passed through the entire sampling process. For example, if a bailer is used, it should be cleaned thoroughly with de-ionized water, and then just before sampling, it should be filled with de-ionized water and that water should be poured into the sample containers for the blank. If a filter is used, it should be precleaned and the blank sample passed through as well. If a peristaltic pump/pressure filter is employed, the entire system should be cleaned and a



*One of the pool replicates shall be analyzed for all eight elements by three standard additions.

FIGURE 8.3 PROCEDURE FOR QUALIFYING FGC WASTE ANALYTICAL PROCEDURES (Liquid Phase)

TABLE 8.1

QC SAMPLES REQUIRED DURING FIELD SAMPLING

Sample	Duplicates	Blanks
Waste (Previously Disposed)	None — A duplicate of each composite will be made after compositing.	One — One extra container to be opened momentarily at site during sampling.
Waste (As Disposed)	None — A duplicate of each composite will be made after compositing.	One per sampling visit — Extra container opened while one grab sample is being taken, then closed.
Groundwater	One per visit — Both the acidified and unpreserved samples will be duplicated. Duplicate to be taken from a different well each time.	One per visit — One unpreserved sample container to be filled with the DI water used for sampler clean-up. Two acidified sample containers to be filled with DI water and acidified.
Soils	None — One duplicate for each sample will be made in the laboratory.	One for every 10 samples — Containers to be opened momentarily during sampling and then sealed.
Surface Water	One set — unpreserved and acidified.	Same as groundwater — one unpreserved and two acidified.

Source: Arthur D. Little, Inc.

quantity of de-ionized water pumped through the entire system to produce the blanks. One unpreserved blank and two acidified blanks should be obtained in this manner.

Since it will not be possible to obtain true duplicates of solid samples in the field, duplicates will be prepared in the laboratory during sample compositing. However, one blank should be taken for each solid sample type during each visit. This blank will be an empty container which is opened at the time one of the sample containers is opened; it is left open while the sample container is being filled and it is then capped when the sample container is capped.

Duplicates and blanks will be indicated by circling the appropriate code on the pre-printed sample labels.

8.3.5.3 Preparation of Duplicates During Compositing

Since it is impossible to obtain a true duplicate sample of solids in the field, duplicate solid samples will be prepared in the laboratory during the final sample size reduction which will be performed on both individual samples or composites of a set of samples. It is recommended that at least one duplicate of each sample or composite sample be made and retained for possible analysis.

For samples that are dried and finally riffled, the duplicate sample should be taken after the last riffling step. For wet solids that are sampled by thiefing, both the original sample and the duplicate should be prepared by combining a number of individual thiefed portions. Both the original sample and the duplicate should be prepared from sub-samples which are as representative as possible of the contents of the container.

8.3.5.4 Quality Control of Sample Digestion

For essentially all of the analyses which will be performed on solid samples, some sort of sample pretreatment, i.e., digestion or leaching, will be performed to obtain a solution

which is finally analyzed. Each of those sample preparation procedures needs to be monitored to ensure that the substances of interest are being quantitatively extracted, that they are not being lost in the process, and that impurities are not being introduced in the reagent used in the preparation. To that end, it is recommended that for every batch of twelve or less samples subjected to a sample preparation procedure, one additional sample of the pooled check sample analyzed during method qualification be passed through the procedure and the resulting solution analyzed. In addition, one reagent blank should be processed for each lot of samples prepared in order to detect contamination introduced by the reagents used. A blank should also be included whenever a reagent from a new lot not previously used is introduced. Since this program involves a large number of similar procedures, it is strongly recommended that substantial quantities of the reagents to be used -- acids in particular -- be acquired at the outset of the program and checked for purity prior to their use in any procedures.

8.3.5.5 QC of the Final Analysis Step

The final step in the sampling and analysis sequence is the measurement of the concentration of the substance of interest by an instrumental or classical method -- the so-called "analytical finish." The prime reponsibility for QC of this very important step in the S/A process is in the hands of the analysts actually performing the analytical finish. The identity of the field and sample preparation QC check samples will not be known to the analysts, so that the results from those analyses can be used by the QA representative to independently monitor overall sampling and analysis precision and accuracy. However, each day the analyst will run his own QC check samples, and he himself will determine whether his measurement method is in control. If it is out of control, he will stop immediately, inform the laboratory analytical supervisor, and seek to correct the problem before proceeding.

The first important responsibility of the analyst is to accurately calibrate the measurement method to be used. For measurement techniques like AA and IC which produce responses proportional to concentration, a calibration curve must be developed from at least four points encompassing the range of concentrations likely to be encountered in the unknown sample. A new calibration curve should be generated each time a particular method is set up for a group of samples. If a particular analysis of one group requires more than a single day to complete, a complete calibration curve may not need to be generated if the single-point calibration check described below produces a response within 5% relative of that obtained when the calibration curve was determined. If concentrations greater than the highest calibration point are found during the course of running unknown samples, those samples must either be diluted and reanalyzed, or the calibration curve must be extended to encompass all of the higher concentrations by analyzing one or more standards.

For analytical methods which are inherently stoichiometric, e.g., titrimetric TOS, alkalinity, and carbonate, the titer of the reagents should be checked daily.

After the analytical instrument has been calibrated and the analysis of unknowns has begun, the analyst must introduce a QC check sample into the sample stream at regular intervals to ensure that the method continues to perform acceptably. Three types of check samples are useful and should be included — a duplicate of one of the unknowns, a reagent blank, and a calibration check. It is recommended that as a minimum one of each of these types of check samples be run for each group of 30 or less samples analyzed. If analysis of a lot of 30 or less requires more than one day, one each of the check samples should be run on each of the days.

The calibration check serves to detect drift in instrument response. If analysis of a group proceeds over more than one day, the calibration check should be the first analysis run at the beginning of each day. If the calibration check is in error by

more than an acceptable amount, the instrument must be completely recalibrated prior to proceeding with analyses. If the error is sufficiently great, all of the samples analyzed since the last successful calibration or calibration check will need to be analyzed. The action levels at which recalibration or reanalysis are required will be determined after the results of the method qualifications study have been analyzed. For many methods, it would be reasonable to assume that recalibration would be required if the check sample response was in error by more than 5% relative, and reanalysis would be required if the error was greater than 10% relative.

Another measure of precision is provided by analyzing one of the unknown samples in duplicate. The duplicate analyses should not be performed one after the other but rather separated by at least one-third of the samples in the lot. Again, the action levels for trouble-shooting the method and then continuing or trouble-shooting and then going back and reanalyzing will be determined at the end of the method qualification process. In many programs of this sort, a deviation between a replicate pair exceeding twice the historical standard deviation of the method on replicates is taken as a warning, and a deviation in excess of three times the standard deviation of the method on replicates is a signal to stop, correct the problem, and reanalyze. Similar criteria for acceptable behavior of the reagent blank which is run periodically will also be developed at the end of the qualification program.

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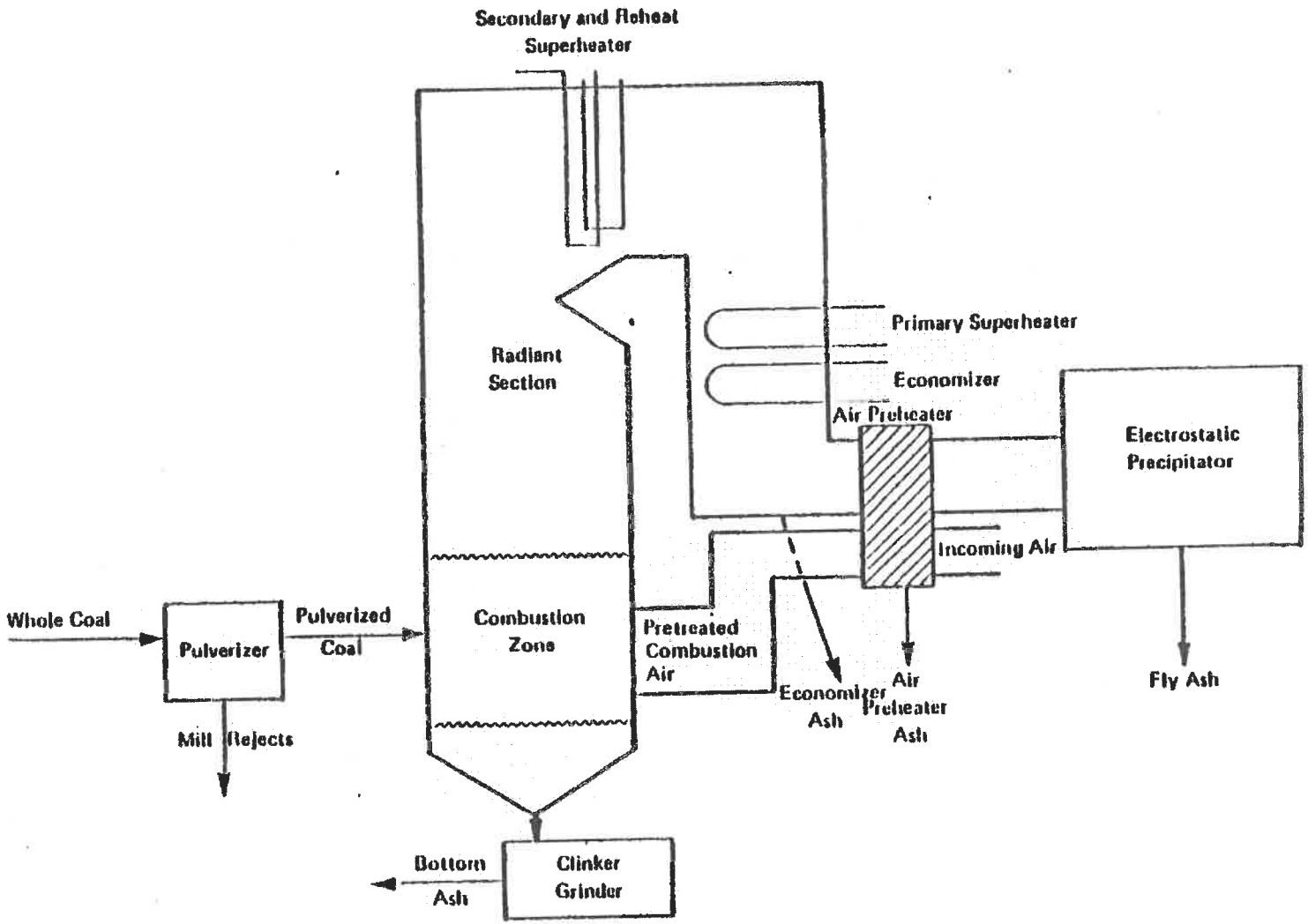
EXHIBIT A.1-1
VARIETY OF ASH AND OTHER WASTE PRODUCED IN COAL COMBUSTION



Note: Soot may be present in all ash streams.
Source: Arthur D. Little, Inc.

FIGURE 1 VARIETY OF ASH AND OTHER WASTE PRODUCED IN COAL COMBUSTION

C-3.2

EXHIBIT A.5-1
GROUNDWATER SAMPLING BACKGROUND

Five general classes of sampling alternatives can be used to obtain groundwater samples from monitoring wells. These consist of:

- Manual collection procedures;
- Vacuum extraction procedures;
- Pneumatic or pressurized collection procedures;
- Mechanical collection procedures; and
- Gas entrainment methods.

Each of these broadly defined categories has numerous alternative strategies that can be used to collect the required sample volume. However, these vary more with respect to equipment selection or configuration, and less with respect to the basic principal used to pull or force the groundwater from the well into a collection reservoir. Since a complete review of all sampling strategies cannot be presented in this manual, a brief generalized description of the major categories is presented here for review. The intent of this introductory material is to highlight the advantages and/or disadvantages of each general class, thereby providing the reader with a basis for evaluating the options selected.

The information contained in this preliminary review is by no means complete, but it is hoped that it will be sufficient to allow the reader to judge or review the selected approach. Should additional detail be required, further review of the literature should be undertaken independently by the reader.

MANUAL COLLECTION PROCEDURES

Manual sampling techniques include all sampling procedures that involve extensive or repetitive manipulation of the identified equipment. As such, manual sampling alternatives encompass many procedures that could also be listed under the other general headings, but are not because they are implemented

by hand. Generally, this category of sampling alternatives includes those simplest to implement on a one-time basis, but often the most difficult to use on a regular basis. Typically, sampling equipment and site preparation procedures are minimal, but frequently, equipment designs are crude and sample yields are small. Furthermore, usage may be labor-intensive, tedious, and time-consuming.

Examples of manual techniques that may be applied to groundwater sampling tasks include bailing with a device like a Kemmerer sampler, or hand pumping using either a suction or pressurized device. In operation, both of these options require only that the well site be accessible by foot, and that the collection device be adequate to draw the desired sample from the depth that it encounters.

The major disadvantage of hand-pumping operations is that only a limited pneumatic head or suction lift can be easily developed. Generally, suction lift is limited to 4.5 m (15 ft), and the pneumatic head is limited to roughly 4.2 kg/sq cm (60 lbs/sq in.). While devices can be obtained that have pressure or vacuum capacities in excess of these levels, their throughput per stroke is low, requiring that considerably more effort and time be expended to collect the required sample volume. For example, one hand-powered vacuum pump develops 70 cm (27.5 in.) of mercury vacuum but has only a 15-cc-per-stroke throughput.

A second approach that can be used to collect samples is bailing, using devices such as Kemmerer or Coliwassa samplers. One of the principal advantages of bailing is that there is no lift limitation. Through the use of extended lengths of cable or cord and winches or block and tackle, provisions can be made which will allow for the acquisition of samples from deep wells without too much effort. Shallow wells can also be readily accommodated by using a shorter cord length.

Bailing does have disadvantages, however. Foremost among these is the significant amount of repetitive work required to prebail and then collect groundwater from a well. Not only is this effort tedious, but also it can be physically exhausting.

depending on the weight of the sampler, cord, and sample and the availability of winches or block and tackle devices.

A second disadvantage of the bailing approach is that extra precautions must be taken to restrict the possibility of contamination. Not only is it essential that the bailer be thoroughly cleaned between well sites, but also it is imperative that provisions be made to protect the quality of the sample during its use at each well. The bailer should not be allowed to touch the surface of the ground during either the initial evacuation of a well or the collection cycles. If it does, it should be recleaned prior to reinsertion into the well.

Another problem that can arise during the use of a bailing method is that it is frequently difficult to completely evacuate a high-yielding well of standing water before it is replenished with fresh groundwater. This limitation may be offset through the use of ancillary equipment to prepare or prebail the well.

VACUUM EXTRACTION PROCEDURES

This sample collection alternative employs equipment that draws a vacuum within some collection device or tube, thereby causing the water to flow upward because of external pressure difference. Although some hand-held or hand-powered devices employ this technology, the emphasis of this discussion is placed on those devices which are driven by electric or gasoline motors or engines. As such, the equipment available for this approach is somewhat larger, heavier, and has a larger pumping capacity than does the manual equipment of the same nature.

In operation, devices such as peristaltic pumps or diaphragm pumps are used to evacuate some type of collection vessel. A suction tube of appropriate composition (non-reactive and non-contaminating) is lowered into the groundwater well, with the inlet point being positioned at or near the bottom. The vacuum source is then started, evacuating the sample line causing the water to be drawn to the surface. In cases where vacuum pumps are used, the water is drawn into a vessel where it is retained until

it is transferred into an appropriate sample container. Alternatively, as is the case with a peristaltic pump, the water sample is drawn from the well through inert tubing, passed through the pump head, and then discharged under pressure to an appropriate collection device.

In theory, vacuum-type collection systems have several advantages, the principal one being that relatively inexpensive and compact devices exist that can rapidly complete the job of water collection. Another advantage of the vacuum-type approach is that, as necessary, provision can be made to flood the well casing with an inert atmosphere (such as nitrogen) without affecting one's ability to obtain a sample. This capability is particularly important in the situation of a low-yielding well, where the captured water cannot be turned over three to five times prior to sample withdrawal. In these cases, it probably is necessary to collect the sample from the available water that has stood within the well for periods of up to one month.

Since it is possible that standing water within a well is representative of existing groundwater chemistry because of oxidation which may have occurred, blanketing of the water with nitrogen may limit such a process, making the available groundwater more representative of what actually exists.

The principal disadvantage of a vacuum-system approach is that there is a limit of between 7.6 and 9.1 m (25-30 ft) on the length (above the groundwater surface) of the suction line. For depths in excess of this level, multiple-staged vacuum systems would have to be used to collect groundwater. Multiple-stage systems are not considered to be appropriate because they require the use of duplicate equipment and extensive site preparation.

A second disadvantage of the vacuum-type approach is that the fate of volatile species contained within the groundwater is unclear. Presumably, the process of pulling a vacuum on the water should cause a disturbance in the established equilibrium, driving some amount of volatile species (e.g., CO_2) out of the water and thus effecting chemical changes in the sample.

PNEUMATIC OR PRESSURIZED COLLECTION PROCEDURES

A third broad class of sampling alternatives that can be applied to groundwater sampling involves the use of pneumatic pressure to drive the desired water volume to the surface. This approach has two optional procedures, one involving the direct contact of the pneumatic fluid and the water and the other involving a pumping device. As has been discussed earlier, it is possible to use manually powered equipment to generate the pneumatic pressure, but these devices generally have limited utility because the pressures obtainable are limited to approximately 4.2 kg/sq cm (60 lbs/sq in.). However, when electric- or gasoline-powered engines or bottled gas are used to supply the pressure, it is quite easy to produce pressures of up to 7.0 to 17.6 kg/sq cm (100-250 lbs/sq in.). These pressure levels are adequate to permit the collection of groundwater from wells up to approximately 100 m (320 ft).

The simplest pneumatic system to visualize requires only that the well be capped and have two tubes feeding down into it. The first of these tubes is connected to the pressure source and is truncated immediately below the sealing cap. The second tube extends below the trapped groundwaters' surface and is used to conduct the sample to the surface. Ideally, as the well is pressurized, the groundwater would be forced upward only through the collection tube and into a collection receptacle. However, as the well itself is not completely leak-tight, groundwater is forced out through the screen and well bottom at varying rates depending on aquifer permeability. Not only may this restrict the amount of sample that can be conveniently collected with one pressurization step, but also it allows for the contamination of the surrounding groundwater with water that may have become stagnant within the well. Furthermore, if excessive pressure is pumped into the well casing and allowed to escape through the screen or the well's bottom, pockets of gas may become trapped within the aquifer which could alter aquifer yield characteristics or possibly even the groundwater chemistry.

Another disadvantage of having the pneumatic fluid come in contact with the isolated groundwater contained within the well is that such contact can cause changes within the dissolved oxygen content of the well water if air (which is the most common pneumatic fluid) is used.

Therefore, it is apparent that other arrangements of pneumatic equipment, in which the contact between the pneumatic fluid and the groundwater is minimized, are preferable. Such systems are commercially available in the form of piston and bladder pumps. The basic concept employed in either of these designs calls for the separation of the pneumatic flood chamber from the groundwater collection chamber. As the pneumatic chamber is pressurized, either the bladder expands or the piston is driven upward forcing trapped groundwater to move upward past a check valve and into a transfer tube. When the pressure is released, the bladder deflates or the piston moves downward, causing the collection chamber to refill. Groundwater contained within the transfer tube is prohibited from flowing back into the collection chamber because the check valve is closed.

As has been mentioned, the major advantage of this approach is that comparatively deep wells [100 m (328 ft)] can be sampled without much difficulty. The major disadvantage of this technique, however, is that the equipment used to complete the sampling is more expensive than alternative devices. Typically, piston or bladder pump systems cost between $400 and $1500, with compressors that develop 7.0 kg/sq cm (100 lbs/sq in.) costing up to an additional $300-$500. Although bottled gases can be used in place of the compressor, they have only a limited volume and must be replaced frequently.

MECHANICAL COLLECTION PROCEDURES

Another approach that can be used to obtain groundwater samples from a monitoring well includes the utilization of mechanical pumps that are located at the surface of or beneath the surface of the isolated water. Of all the approaches

discussed to this point, this alternative appears to be the one that has the greatest flexibility with respect to speed of sample acquisition and preservation of sample integrity, but it also represents the one that is most difficult to implement under field conditions.

In operation, the pumping device is lowered down into the well and connected to the surface by means of an electrical cord and a sample recovery tube. When in place, the pump is switched on, drawing groundwater through the pump head and forcing it upward to the surface, where it may be collected within an appropriate receptacle. Since the pump (the body containing the motor and the head) may become partially wetted or immersed within the well water, the selected pump should be of an appropriate submersible or immersible design. Several such models are commercially available.

The major disadvantage of this sampling approach arises because most submersible pumps are 101 mm (4 in.) or larger in size. Since it is presumed at this time that most of the groundwater wells drilled will not be any larger than 50 mm (2 in.) or so in diameter, the use of this approach is precluded unless a smaller mechanical pump can be found.

GAS ENTRAINMENT METHODS

Gas entrainment or air-lifting is a fifth approach that can be used to collect groundwater samples from monitoring wells. Requiring similar equipment to that which is used in pneumatic systems, this technique represents little more than an alternative equipment configuration that can be used to force groundwater to a well's surface.

In operation, an air-lift system is comprised of two tubes and a source of pressurized air or other gaseous media. One of the tubes is used to conduct the pressurized gaseous media from grade level down to a point below the groundwater level. Upon release from the transport tube, the pressurized gas rises into the second tube, which is also positioned below the groundwater

level. The mixing of the gaseous media with the groundwater causes a decrease in the unit weight of the trapped water allowing it to flow upward through the second tube. Because a void now exists within the second tube, groundwater flows into this tube and in turn is mixed with gas causing it to rise. By regulating the flow of compressed gas, it becomes possible to drive the groundwater all the way to the well's surface where it can be collected.

The application of gas entrainment techniques to groundwater sampling exercises has several disadvantages. One obvious disadvantage is that large volumes of compressed gases are usually required to drive the groundwater to the well's surface. This implies that either high-capacity compressors or numerous gas cylinders may be required to complete individual sampling operations. As such, field transport of the necessary equipment becomes more troublesome, and may prove to be impossible in any situation where a monitoring well is remotely situated.

Another disadvantage of the gas entrainment technique, however, lies in the fact that the chemical, physical, or biological integrity of the sample is very likely to be lost. Several avenues of sample degradation exist. First, because of the unit density reduction, volatile species (such as dissolved oxygen) and carbon dioxide trapped within the groundwater may be liberated, thereby changing the chemistry of the sample, and may produce, in some cases, precipitation of trace elements. Alternatively, contaminants present within the lift gas may replace volatile species contained within the well water, thereby altering the chemistry of the sample.

EXHIBIT A.7-1
PROCEDURE FOR MEASUREMENT OF GROUNDWATER LEVEL

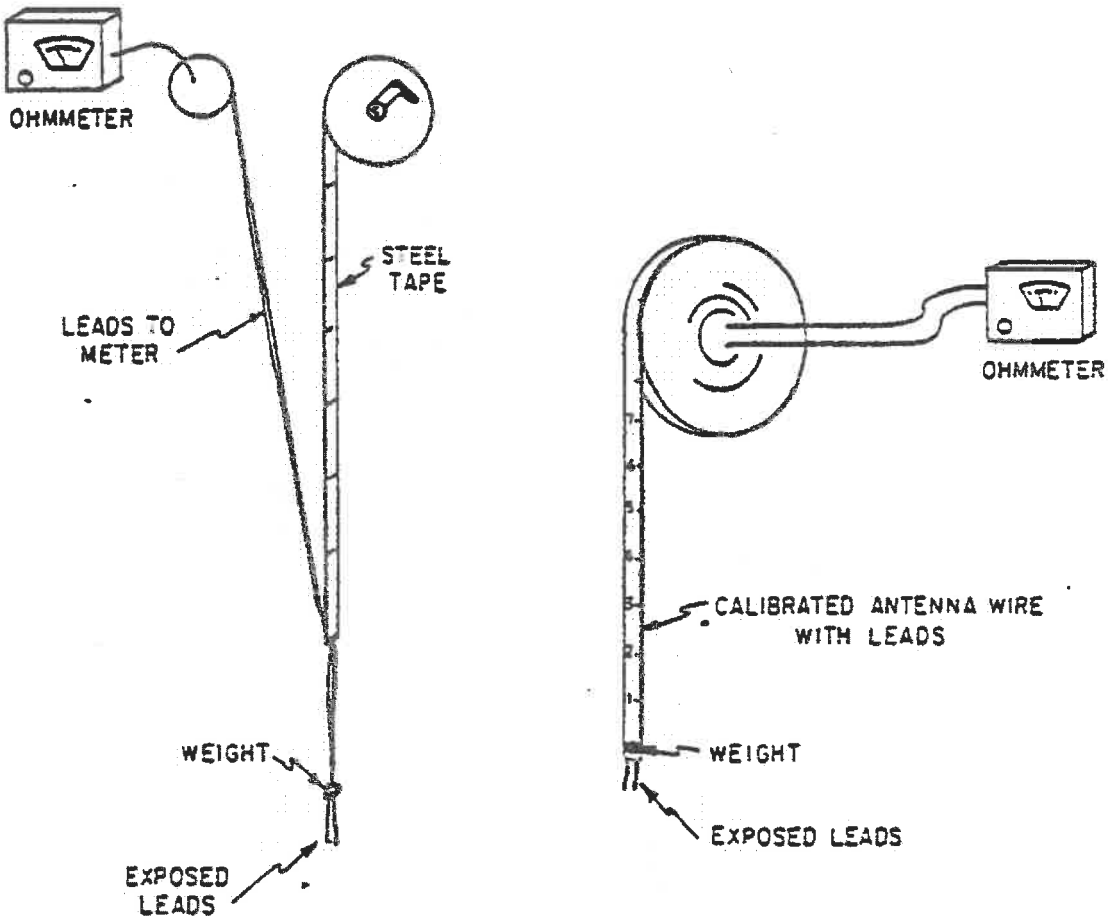
The following steps describe the procedure for measuring groundwater level with devices such as those shown in Figure 1.

1. Remove the locking protective cover at the well to be monitored.
2. Attach the cable to the ohmmeter and turn on the unit. An open circuit (zero reading) should be observed. The exposed ends of the cable should be wiped dry before insertion into the well riser pipe.
3. Insert the cable until the ohmmeter registers a closed circuit. Several readings should be obtained for consistency and repeatability.
4. Mark the cable at the point which coincides with an established survey elevation mark on the protective casing. It is often desirable to check each reading to be sure that the circuit is closed by true water surface rather than water on the side of the wire or pipe. A sharp tug should shake water off the cable.
5. If permanent pressure gauges are installed on the user pipe (artesian wells), bleed off any air bubbles within the system through the needle valve and record the stabilized pressure gauges reading in psi.

The following items should be recorded on the appropriate data sheets (metric and English units):

Identification: Plant name, state, piezometer number, location tip, elevation.

Observations: Date and exact time, elevation of top of riser pipe, water level (elevation), gauge pressure (if applicable), temperature (from SCT meter), weather, any unusual activities in progress in area of well.



Source: Arthur D. Little, Inc.

FIGURE 1 GROUNDWATER LEVEL MEASUREMENT DEVICES

EXHIBIT A.8-1
CLEANING OF EQUIPMENT

The following procedure is recommended for cleaning sampling and analysis equipment*:

1. Wash with hot detergent.
2. Rinse at least three times with tap water.
3. Rinse all sample containers and analytical glassware with 1:1 HNO_3:H_2O.
4. Rinse at least three times with tap water.
5. Rinse at least three times with distilled water.
6.** Rinse one time with high-purity water (MilliQ^R).
7. Dry in air.

* Quantities are not specified but sufficient volume should be used to thoroughly soak and/or rinse both internal and external surfaces.

** For those containers to be used to obtain samples for organic analysis, a final rinse using acetone will be made.

EXHIBIT A.11-1
CHAIN-OF-CUSTODY PROCEDURES

To implement the chain-of-custody procedures in the field, the following steps must be taken:

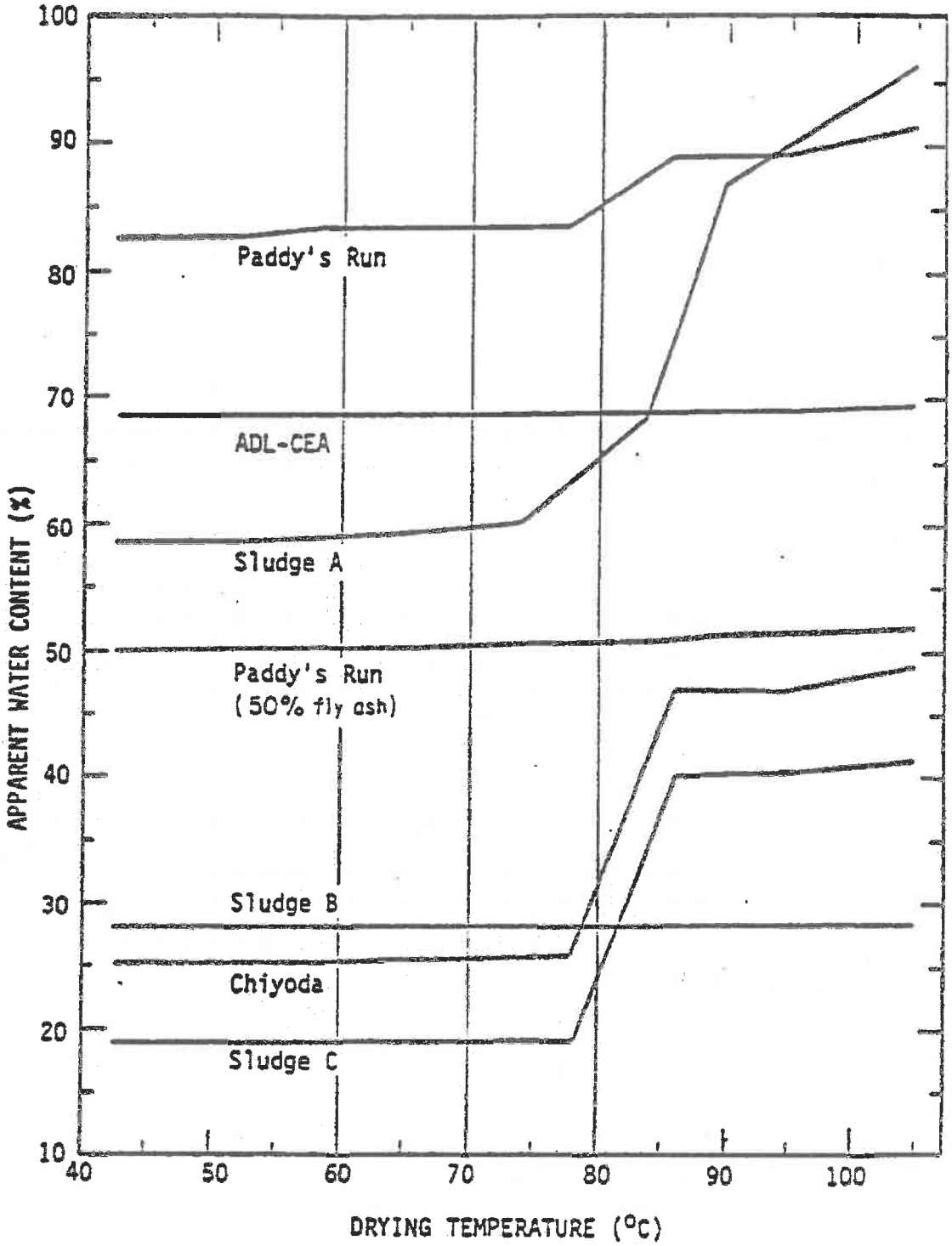
1. At the time of sample collection, all sample labels must be filled out completely and clearly. In addition to filling out all appropriate sample identifiers, each label must be signed or initialed by the collector.
2. When a sample is collected, an entry of that fact should be made within the field observation notebook. This page and all others should be signed and dated.
3. The cap of any sampling container should be sealed with tape. Any attempt to open the container subsequent to the application of sealing tape should irreparably damage the tape.*
4. Entries into the packing log book should be clear and concise. At the completion of the packing exercise, the shipping list should be signed and dated. The tear-out page should be removed and attached to the shipping container to serve as the packing list.
5. When full, the shipping container should be sealed with tape. Any attempt to open the package should cause irreparable damage to the tape.
6. Upon shipment, a copy of the bill of lading should be obtained from the carrier. This bill should be signed by a representative of the carrier and be dated. This bill of lading should be retained by the sampling crew chief until such time as he can personally turn it over to the sample custodian in the laboratory.
7. Upon receipt of the samples in the lab, the custodian should receive a second copy of the bill of lading. As before, this should be signed and dated.
8. The custodian should inspect the shipping container to see if any obvious signs of tampering have occurred. If signs are noted, this should be entered in the

laboratory log book.

9. The package may then be opened and each sample container then inspected individually. If tampering is noted, an indication of this should be entered in the notebook.
10. Using the packing list provided, the custodian should log in all samples. This should be cross-checked by actual bottle inspection.
11. The custodian then attaches and signs a chain-of-custody tag to each sample container. The containers are then secured in a lock-safe location.
12. As the samples are distributed, each person handling the samples should sign and date the chain-of-custody tag. The date tag should list all days that the sample was under their control. As additional tags are needed, they should be added. Old tags should be returned to the custodian for his records.
13. When all analyses are complete the final disposition of any remaining sample (i.e., disposal or archival storage) should be entered into the laboratory log book.

- Any wells installed under this program will be locked and sealed with tape as described. Existing utility wells which may also be sampled in this program will also be sealed; however, the utility will maintain access to these wells.

EXHIBIT B.2-1
EFFECT OF DRYING TEMPERATURE ON WATER-CONTENT DETERMINATION OF FGC WASTES



Source: Reference 5.5.

FIGURE 1 EFFECT OF DRYING TEMPERATURE ON WATER-CONTENT DETERMINATION OF FGC WASTES

EXHIBIT B.3-1

PROCEDURE FOR PRESSING LIQUOR FROM FGC AND SOIL SAMPLES

Figure 1 shows a schematic of the pressing apparatus. The following is a procedure for using this apparatus to obtain water samples for analysis from wet solid (FGC or soil) materials.

1. Tighten the steel jacket onto the base plate with the wingnuts. Place the stainless steel (325-mesh) screen into the jacket and hold it flat with a rod while filling the container with sample. Guidance as to the volume (or weight) of sample to be used is given in Table 1. A layer of 1 in. in the apparatus roughly corresponds to 200 mL volume of solid.
2. Place the plunger inside the jacket and push until it is firmly held by the sides. Place the apparatus into the hydraulic press. Place a thick plate on top of the plunger to avoid deformation by the ram of the press. Place a graduate of appropriate size at the liquid outlet.
3. Apply 20 tons of pressure on the plunger for an appropriate period of time, either until a required volume of liquid is obtained or until it is determined that this method will not wash. The pressure may need readjustment from time to time. The liquid is then filtered through 0.45 um filter and preserved as needed for subsequent analysis.

In special cases where exposure to air may cause major chemical changes, the whole apparatus may have to be maintained under a nitrogen atmosphere. In this case, it may be necessary to load the apparatus in a nitrogen bag and to protect it and the liquor squeezed out from oxygen during this squeezing process.

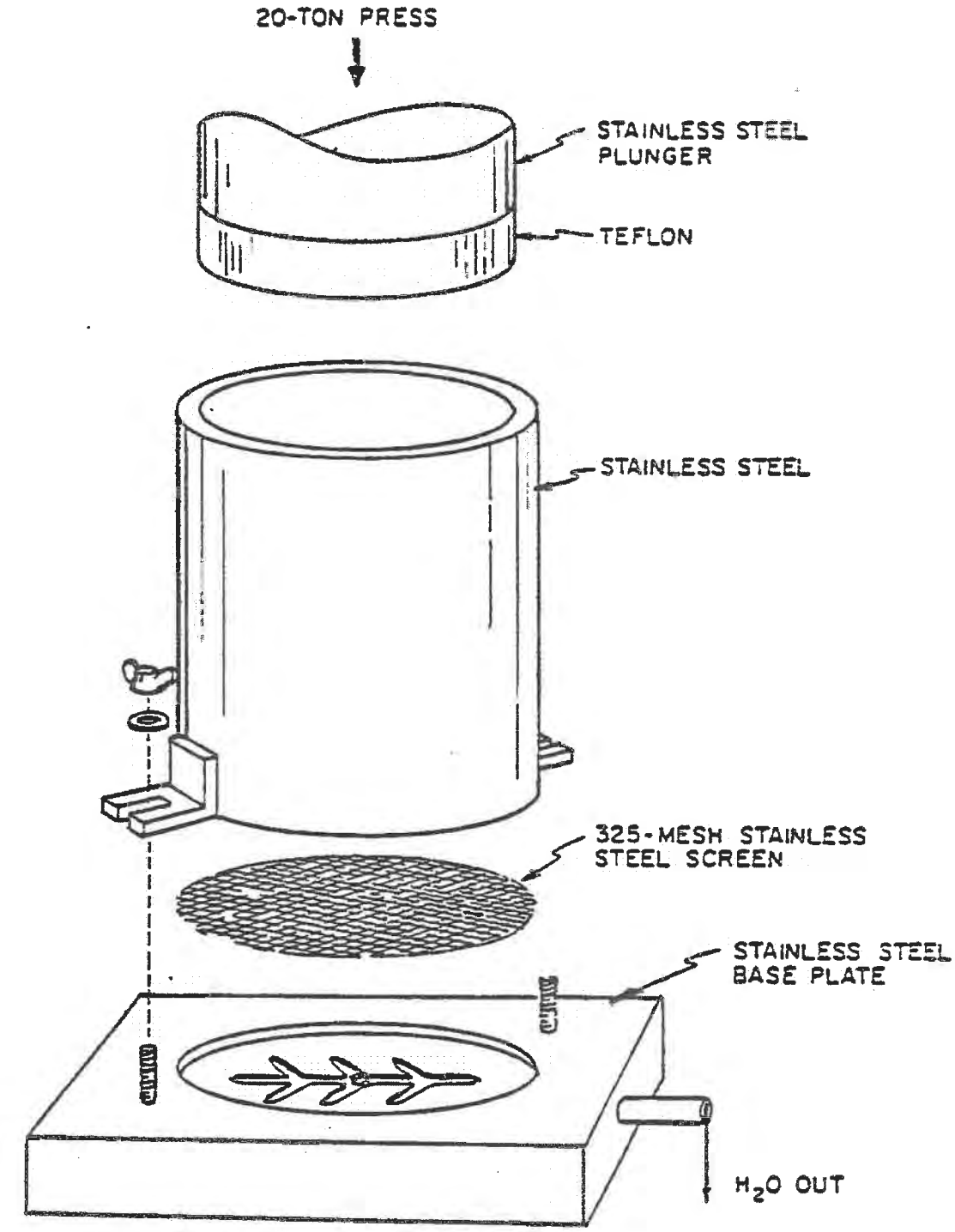
TABLE 1

EXAMPLE DATA FOR SQUEEZING VARIOUS SAMPLES

Sample	Weight (g)	Initial % Moisture	Final % Moisture	Volume H_2O Obtained (mL)	Time Squeezed [1] (hrs)
Soil	196	~26	~15	27	2
Soil	590	~26	~15	85	2
Forced Oxidation FGD Waste	303	~20	~19	7	2
Forced Oxidation FGD Waste	303	~20	~19	10	18
Dual Alkali Waste	236	~42	~24	58	2
Dual Alkali Waste	236	~42	~23	60	6
Fly Ash	133	~30	~23	9	2

1. Initial load of 20 tons.

Source: Arthur D. Little, Inc.



Source: Arthur D. Little, Inc.

FIGURE 1 SCHEMATIC OF PRESSING APPARATUS

EXHIBIT B.4-1
DIGESTION AND FUSION PROCEDURES

SUMMARY OF DIGESTION PROCEDURES FOR LIQUID SAMPLES

1. For analysis of liquid samples by ICAP, no predigestion is needed.
2. For analysis of liquids for mercury by cold vapor, a HNO_3/H_2SO_4 reflux followed by dichromate addition is needed.
3. For analysis of liquids for arsenic and selenium by hydride evolution and all other metals by graphite furnace AA, the following procedure is given. Transfer 100 mL of sample into a 250-mL Griffin beaker and add 3 mL of concentrated redistilled HNO_3 and 5 mL of 30% H_2O_2. Heat for one hour at 95°C or until volume is slightly less than 50 mL. Cool and bring to 50-mL volume with de-ionized water (Ref. 5.9).
4. For analysis of liquid samples for metals using flame AA, the following procedure is given. Transfer an appropriate volume of well-mixed sample into a Griffin beaker and add 3 mL of concentrated redistilled HNO_3. Place beaker on a hot plate and evaporate to dryness, making certain the sample does not boil. Cool and add another 3 mL of concentrated redistilled HNO_3. Reflux and keep adding acid until digestion is complete (indicated by a light-colored residue). Add sufficient dilute HCl (1 volume concentrated HCl to 1 volume de-ionized water); warm to dissolve residue. Transfer to a volumetric container and dilute to the appropriate volume with water. Let any insoluble residue settle (SiO_2) and aspirate the supernate into the atomizer.

SUMMARY OF DIGESTION PROCEDURES FOR SOLIDS

1. Reverse HF, Total Acid Attack (for high organic soil and FGC samples, ICAP analysis).*

   a) Add a 500-mg sample to a 60-mL. Teflon beaker.
   b) Add 4 mL of concentrated $HClO_4$ and 16 mL concentrated HNO_3.
   c) Heat in a sand bath to reflux.
   d) If pale yellow (indicates little organic remains) carry to $HClO_4$** fumes. If brown, repeat adding concentrated HNO_3 until pale yellow, then carry to $HClO_4$ fumes.
   e) Add 1 mL of HNO_3 and 15 mL of concentrated HF.**
   f) Heat to dryness in a sand bath at 100°C.
   g) Add 2 mL concentrated HCl.
   h) Add contents to a 50-mL volumetric, make up with 0.5 M HCl; warm to dissolve insoluble material.

2. Normal HF Digestion (for low-organic FGC waste and soil samples)*

   a) Add a 500-mg sample to a 60-mL Teflon beaker.
   b) Add 15 mL concentrated HF,** 4 mL $HClO_4$,** 1-2 mL HNO_3.
   c) Heat in a sand bath at 100°C.
   d) Carry to the digestion dryness.
   e) Add 2 mL concentrated HCl and make to volume (50 mL) with 0.5 N HCl. Heat to dissolve insoluble residue.

* This digestion procedure will be performed by Barringer Magenta Ltd., Toronto, Canada. One half or more of this digest will be sent to the laboratory sending the sample (Arthur D. Little, Inc. or TRW) for QC or other required AA analyses.

** Extreme caution must be exercised when working with perchloric and hydrofluoric acids because $HClO_4$ can form explosive by-products when contacted with certain organics and HF can cause extensive skin, tissue and bone damage if contacted with the skin.

3. Digestion for Hg Analysis (by cold vapor)* (See Figure 1 for apparatus).

a) Place sample (5 g or less) into 250-mL round-bottom flask and wash down with distilled water.

b) Add 10 mL of nitric acid and attach condenser with Raschig rings; turn on cold water to condenser.

c) Add 20 mL of H_2SO_4 slowly through the top of the condenser; wash down with 10% HNO_3. Maintain temperature of 120°C with heating mantel until all frothing due to reaction with organic materials has subsided.

d) Cool, and add 10 mL perchloric acid and 10 mL of nitric acid. Remove water from condenser jacket. Increase temperature to 160°C and then raise in slow increments until H_2SO_4 fumes appear.

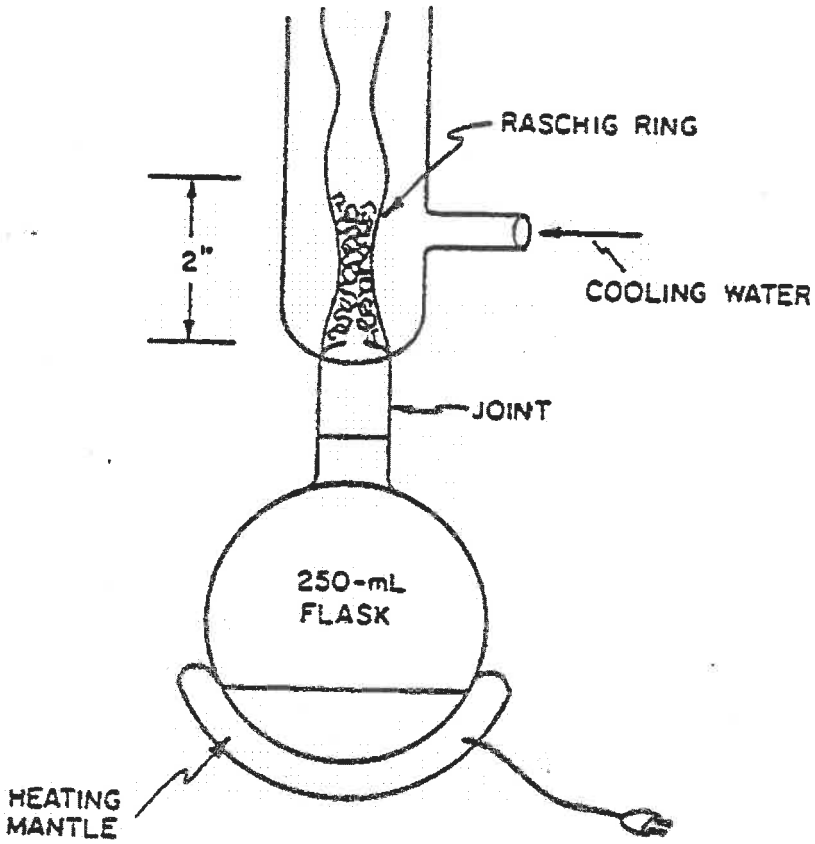
e) Cool, and wash down condenser with water (not HNO_3). After condenser is cooled by water, wash with 10% HNO_3.

f) Carefully smell the solution. If a strong Cl_2 smell is present, continue digestion until all Cl_2 has been expelled.

g) Add a small amount of HF to dissolve silica film inside flask; warm 1 hour to dissolve.

h) Add sufficient dichromate to make solution 0.01% in $Cr_2O^{=}_7$ when diluted to final volume.

* M.S. Epstein, et al., "Analysis of Mercury in Standard Reference Materials by Cold-Vapor Atomic Absorption," FACSS Second National Meeting Indianapolis, Indiana, Oct. 6-10, 1975.



Source: Arthur D. Little, Inc.

FIGURE 1 MERCURY DIGESTION APPARATUS

4. Digestion of Solids for As and Se Determination by Hydride Evolution

This procedure is similar to the one used for Hg (part 3) except for the following modifications:

a) Use HCl instead of HNO_3 throughout.

b) Add 5 mL H_2SO_4, 5 mL $HClO_4$, and 5 mL HCl in the first step (to 0.5-g sample).

c) Use only air condenser, no water.

d) Take mixture to fumes of H_2SO_4.

e) Wash condenser with 20% HCl.

f) The final solution should be 20% in HCl and 5% in H_2SO_4 and minimum of HF to dissolve silica. Heat in Teflon beaker.

g) Add nitric acid as needed as part of analysis procedure.

5. Fusion with Na_2CO_3, $Ca(OH)_2$ (for B or Si analysis)

(a) Weigh an approximately 0.1-g sample into a platinum crucible. Fuse with 1 g of Na_2CO_3. Then add sufficient 1 N HCl to dissolve the melt and dilute to 100 mL.

(b) Alternatively, fuse 1 g with 0.1 g of $Ca(OH)_2$ at 500°C for 1 hour. Dissolve in 1 N HCl.*

*Higgins D.J., J. Sci. Food. Agr. 2 (1951) 498.

EXHIBIT C.2-1
DESCRIPTION FOR CONSOLIDATED-UNDRAINED TRIAXIAL COMPRESSION TEST WITH PORE PRESSURE MEASUREMENTS*

Procedures for the consolidated-undrained triaxial compression test with pore pressure measurements will be divided into sample preparation, chamber preparation, line saturation, consolidation, shearing, and end-of-test phases. A complete test will include a minimum of three samples consolidated to the desired pressure and loaded to failure. Results of the tests will be plotted on stress-path tangency curves. If necessary, additional points will be added to prepare a straight line failure plot of the waste material.

Sample preparation involves extruding the sample from the Shelby tube, trimming the sample, and placing the membranes over the heads and the sample. A sample will be extruded from the Shelby tube and trimmed to a height of approximately 15 cm (5.9 in.). After weighing, the sample will be placed on the bottom head of the trimmed chamber pedestal, the top head will be set on the sample, and a membrane will be placed over the entire arrangement. Two rubber "O"-rings each will be placed around the membranes at the top head and at the bottom head.

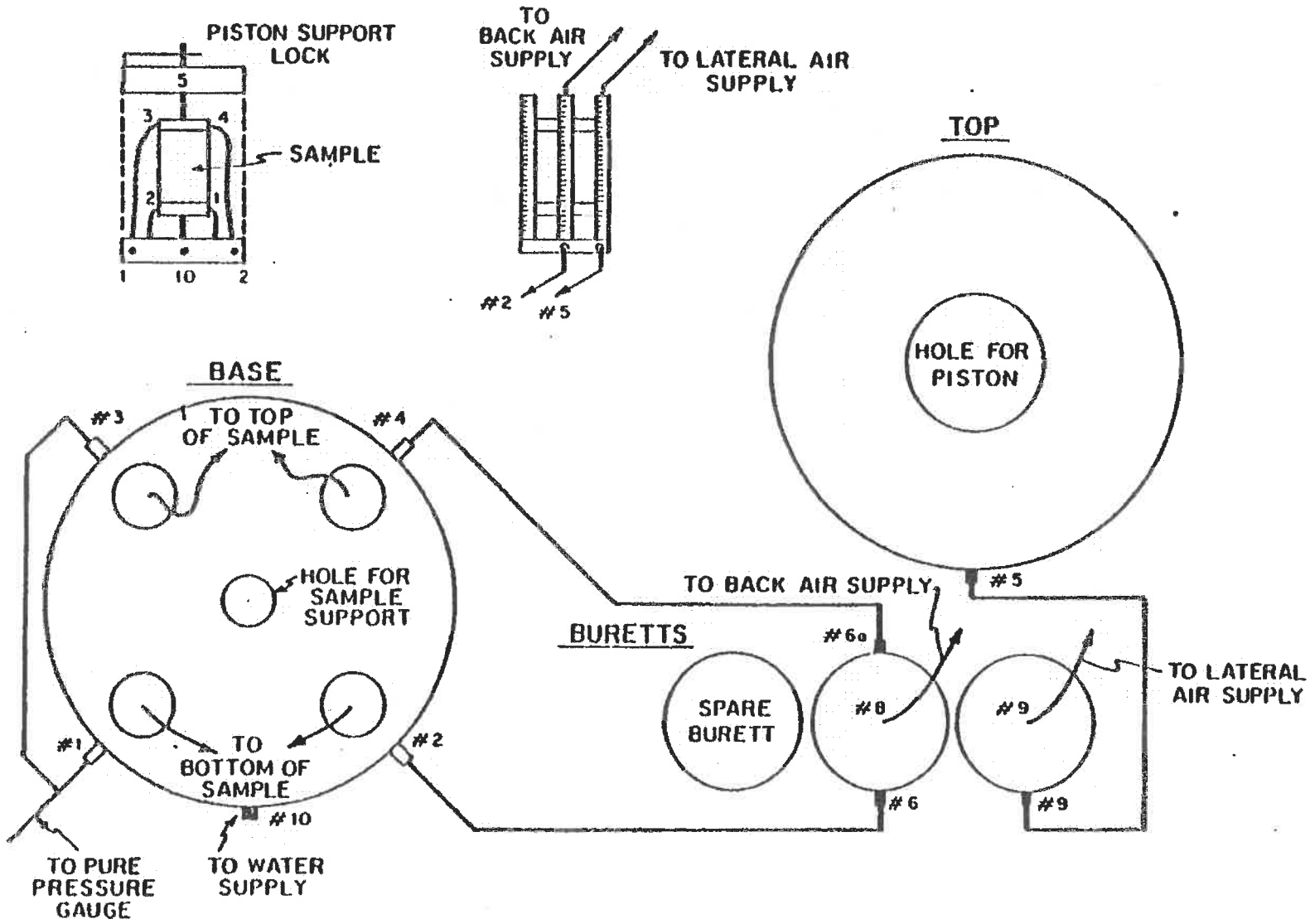
Once the membranes are attached, the remaining chamber apparatus will be assembled as shown on Figure 1. The chamber will then be filled with water and all the air will be flushed and replaced with water.

Samples will be consolidated in the chamber by applying a specified chamber pressure and recording the volume change of the sample through the line connected to the bottom head. Volume change-time data will be taken to determine when primary consolidation is completed and also to calculate compression data for the sample. A Casagrande construction on a volume change-log time scale will be applied to calculate when loading of the sample can begin.

Sample saturation will be determined by increasing the cell pressure by 10 psi and measuring the instantaneous pore pressure

reading. If the pore pressure is also 10 psi, the sample is fully saturated. If not, an equal back pressure will be applied before further consolidation can occur. This sequence of steps will be repeated until all air is forced into saturation.

Once the sample has been properly consolidated and saturated, shearing will begin in strain-controlled compression machines. Shearing will proceed at a constant rate of deformation and readings of load, pore pressure, and deformation will be recorded. Because of the permeability of the wastes to be tested, a deformation rate of 0.01 in./min will be used to allow proper equalization of pore pressure.



Source: Bowser Morner Testing Laboratories, Inc.

FIGURE 1 CHAI APPARATUS ASSEMBLY

C-E.27

EXHIBIT C.2-2
DESCRIPTION FOR EXTENDED PERMEABILITY ANALYSES

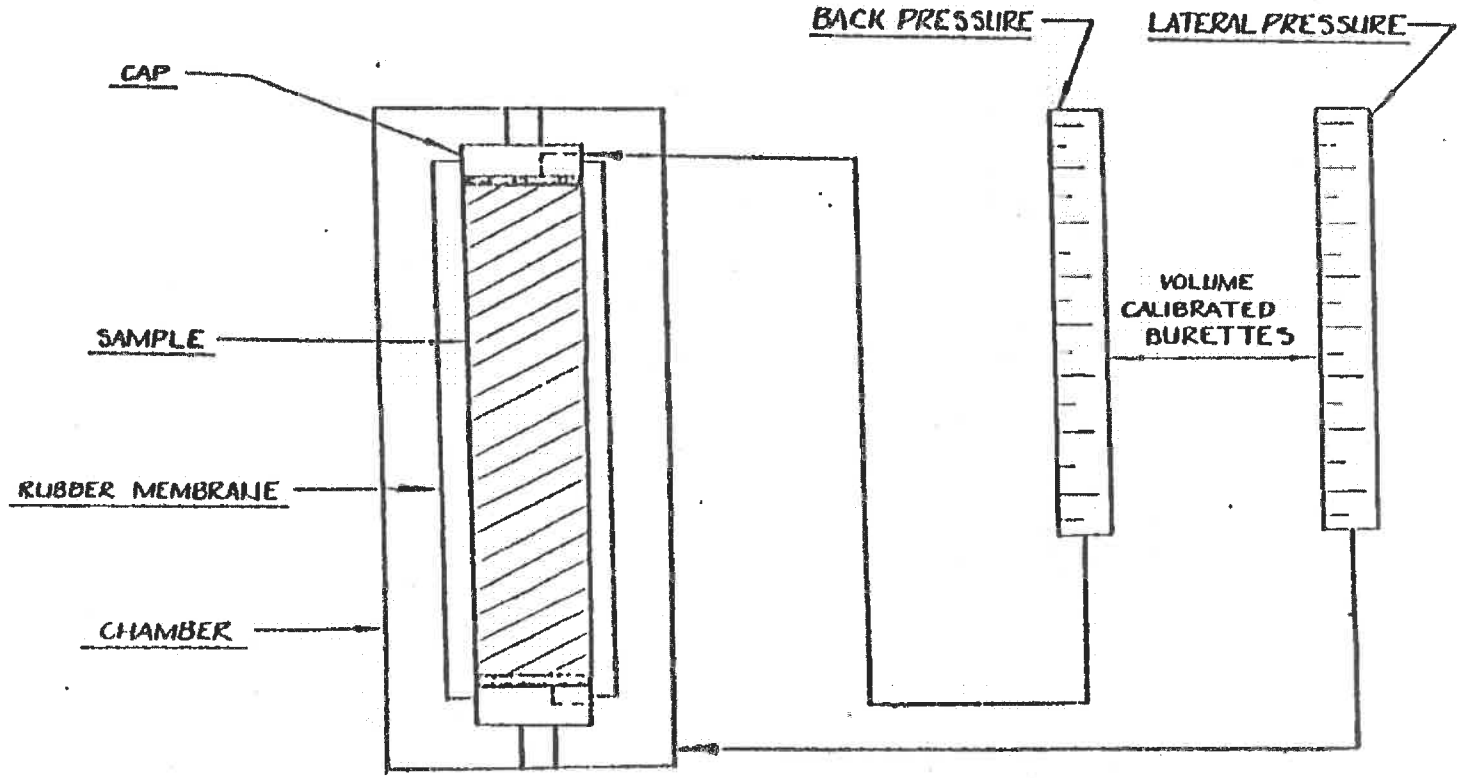
Permeability analyses will be performed in accordance with ASTM procedures and guidelines presented in "Soil Testing for Engineers" by T.W. Lambe* as previously documented. Triaxial chambers will be adapted for the permeability and extended permeability testing. Undisturbed samples recovered from the site development will be prepared and installed in the chambers as shown in Figure 1. Back pressure saturation will then be performed as described in the procedure outlined in Exhibit C.2-1 for "Consolidated-Undrained Triaxial Compression Tests with Pore Pressure Measurements."* Once this procedure has been accomplished, water will be allowed to pass from a pressurized high through the sample out to atmospheric pressure. The back pressure will remain constant as water passes through the sample and the water intake will be monitored using a calibrated burette. During the permeability tests, lateral pressures will exceed back pressure by no more than 2.5 psi to avoid any excess consolidation. Several pressures will be utilized over several days to ensure consistent determinations of the coefficient of permeability.

An extended permeability analysis will be made using the same basic procedure. However, in extended permeability tests the previously described permeability tests will be performed and then incremental increases in lateral pressure will be applied to consolidate the sample to higher densities. The change in volume will be monitored by observation of the water level in a calibrated burette to determine when primary consolidation has finished. The initial dry density and moisture content can be calculated as described by Lambe. Further dry density calculations can be made as follows.

$$\text{Final dry density} = \frac{(\text{initial volume})\,(\text{initial dry density})}{(\text{initial volume} - \text{change in volume})}$$

The coefficient of permeability during each stage of the permeability test is calculated based on Darcy's law as follows:

$$k = \frac{QLC}{thD^2}$$



Source: Arthur D. Little, Inc.

FIGURE 1 SCHEMATIC DRAWING OF SATURATION PHASE

where

Q = quantity of water flow in cc;

L = height of samples in in.;

t = time in sec;

h = back pressure in psi;

D = diameter of samples in in.;

C = conversion factor, 7.13×10^{-3}; and

k = permeability in cm/sec.

A plot of dry density versus coefficient of permeability (semi-log) can then be developed for one sample.

* Soil Testing for Engineers. T.W. Lambe, John Wiley & Sons, Inc., New York, 1951, pp. 52-62.

EXHIBIT D.3-1
ATOMIC ABSORPTION SPECTROPHOTOMETRIC DETERMINATION OF ARSENIC BY HYDRIDE GENERATION

SUMMARY OF METHOD

An aqueous solution of sodium iodide is added to an aliquot of the acidified sample to reduce As(V) to As(III). AS(III) is converted to arsine, AsH_3, by addition of an aqueous solution of sodium borohydride. The AsH_3 thus formed is immediately transferred by argon carrier gas flowing through the reaction vessel into the atomizer of an atomic absorption spectrophotometer. The AsH_3 is burned in an argon-hydrogen flame, and the absorption signal at 193.7 nm is recorded.

APPARATUS

Perkin-Elmer Model 303 Atomic Absorption Spectrophotometer, equipped with 3-slot 10-cm burner or equivalent

Perkin-Elmer Arsenic Electrodeless Discharge Lamp or equivalent

Strip-chart recorder

Hydride generation apparatus:

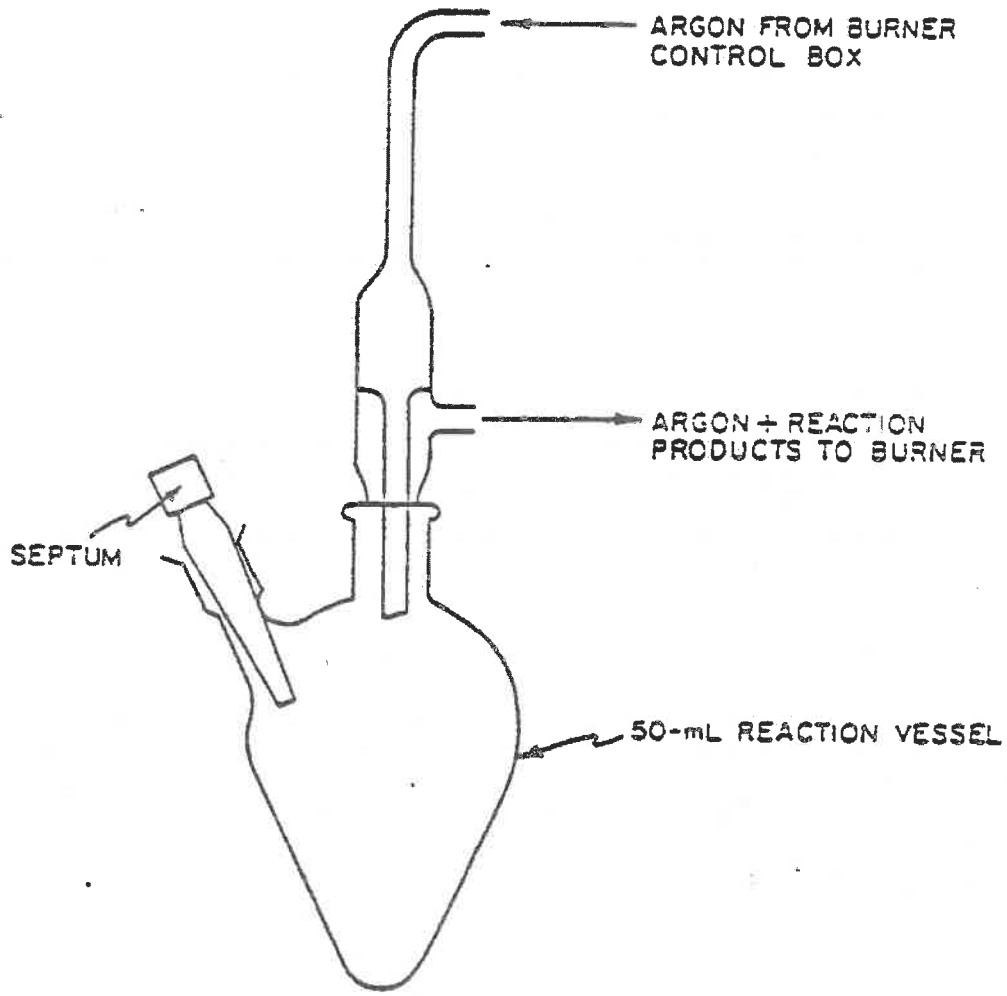
Gas inlet-outlet tube; Ace Glass 9513-04 gas burning apparatus, inner portion only with glass frit removed, 14/20

Reaction flask; Ace Glass 9481-08 pear-shaped microflask

Syringe; Becton-Dickinson 3-cc PLASTIPAK disposable syringe needles (SGA Scientific S-9950), 22-gauge.

PIPETMAN 2-200 microliter adjustable autopipet; Rainin Instrument Company, P200D.

The hydride generation apparatus and transfer system are shown in Figure 1. The reaction flask is supported by a ringstand. Tygon tubing is used for all connections. Hydrogen is introduced through the fuel ("acetylene") port, argon through the oxidant ("air atom") port, and AsH_3 through the auxiliary oxidant



Source: Arthur D. Little, Inc.

FIGURE 1 HYDRIDE GENERATION APPARATUS AND TRANSFER SYSTEM

("air aux") port on the burner head. Argon flow rates of 18.5 L/min to the atomizer and 5 L/min through the reaction vessel are obtained by appropriate adjustments of the aspirator and the auxiliary oxidant flow control valve on the burner control box.

REAGENTS AND GASES

Hydrochloric acid, concentrated, reagent grade.

Sodium hydroxide, electrolytic pellets.

Sodium borohydride solution. Dissolve 4 g $NaBH_4$ (Alfa Products 14122 10/32" pellets) in 100 mL of a 10% (w/v) NaOH solution.

Sodium iodide solution. Dissolve 10 g NaI (reagent grade) in 100 mL distilled water.

Arsenic stock solution. Prepare a 1-ppm arsenic stock solution by serial dilution of 1000-ppm reference standard (Fisher-Certified Arsenic 1000-ppm Atomic Absorption Standard).

Argon gas, commercial grade (99.9%).

Hydrogen gas, commercial grade (99.95%).

PROCEDURE

Pipet 10 mL of sample into a reaction flask. Add 10 mL concentrated HCl. Add 0.5 mL NaI pre-reductant and allow a minimum of one minute for the reaction to occur. Prepare standards, including a reagent blank, from the 1-ppm arsenic stock solution by appropriate microliter additions to 10 mL of distilled water in the reaction flasks and treat similarly.

Attach the reaction flask to the transfer system. Allow at least 10 seconds for the argon to flush out the system and then inject rapidly, but with uniform pressure, 2.5 mL sodium borohydride solution into the reaction vessel using a syringe and 22-gauge needles. Record the absorption signal. Repeat for each standard and sample. Determine concentrations from peak heights.

APPLICATION

This method may be used to analyze solutions containing as little as 0.5 ug/L As (amount of element which produces 1% absorption).

Representative calibration data are shown in Table 1. The relative standard deviations of measured absorbance range from 0.9 to 4.1% over the 0.05 ug As range. Typical absorption signals for samples containing 0.3 ug As in 4 M HCl are shown in Figure 2.

INTERFERENCES

No significant effect on the arsenic absorbance is observed in the presence of 1000-fold excesses of Mn, Pb, Cu, Fe, Sb, and Se in 4 M HCl.

The sensitivity obtained by analyzing standards containing 3 mL HCl and 1.5 mL HNO_3 (0.83 abs/ug As) was found to be only slightly less than the sensitivity in 4 M HCl (0.89 abs/ug As over the same range).

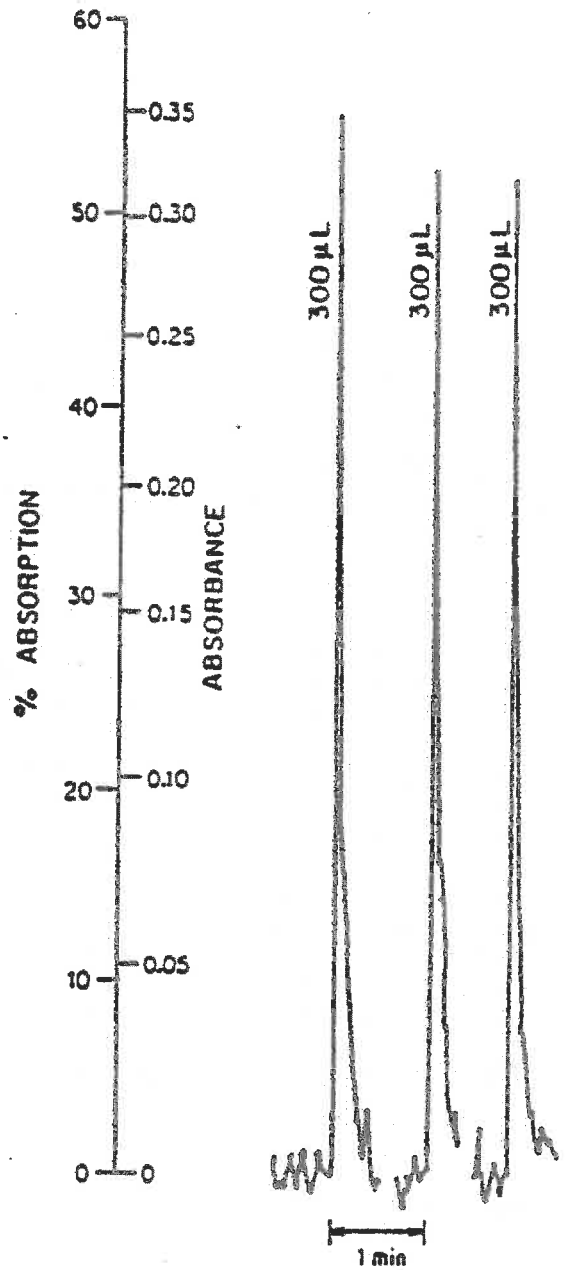
TABLE 1

CALIBRATION DATA FOR ARSENIC IN 4M HCl[1,2]

Arsenic Added (µg)	Absorbance	Mean	Standard Deviation	Relative Standard Deviation (%)
Blank	.087, .097, .096	.093	.006	–
.05	.135, .140, .135	.137	.003	2.2
.10	.200, .184, .195	.193	.008	4.1
.15	.230, .226, .228	.228	.002	0.9
.20	.265, .277, .275	.272	.006	2.2
.25	.318, .321, .333	.324	.008	2.5
.30	.345, .348, .353	.349	.004	1.1

1. All samples contain 10 mL H_2O, 5 mL conc. HCl.
2. 0.5 mL 10% NaI added to all samples; 1 minute allowed for reaction before addition of $NaBH_4$.

Source: Arthur D. Little, Inc.



Source: Arthur D. Little, Inc.

FIGURE 2 TYPICAL ABSORPTION SIGNALS FOR SAMPLES CONTAINING 0.30 µg ARSENIC IN 4 M HCl

EXHIBIT D.3-2
ATOMIC ABSORPTION SPECTROPHOTOMETRIC DETERMINATION OF SELENIUM BY HYDRIDE GENERATION

SUMMARY OF METHOD

Se(IV) is converted to selenium hydride, SeH_2, by addition of an aqueous solution of sodium borohydride. The SeH_2 thus formed is immediately transferred by argon carrier gas flowing through the reaction vessel into the atomizer of an atomic absorption spectrophotometer. The SeH_2 is burned in an argon-hydrogen flame and the absorption signal at 196.1 nm is recorded.

APPARATUS

Perkin-Elmer Model 303 Atomic Absorption Spectrophotometer, equipped with 3-slot 10-cm burner (or equivalent)

Perkin-Elmer Arsenic Electrodeless Discharge Lamp (or equivalent)

Strip-chart recorder

Hydride generation apparatus:

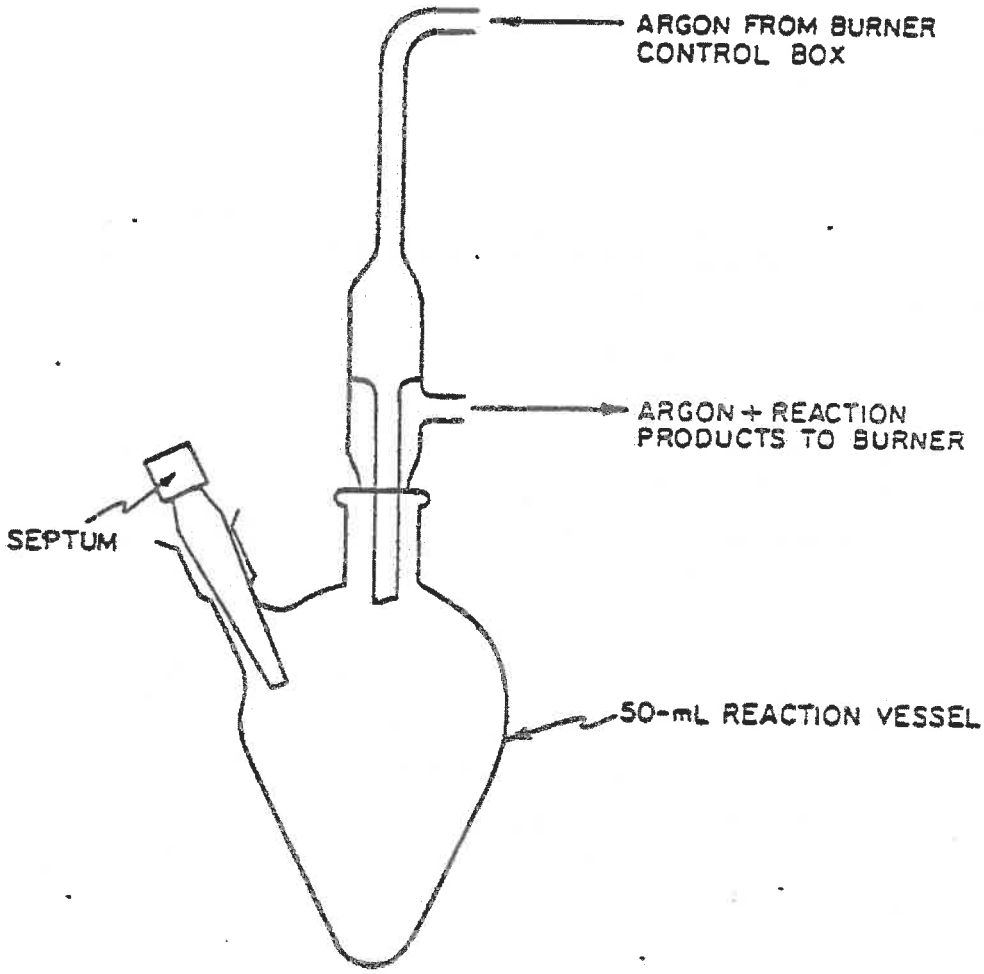
Gas inlet-outlet tube; Ace Glass 9513-04 gas burning apparatus, inner portion only with glass frit removed, 14/20

Reaction flask; Ace Glass 9481-08 pear-shaped microflask

Syringe; Becton-Dickinson 3-cc PLASTIPAK disposable syringe needles (SGA Scientific S-9950), 22-gauge (or equivalent).

PIPETMAN 2-200 microliter adjustable autopipet; Rainin Instrument Company, P200D.

The hydride generation apparatus and transfer system are shown in Figure 1. The reaction flask is supported by a ringstand. Tygon tubing is used for all connections. Hydrogen is introduced through the fuel ("acetylene") port, argon through the oxidant ("air atom") port, and AsH_3 through the auxiliary oxidant ("air aux") port on the burner head. Argon flow rates of 18.5 L/min to the atomizer and 5 L/min through the reaction vessel are



Source: Arthur D. Little, Inc.

FIGURE 1 HYDRIDE GENERATION APPARATUS AND TRANSFER SYSTEM

obtained by appropriate adjustments of the aspirator and the auxiliary oxidant flow control valve on the burner control box.

REAGENTS AND GASES

Hydrochloric acid, concentrated, reagent grade.

Sodium hydroxide, electrolytic pellets.

Sodium borohydride solution. Dissolve 4 g $NaBH_4$ (Alfa Products 14122 10/32" pellets) in 100 mL of a 10% (w/v) NaOH solution.

Selenium stock solution. Prepare a 1-ppm selenium stock solution by serial dilution of 1000-ppm reference standard (Fisher-Certified Arsenic 1000-ppm Atomic Absorption Standard).

Argon gas, commercial grade (99.9%).

Hydrogen gas, commercial grade (99.95%).

PROCEDURE

Pipet 10 mL of sample into a reaction flask. Add 10 mL concentrate HCl. Prepare standards, including a reagent blank, from the 1-ppm selenium stock solution by appropriate microliter additions to 10 mL of distilled water in the reaction flasks and treat similarly.

Attach the reaction flask to the transfer system. Allow at least 10 seconds for the argon to flush out the system and then inject rapidly, but with uniform pressure, 2.5 mL sodium borohydride solution into the reaction vessel using a syringe and 22-gauge needles. Record the absorption signal. Repeat for each standard and sample. Determine concentrations from peak heights.

APPLICATION

This method may be used to analyze solutions containing as little as 0.5 ug/L Se (amount of element which produces 1% absorption).

Representative calibration data are shown in Table 1. The

TABLE 1

CALIBRATION DATA FOR SELENIUM[1]

Selenium Added (µg)	Absorbance	Mean	Standard Deviation	Relative Standard Deviation (%)
Blank	.025, .021, .021	.022	.002	–
.05	.066, .061, .067	.065	.003	4.6
.10	.109, .115, .115	.113	.003	2.7
.15	.151, .151, .149	.150	.001	0.7
.20	.203, .198, .196	.199	.004	2.0
.25	.239, .243, .234	.239	.005	2.1

1. All samples contain 10 mL conc. HCl and 10 mL of water.

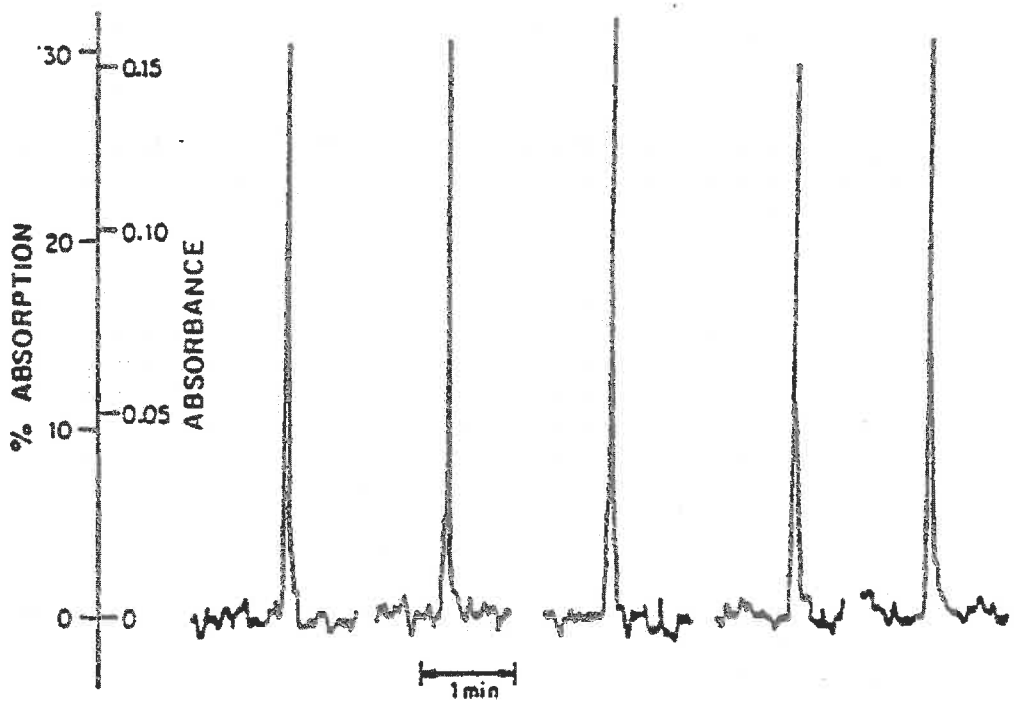
Source: Arthur D. Little, Inc.

relative standard deviations of measured absorbance range from 0.7 to 4.6 over the 0.05 to 0.25 ug Se range. Typical absorption signals for samples containing 0.15 ug Se in 6 M HCl are shown in Figure 2.

INTERFERENCES

No significant effect on the selenium absorbance is observed in the presence of 1000-fold excesses of Mn, Pb, Cu, Fe, Sb, and As in 6 M HCl.

The sensitivity obtained by analyzing standards containing 1.0 mL HCl and 6.5 mL HNO_3 (1.13 abs/ug Se) was found to be only slightly different from the sensitivity in 6 M HCl (1.01 abs/ug Se over the same range). However, the sensitivity obtained by analyzing standards containing no HCl and 7.5 mL HNO_3 (0.36 abs/ug Se) was much less than the sensitivity in 6 M HCl.



Soures: Arthur D. Little, Inc.

FIGURE 2 TYPICAL ABSORPTION SIGNALS FOR SAMPLES CONTAINING 0.15 μg SELENIUM IN 1:1 HCl

EXHIBIT D.3-3
COMPARISON OF HYDRIDE EVOLUTION AND GRAPHITE FURNACE METHODS FOR ARSENIC, SELENIUM, ANTIMONY, AND MERCURY

Table 1 summarizes the analysis conditions and precision and accuracy of the various hydride and graphite furnace methods. This summary is included to illustrate the capabilities of these methods and to cover the range of variable operating parameters which will be studied during the method qualification period to determine the applicability of these methods for the various types of samples in this study.

TABLE 1

DATA FOR ATOMIC ABSORPTION MEASUREMENT OF ARSENIC, SELENIUM, ANTIMONY, AND MERCURY

Analyte	Method	Arthur D. Little, Inc., Method[1]	EPA Method[2]
Arsenic (As)	Hydride Generation	Matrix 4M HCl Detection Limit 0.5 µg As/L Precision 0.7 to 4.1% r.s.d. on triplicate samples over 5-30 µg/L range	H_2SO_4/HCl/HNO_3 2 µg As/L 5.5-9% r.s.d. on 10 replicates over 5-20 µg/L range
		EPA Method[2]	**I.L. Manual Method[3,4]**
	Graphite Furnace (all candidate methods use Ni matrix modifications)		
	Furnace Conditions: Dry	125°C/30 sec.	ramp to 100°C/50 sec.
	Furnace Conditions: Ash	1,100°C/30 sec	ramp to 1000°C/4 sec
	Furnace Conditions: Atomize	2,700°C/10 sec	2,000°C/10 sec.
	Added Ni Concentrations	1.0%	0.05%
	Reported Range	5-100 µg/L	1-24 µg/L
	Detection Limit	1 µg/L	0.25 µg/L
	Injection Volume	20 µL	25 µL
	Precision	5.4-8.8% r.s.d. over 15-40 µg/L range in waste 1.6 3.5% r.s.d. over 20-100 µg/L range in tap water	

TABLE 1 (Continued)

Analyte	Method	Arthur D. Little, Inc., Method[1]	EPA Method[2]
Selenium (Se)	Hydride Generation	Matrix 6M HCl Detection Limit 0.5 µg Se/L Precision 0.7-4.6% r.s.d. in the 5-25 µg/L range	$HCl/H_2SO_4/HNO_3$ 2 µg Se/L 12-20% r.s.d. on 10 replicates in the 5-18 µg/L range
		EPA Method[6]	I.L. Manual Method[3,7]
	Graphite Furnace (all candidate methods use Ni matrix modifications)		
	Furnace Conditions: Dry	125°C/30 sec	ramp to 100°C/45 sec
	Furnace Conditions: Ash	1,100°C/30 sec	ramp to 900°C/40 sec
	Furnace Conditions: Atomize	2,700°C/10 sec	2250°C/5 sec.
	Ni concentration	0.1%	.001% Ni
	Reported Range	5-100 µg/L	2-40 µg/L
	Detection Limit	2 g/L	0.4 µg/L
	Precision	4.1-14.2 r.s.d. over 5-100 µg/L range in water	
		EPA Method[6]	I.L. Manual Method[3]
Antimony (Sb)	Graphite Furnace		
	Furnace Conditions: Dry	125°C/30 sec	ramp to 100°C/450 sec
	Furnace Conditions: Ash	800°C/30 sec.	ramp to 400°C/30 sec
	Furnace Conditions: Atomize	2,700°C/10 sec	2,250°C/15 sec.
	Reported Range	20-300 µg/L	6-320 µg/L
	Detection Limit	3 µg/L	3.2 µg/L

EXHIBIT D.4-1

PROCEDURE FOR OBTAINING ION CHROMATOGRAMS USING THE DIONEX MODEL 14 SYSTEM EQUIPPED WITH A WISP AUTO INJECTOR

This procedure is written for the Dionex Model 14 ion chromatograph using system #2, equipped with a 150-mm anion precolumn, a 500-mm anion separator column, an anion suppressor column, and a 0.003 M $NaHCO_3$/0.0024 M Na_2CO_3 aqueous eluent.

The suppressor column needs to be regenerated after approximately every 20 hours of operation. If the suppressor column has not been regenerated (check with last operator), perform the regeneration steps; if system has been regenerated skip to step 9.

ANALYSIS AND REGENERATION

1. Fill the bubble trap tube attached to pump #3 with de-ionized water.
2. Set control valves in the front panel of the instrument for system #2 all in the down position except the suppressor switch (last one). The flow sheet should show water flowing only through the suppressor and into the detector.
3. Start pump #2 and adjust flow rate to 90% on the micrometer adjustment located at the right side of the pump. (System pressure should not exceed 600 psi.)
4. Let water run through the suppressor for 10 minutes. (Note the conductivity meter decreasing to that of water [1-10-uMhos] on the log scale.)
5. Stop pump #2.
6. Flip suppressor switch to bypass/Rgn (down position).
7. Make sure water container and 1 N H_2SO_4 containers have solutions in them (if less than 1/4 full, refill).
8. Push regeneration start (green button). (Make sure regeneration timer is set for 15 min and rinse timer is set for 30 min.) Once started, this operation is

automatically performed and stops after 45 minutes when completed.

9. Empty water from bubble trap (see step 1), and replace it with the eluent (Na_2HCO_3/Na_2CO_3 solution).
10. Set pump flow at recommended flow rate for analysis (approx. 25% of full scale or about 2.0 mL/min) (DO NOT switch pump on at this time.)
11. Verify that there is sufficient eluent in the container (in this case 0.003 M $NaHCO_3$/0.0024 M Na_2CO_3 in water) to be able to operate for the entire analysis time at 2.0 mL/min (the container holds 4 L of solution). Air bubbles caught in the line during this operation should be released by inverting the container or by flushing the line with columns and detector bypassed.
12. Flip valves marked E_2, separator, and suppressor on system #2 to the up position (columns engaged) and detector on system #2.
13. Switch pump #2 on. System pressure should pulsate between 400-600 psi (700 psi should not be exceeded).
14. Set conductivity meter sensitivity to 30 uMhos full scale.
15. Set conductivity meter mode to log. Needle will read about 1/2 scale then drop down to 1-10 uMhos with time. This may occur more than once.
16. When meter settles to 1-10 uMhos on log scale, switch to linear scale and adjust to about 2 uMhos (on 30 uMhos scale) using coarse or fine offset. Very little offset should be required. Switch pump #2 off.
17. If using a 2-recorder system (2 sensitivities simultaneously), set recorder #1 to 100 mV full scale.
18. Set recorder #2 to 1000 mV full scale. (for 1 or 2 recorder systems).
19. Set scales by switching conductivity meter to zero (on Dionex Model #14) and adjust pens of both recorders to read 20% of full scale.
20. Set specific conductivity switch on Dionex to CAL. Pen

on recorder #2 should settle on approximately 100% full scale. Full scale should be approximately 200 mm of paper divisions. (Using this procedure for example gives actual ranges recorded by recorder #1 as 3 uMhos full scale and recorder #2 as 30 uMhos full scale with the Dionex switch set on 30 uMhos full scale.)

21. Switch both recorders off and condition the system by running pump #2 on for 45 min. (While the system is conditioning, steps 22 and 23 may be performed.)
22. After 45 minutes, set specific conductivity to linear and set both recorders on. Bring response on-scale with offset switch and check for a flat baseline on recorder #1.
23. When baseline is achieved, set recorder #1 on approximately 30% full scale by the coarse/fine offset. (This serves to allow a downward drift in the baseline when temperature fluctuates.)
24. Push start on WISP (See WISP directions in the next section.) Let system run to completion.
25. Switch off recorders manually or automatically after all samples have been processed. Switch pump #2 off.
26. Start regeneration cycle as in step 1.
27. Remove charts and evaluate data.

DIRECTIONS FOR USE OF AUTOMATIC SAMPLE INJECTION APPARATUS (WISP SYSTEM) FOR ION CHROMATOGRAPHY (WISP)

With system power on and eluent running:

1. Place samples in vials and place vials in tray.
2. Place tray into the WISP and close door, the tray will automatically align to proper location.
3. Flip to auto.
4. Set sample no. to zero.
5. Set desired sample injection volume (usually 100 mL) by pressing sample volume button, then pressing 100, then pressing enter.

6. Choose run time (usually chromatogram length for anions is 30 min). Enter by pressing run time, then pressing 30, then pressing enter.
7. Choose number of replicates (1 generally, unless otherwise noted).
8. Check system messages to read:

System Message	Read
66	00
67	00
79	20 (2.0 mL/min purge)

(Example: press system message 66, then press 00, then enter.)

9. After pressing enter for system message 79, press enter once more, wait until system performs all of its automatic functions. System will be ready to start when it reads sample No. 1.
10. Press run when ready to run samples (when baseline has been achieved); system will then purge, and then display error 103. IGNORE the error. The first injection will occur after 10 minutes, and a delay between injections of about two minutes will occur.

ION CHROMATOGRAPHY SOLUTIONS

Standard Anion Solutions

One liter of each of the following solutions should be part of the laboratory supply for preparation of calibration curves and determination of retention times when trying to identify unknown species. A mixed ion standard solution is used to check column set resolution. (For the most accurate standards, oven-dry chemicals at 105°C for one half hour and cool prior to weighing.)

To obtain the following 1000-ppm solutions, dissolve reagent grade chemicals in de-ionized water.

F^-:	Dissolve 2.2100 g NaF/liter
Cl^-:	Dissolve 1.6484 g NaCl/liter
NO_2^-:	Dissolve 1.4998 g $NaNO_2$/liter
PO_4^{-3}:	Dissolve 3.7710 g Na_2HPO_4 . 12 H_2O/liter (undried)
Br^-:	Dissolve 1.2877 g NaBr/liter
NO_3^-:	Dissolve 1.3707 g $NaNO_3$/liter
SO_4^{-2}:	Dissolve 1.8142 g K_2SO_4/liter

To prepare a mixed dilute anion standard solution, add in a 1-liter volumetric flask and dilute to 1 liter with de-ionized water the following quantities of 1000-ppm standard solutions:

F^- solution:	3 mL = 3 ppm
Cl^- solution:	4 mL = 4 ppm
NO_2^- solution:	10 mL = 10 ppm
PO_4^{-3} solution:	50 mL = 50 ppm
Br^- solution:	10 mL = 10 ppm
NO_3^- solution:	30 mL = 30 ppm
SO_4^{-2} solution:	50 mL = 50 ppm

Various other standard mixes for different analyte concentrations may be made.

Regeneration Solution (1 N H_2SO_4)

To prepare a sulfuric acid solution for regeneration of the anion suppressor column, dilute 111 mL conc. H_2SO_4 in 4 L DI H_2O; or dilute 555 mL conc. H_2SO_4 in 20 L DI H_2O.

Standard Eluent for Anion Analysis (0.003 M $NaHCO_3$, 0.0024 M Na_2CO_3)

The standard eluent solution for anion analysis is prepared by dissolving 1.0080 g $NaHCO_3$ and 1.0176 g Na_2CO_3 in 4 L DI H_2O, (or 5.0400 g $NaHCO_3$ and 5.0880 g Na_2CO_3 in 20 L DI H_2O).

General eluents should be prepared from filtered DI or

distilled water and reagent-grade chemicals. They are normally prepared in 4-liter collapsible bottles which are placed in labeled cardboard boxes. After measuring 4.0 liters of water into a bottle, outline the top of the water line with a pen to reduce future preparation time. Also 5-gallon carboys (or 20 liters) of eluent may be prepared for long-term use. Equilibrium time for the eluents depends on temperature, the particular eluents being prepared and the columns. For all except very warm solutions, one half hour to one hour is sufficient.

EVALUATION OF IC DATA

1. Use form shown in Figure 1 to summarize the data. Plot peak height (or area) vs. concentration.
2. Data are reported for F^-, Cl^-, NO_3^-, $SO_4^=$ and any other identified peaks.

Sheet ____ of ____

Chart No. _____

Date __/__/__ Client _____ Case No. _____ Operator's Signature _____

Analysis: Anion ☐ Cation ☐ ICE ☐ Precolumn No. _____ Column No. _____ Column Type _____

Suppressor Column No. _____ Eluent _____ Flow Rate _____ ml./min. Pump % _____

No. of Inject. _____ Inject Vol. _____ µL Run Time _____ min. Chart Speed ____ cm/min Chart Sc. _____ µMho

Vial No.	Sample Code	SPECIES IDENTIFICATION R.T. ____ Peak Height ☐ Area ☐ Conc. ☐ µg/mL	R.T. ____ Peak Height ☐ Area ☐ Conc. ☐ µg/mL	R.T. ____ Peak Height ☐ Area ☐ Conc. ☐ µg/mL	R.T. ____ Peak Height ☐ Area ☐ Conc. ☐ µg/mL	R.T. ____ Peak Height ☐ Area ☐ Conc. ☐ µg/mL	R.T. ____ Peak Height ☐ Area ☐ Conc. ☐ µg/mL
1							
2							
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18							

*Below Base Line **Below Detection Limit

FIGURE 1 ION CHROMATOGRAM RECORD

C-21.54

EXHIBIT D.5-1
MEASUREMENT OF pH

Measurement of pH using this procedure may be made on liquid or slurry samples in the field and/or in the laboratory.

The pH can be measured with any glass reference (i.e., saturated calomel) electrode set provided that the following points are observed:

1. The glass electrode must be clean and free of cracks and other marks. A wide-range (0-14 pH) industrial-quality electrode is recommended. A new glass electrode should be soaked in water (of pH4 buffer solution) for one half hour before use.
2. The reference electrode must be filled with the appropriate electrolyte (generally 4 M KCl saturated with AG^{+}) for the calomel electrode. Electrical conductivity through the liquid junction must be confirmed (generally indicated by different response for different pH buffers). A sleeve-type junction is best for this purpose, although the electrolyte level must be checked frequently since the electrolyte leakage rate tends to be high with this junction.
3. The electrode pair or combination electrode must be set (i.e., standardized) using a standard buffer reasonably near the expected sample pH, and cross-checked against a buffer beyond the expected sample pH. This latter check is extremely important to prove the linearity of electrode response in the region of interest. Provided that fresh buffers are used, the indicated pH should be within 0.1 pH unit for the check (second) buffer. At least three buffers should be used. The manufacturer's instructions should be referred to for a detailed procedure.
4. Care should be taken in limiting exposure of the sample to the atmosphere (i.e., minimal agitation during analysis).

Additional information can be obtained in Reference 7.18.

EXHIBIT D.5-2
ANALYSIS OF TOTAL DISSOLVED SOLIDS (TDS)

SCOPE AND APPLICATION

The purpose of this analysis is to evaluate the amount of dissolved solids in various liquids. The samples will include liquid aliquots from ash slurries, FGC waste liquors, groundwater, and surface waters.

SUMMARY OF METHOD

An aliquot of filtered liquid is dried completely at 120°C and the residue weighed.

APPARATUS

- Clean 150-mL beakers
- Drying oven equipped with a thermostatic control capable of maintaining the temperature within a 2°C range
- Desiccator, provided with a desiccant containing a color indicator of moisture concentration
- Analytical balance, 200-g capacity, capable of weighing 0.1 mg
- 50-mL volumetric pipets

REAGENTS

None required

PROCEDURE

1. A clean 150-mL beaker is placed in the drying oven at 120°C overnight. After heating, it is placed in the desiccator, cooled, and then weighed.
2. The beaker is then replaced in the oven and heated for 1 hour at 120°C, desiccated, and weighed to constant

weight.

3. A 50-mL aliquot of the sample is pipetted into the tared beaker.
4. The beaker is placed in the oven overnight at 120°C.
5. The solids are desiccated and weighed according to desiccator procedures.

CALCULATION

$$\frac{(A-B) \times 10^{-6}}{C} = \text{mg/L TDS at } 110^{\circ}C$$

where A = weight of dried residue and beaker in grams;
B = weight of beaker in grams; and
C = mL filtrate used.

EXHIBIT D.5-3
PROCEDURES FOR ANALYSIS OF SULFITE AND TOTAL OXIDIZABLE SULFUR (TOS)

Three sulfite and/or TOS procedures are included in this section. (See Reference 7.19.) The first two are for high levels in solids and liquids and the third is for trace levels in liquids. High levels of sulfite are measured by reaction with iodine and back titration with thiosulfate. Trace levels may be measured using a modified West-Gaeke colorimetric procedure.

TOTAL OXIDIZABLE SULFUR (TOS) IN LIQUIDS (HIGH LEVELS)

1. Transfer 30 mL (measured to ±.02 mL) of 0.1 I_2 solution into a 125-mL Erlenmeyer flask and cover with a watchglass. Note: Experience may show that some samples may require more or less iodine.
2. Add approximately 20 mL of distilled water and 2 mL of glacial acetic acid. In lieu of acetic acid, 15 mL of 0.1 N HCl may be used.
3. Pipet 2 mL of sample (volumetric pipet) directly into the acidified iodine solution while swirling the solution to assure rapid mixing of the sample. If all iodine color is discharged, repeat the procedure using more I_2 solution and adjust calculations accordingly.
4. Back titrate with 0.1 N $Na_2S_2O_3$ to pale yellow color. Add starch solution to give blue color and continue dropwise addition of titrant to disappearance of blue color.
5. Calculations:

$$\text{TOS (moles/L)} = \frac{[(\text{mL } I_2)(\text{N } I_2)] - [(\text{mL } S_2O_3)(\text{N } S_2O_3)]}{(2)(2\text{mL})}$$

where

N I_2 is the normality of the I_2 solution;
N S_2O_3 is the normality of the $Na_2S_2O_3$; and
2 is the equivalence factor for moles of oxidizable sulfur.

TOTAL OXIDIZABLE SULFUR (TOS) IN SOLIDS

1. Weigh out from 0.11 to 0.12 g (weighed to i.e., ±0.0001 g) of solids on a weighing paper or boat.
2. Transfer 25 mL of 0.1 N I_2 solution into a 250-mL Erlenmeyer flask. Add approximately 75 mL of distilled water and 10 mL of 10% HCl.
3. Quick transfer the weighed solids to the iodine solution and cover the flask with a watchglass.
4. Stir the suspension until all of the solids have dissolved. A magnetic stirrer is useful for this operation. Break up any lumps with a glass rod. Note: In solids with a very high $CaSO_4$ content, not all of the solids will dissolve in the acid. In general, all solids should dissolve in 30 minutes.
5. As soon as all solids have dissolved, back titrate the excess I_2 with 0.1 N $Na_2S_2O_3$. When the solution has reached a pale yellow color, add starch solution to give a blue color. Continue the titration dropwise until the blue color is discharged.
6. Carry at least one reagent blank through the process, using the same length of stirring time as for the sample. This will help to ascertain whether air oxidation is causing an interference in the method. The blank titer (volume of $Na_2S_2O_3$ per volume of I_2 taken) should be within 0.005 of the standardization titer.

7. Calculations:

$$\text{TOS (millimoles/g)} = \frac{(\text{mL } I_2 \times \text{N } I_2) - (\text{mL } S_2O_3 \times \text{N } S_2O_3)}{(2)(\text{g sample})}$$

where

N I_2 and N S_2O_3 are the normalities of the I_2 and $Na_2S_2O_3$ solutions; and
2 is the equivalence factor for moles of oxidizable sulfur.

DETERMINATION OF LOW CONCENTRATIONS OF SULFITE IN WATER

Principle: Sulfite in an aqueous sample is determined by an extension of the method of West and Gaeke[8] in which sulfite is stabilized by reaction in tetrachloromercurate ion and measured by colorimetry using a formaldehyde/p-rosaniline color reagent.

Reagents: Na_2HgCl_4 solution, 0.04 M, prepared by dissolving 10.86 g $HgCl_2$ and 4.68 g NaCl in 1 L volume with H_2O
Para Rosaniline stock solution, 0.2% in 1 M HCl obtained from Eastman Chemicals
Phosphoric Acid, 85%
Phosphoric Acid, 3 M, prepared by diluting 205 mL of 85% into 1 L volume with H_2O
Formaldehyde, 36-38%
Formaldehyde Reagent, approximately 0.02 M, prepared by dissolving 1.25 g of Na_2SO_3 in 500 mL of deoxygenated water under a nitrogen atmosphere; standardize by back titration with iodine and thiosulfate. Store under nitrogen.
I_2 solution, 0.1 M
Dilute Na_2SO_3 standard solution, approximately 4×10^{-4} M; prepare by dilution of 2 mL of

approximately 0.02 M in 100-mL volume of deoxygenated water. Prepare immediately before use and maintain under a nitrogen atmosphere while sampling the solution.

Nitrogen, purified

Spectrophotometer equipped with two 1-cm cells

Procedure:

1. Pipet 200 mL of the Na_2HgCl_4 solution into a 50-mL volumetric flask which is covered with aluminum foil to protect it from light. Deoxygenate the solution by bubbling N_2 through it for 10 minutes.
2. Pipet 2 mL sample [concentration (1-4) x 10^{-4} M sulfite] into the solution inserting the tip of the pipet under the surface of the liquid. The sulfite is now stabilized, and these samples can be stored for several hours as long as they are protected from light. For higher concentrations of sulfite, stabilize 2 mL of sample and take an aliquot containing (2-8) x 10^{-4} moles of sulfite.
3. Prepare a set of standard stabilized solutions, covering the range of (4-20) x 10^{-6} M, using 0.5 to 2.0 mL of the dilute standard sulfite solution in place of the samples. Analyze these standards simultaneously with the samples.
4. Pipet 4 mL of 0.2% formaldehyde solution into all of the samples and standards.
5. Pipet 10 mL of the para-rosaniline reagent into all the flasks and start a laboratory timer that has been set for 30 minutes after addition to the first flask.
6. After addition of the reagents, bring all the flasks to volume (50 mL) with distilled water which has been deoxygenated by sparging with nitrogen for 10 minutes just prior to use.
7. After 30 minutes determine the absorbance of the samples, standards, and blank, at 548 nm versus

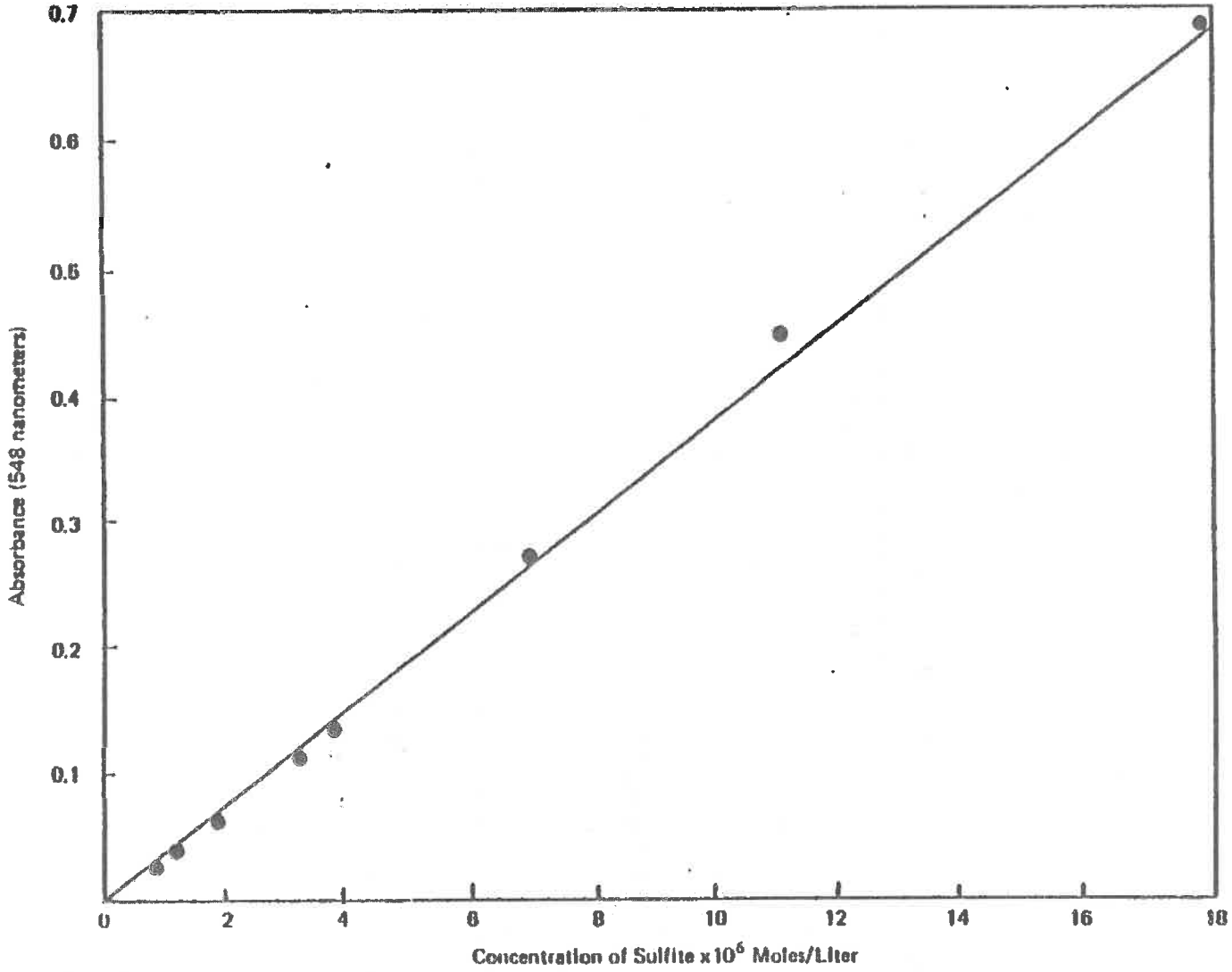
distilled water. If the absorbance of the blank exceeds 0.12, the measurements must be repeated with new reagents.

8. Prepare a calibration curve by plotting the corrected absorbance ($Abs_{sample} - Abs_{blank}$) vs. concentration of sulfite.

9. Determine the concentration of sulfite in the samples by comparing the corrected absorbance ($Abs_{sample} - Abs_{blank}$) of the samples with the standard curve.

An example of a typical calibration curve is given in Figure 1. The sulfite concentrations given are those present in the measured solution. If the absorbance of the sample is outside of the calibration range, an aliquot of the stabilized sulfite solution may be taken to bring the concentration to the measurable range.

*Anal. Chem. 28, 1816, 1956.



Source: Arthur D. Little, Inc.

FIGURE 1 EXAMPLE OF CALIBRATION CURVE FOR PARA ROSANILINE SULFITE REACTION PRODUCT

EXHIBIT D.5-4
MEASUREMENT OF ALKALINITY/ACIDITY/CARBONATE

The following procedures are given for determining the hydroxide carbonate, bicarbonate of various samples using several alkalinity measurements. These are:

- Phenolphthalein alkalinity;
- Total alkalinity by mixed bromocresol green-methyl red indicator method;
- Total alkalinity by methyl-orange indicator method;
- Potentiometric titration of low alkalinity;
- Thymolphthalein alkalinity in solids and liquids; and
- Thymolphthalein acidity in liquid samples.

Use sample volumes requiring less than 25 mL of titrant because they yield the sharpest color changes at the end point. If indicator methods are used, remove the free residual chlorine by adding 0.05 mL (1 drop) 0.1 N sodium thiosulfate solution or by ultraviolet irradiation.

PHENOLPHTHALEIN ALKALINITY

Add 0.1 mL (2 drops) phenolphthalein indicator to a sample of suitable size, 50 or 100 mL if possible, in an Erlenmeyer flask. Titrate over a white surface with 0.02 N standard acid to the coloration corresponding to the proper equivalence point of pH 8.3.

TOTAL ALKALINITY BY MIXED BROMOCRESOL GREEN-METHYL RED INDICATOR METHOD

Add 0.15 mL (3 drops) indicator to the solution in which the phenolphthalein alkalinity has been determined, or to a sample of suitable size, 50 or 100 mL if possible, in an Erlenmeyer flask. Titrate over a white surface with 0.02 N standard acid to the proper equivalence point. The indicator yields the following color responses: above pH 5.2, greenish blue; pH 5.0, light blue

with lavender gray; pH 4.8, light pink-gray with a bluish cast; pH 4.6, light pink.

TOTAL ALKALINITY BY METHYL ORANGE INDICATOR METHOD

Add 0.1 mL (2 drops) indicator to the solution in which the phenolphthalein alkalinity has been determined, or to a sample of suitable size, 50 or 100 mL if possible, in an Erlenmeyer flask. Titrate over a white surface with 0.02 N standard acid to the proper equivalence point. The indicator changes to orange at pH 4.6 and to pink at 4.0.

POTENTIOMETRIC TITRATION OF LOW ALKALINITY

For greatest accuracy, titrate low alkalinites (less than 10 mg/L) potentiometrically rather than by indicator methods. Potentiometric titration avoids the error due to the sliding end point caused by free CO_2 in the sample at completion of the titration.

With a microburette, titrate carefully a sample of suitable size, 100 to 200 mL, and record the volume C (in mL) of standard acid titrant (normality N) required to reach a pH of 4.5. Continue the titration to pH 4.2 and record the total volume D (in mL) of acid titrant. (Precise standardization of the pH meter is unnecessary.)

Calculations

1. Indicator Methods

$$\text{Phenolphthalein alkalinity as mg/l } CaCO_3 = \frac{A \times N \times 50{,}000}{\text{mL Sample}}$$

$$\text{Total alkalinity as mg/L } CaCO_3 = \frac{B \times N \times 50{,}000}{\text{mL Sample}}$$

2. Potentiometric Method for Low Alkalinity

$$\text{Total alkalinity as mg/L } CaCO_3 = \frac{(2C - D) \times N \times 50{,}000}{\text{mL Sample}}$$

where

A = mL titration for sample to reach the phenolphthalein end point;

B = total mL titration for sample to reach the second end point;

C = mL titration for sample to reach pH 4.5;

D = total mL titration for sample to reach pH 2.4; and

N = normality of acid.

Note: If total alkalinity is determined on the sample used for phenolphthalein alkalinity, be sure to include the volume of acid required for the phenolphthalein titration, A, in the total milliliters, B, of standard acid.

Calculation of Alkalinity Relationships

The results obtained from the phenolphthalein and total alkalinity determinations offer a means for the stoichiometric classification of the three principal forms of alkalinity present in many water supplies. The classification ascribes the entire alkalinity to bicarbonate, carbonate, and hydroxide, and assumes the absence of other (weak) acids of inorganic or organic composition, such as silicic, phosphoric, and boric acids. This classification system further presupposes the incompatibility of hydroxide and bicarbonate alkalinities in the same sample. Since the calculations are made on a stoichiometric basis, ion concentrations in the strictest sense are not represented in the results. According to this scheme:

1. Carbonate alkalinity is present when the phenolphthalein alkalinity is not zero but is less than the total alkalinity.
2. Hydroxide alkalinity is present if the phenolphthalein

alkalinity is more than half the total alkalinity.

3. Bicarbonate alkalinity is present if the phenolphthalein alkalinity is less than half of the total alkalinity.

The mathematical conversion of the results is shown in Table 1.

TABLE 1

ALKALINITY RELATIONSHIPS[1]

Result of Titration	Hydroxide Alkalinity as $CaCO_3$	Carbonate Alkalinity as $CaCO_3$	Bicarbonate Alkalinity as $CaCO_3$
P = 0	0	0	T
P < 1/2T	0	2P	T-2P
P = 1/2T	0	2P	0
P > 1/2T	2P-T	2(T-P)	0
P = T	T	0	0

1. P-phenolphthalein alkalinity; T = total alkalinity.

THYMOLPHTHALEIN ALKALINITY IN SOLIDS AND LIQUIDS

Hydroxide (Solids)

1. Weigh out from 0.50 mg to 0.55 g (weighed to ±0.0001 g) of sample and transfer to a 125-mL Erlenmeyer flask containing 40 mL of distilled water and magnetic stirring bar.
2. Add 2 to 3 drops of thymolphthalein indicator solution and 10 mL of 2.5% calcium chloride solution.
3. Titrate with 0.1 N HCl to the disappearance of the blue color. The indicator color may reappear on continued stirring. The titration should be continued until the end point holds for at least one minute. Note: If too much indicator has been added, the end point is seen as a marked decrease in the intensity of the blue color.
4. Calculations:

$$\text{Hydroxide (millimoles/gram)} = \frac{(\text{mL HCl})(\text{NHCl})}{\text{g sample}}$$

Hydroxide (Liquids)

1. Pipet a 10-mL aliquot of sample into a 125-mL Erlenmeyer flask. Add approximately 25 mL of distilled water, 10 mL of 2.5% calcium chloride solution, and 2 to 3 drops of thymolphthalein.
2. Titrate with 0.1 N HCl to the disappearance of the blue color. Note: If too much indicator has been added, the end point is seen as a marked decrease in the intensity of the blue color, rather than complete disappearance.
3. Calculations:

$$\text{Hydroxide (moles/L)} = \frac{(\text{mL HCl})(\text{NHCl})}{10}$$

THYMOLPHTHALEIN ACIDITY IN LIQUID SAMPLES

Acidity measurements may be made on ash liquors. Interpretation of the acidity must include data on any resultant precipitation of metals during the titration which consumes alkalinity. The following procedure is given for samples which contain negligible concentrations of metals which precipitate in the pH 4-10 region.

Acidity Liquids

1. Transfer 15 mL (±.01 mL) of 0.1 N NaOH solution into a 125-mL Erlenmeyer flask, and add 2 to 3 drops of thymolphthalein indicator solution.
2. Pipet a 10-mL aliquot of sample into the NaOH solution and mix well.
3. If solution remains blue, titrate with 0.1 N HCl to disappearance of blue. Note: If too much indicator has been added, the end point is seen as a marked decrease in intensity of the blue color when 1 to 2 drops of HCl are added.
4. If indicator color disappears during addition of sample and does not reappear upon mixing, repeat the determination using a larger aliquot of 0.1 N NaOH.
5. The exact N of the NaOH is determined by titrating a known volume (15 mL ±.01 mL) with 0.1 N HCl to the thymolphthalein endpoint. Then

$$N\,NaOH = \frac{mL\ HCl}{mL\ NaOH} \times (N \text{ of } HCl) \ .$$

6. Calculations:

$$\text{Acidity (moles/L)} = \frac{[(mL\ NaOH)(N\ NaOH)] - [(mL\ HCl)(N\ HCl)]}{10\ mL}$$

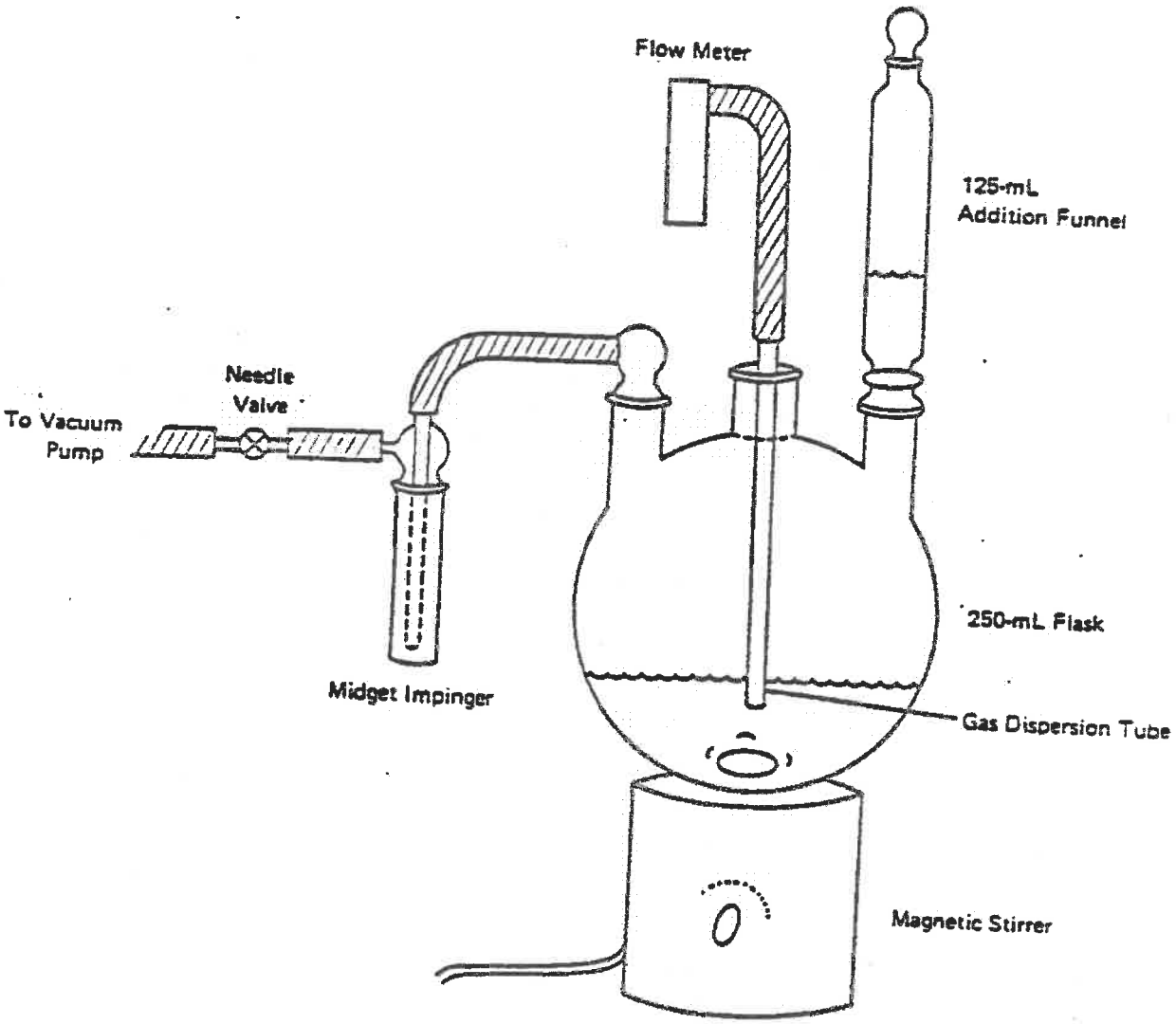
where N NaOH = the exact normality determined above.

EXHIBIT D.5-5

PROCEDURES FOR ANALYSIS OF CARBONATE (IN SOLIDS)

Because calcium is present in many FGC waste solids, the carbonate is separated and measured as CO_2 after first oxidizing all sulfite species to sulfate. Note: Once the determination is started, it must be carried through step 13 (acid to bromocresol green) in order to avoid error from absorption of atmospheric CO_2.

1. Set up the apparatus shown schematically in Figure 1. Three midget impingers or midget bubblers in series will give a 98% collection efficiency for CO_2.
2. Just prior to performing the analysis, place 50 mL of 0.1 N HCl and 3 mL of methyl red indicator solution into the addition funnel. Also transfer 15 mL of 0.5 N NaOH into each of the midget impingers.
3. Transfer between 1.0 and 1.1 g (weighed to ±0.0001 g) of the solids into the reactor, and add a magnetic stirring bar and 50 mL of distilled water.
4. Add 1 drop of phenolphthalein solution, and then add 0.1 N NaOH dropwise until a permanent faint pink color is seen in solution.
5. Add 5 mL of 30% hydrogen peroxide and immediately seal the system. Then start the magnetic stirrer.
6. Start the sparging system and adjust to give an air flow of approximately 2 liters/minute.
7. Add the 0.1 N HCl slowly into the reactor until the yellow color (from the methyl red) turns red.
8. Continue stirring and sparging until all the solids dissolve. It may be necessary to add more the of 0.1 N HCl dropwise in order to achieve complete solution.
9. Once all solids have dissolved, continue the purge for 15 more minutes.
10. Transfer the impinger solutions to a 150-mL beaker washing the impinger with distilled water to effect quantitative transfer.



Source: Arthur D. Little, Inc.

FIGURE 1 APPARATUS FOR CARBONATE IN SOLIDS

11. Add 1 mL of 30% H_2O_2; mix and let stand 15 minutes (covered).

12. Add 1 mL of the 10-mg/liter manganese solution and boil the solution (covered with a watchglass) for 5 minutes. Cool the solution to near room temperature quickly (to minimize exposure to atmospheric CO_2).

13. Add to the impinger solution 1 drop of phenolphthalein solution and 5 mL (pipet) of 1 N HCl.

14. Titrate with 0.1 N HCl to disappearance of pink color. Note: if too much indicator has been added, the end point is seen as a marked decrease in intensity of the red color. Note the volume (level) of 0.1 N HCl in the burette, and call this "A."

15. Add 3 to 4 drops of bromcresol green indicator solution to titration solution, and continue titration with 0.1 N HCl until a permanent yellow color is seen. Then add 3 mL of titrant in excess. Note the reading of the HCl burette and call this "B."

16. Quantitatively transfer the titrated solution to a 150-mL beaker and boil (uncovered) for 10 minutes. Note: It may be necessary to add small amounts of distilled water during the boiling in order to avoid spattering losses.

17. Cool the solution and back-titrate with 0.1 N NaOH to a green end point. Call this volume "C."

18. Run at least one blank determination including sparging for the same amount of time.

19. Calculations:

$$\text{Millimoles carbonate} = [(B-A) \times N\ HCl] - [C \times N\ NaOH]$$

$$\text{Carbonate (millimoles/g)} = \frac{(\text{millimoles } CO_3 \text{ in sample}) - (\text{millimoles } CO_3 \text{ in blank})}{\text{g sample}}$$

where

N HCl = normality of HCl; and

N NaOH = normality of NaOH to bromocresol

A = mL titration for sample to reach phenolphthalein end point.

B = total mL titration of acid added.

C = mL of NaOH for back titration to bromocresol green end point.

EXHIBIT 5-6

DETERMINATION OF THE QUANTITY OF ACID INSOLUBLE MATERIAL*

This procedure is applicable to FGC waste solids which are mixtures of ash and FGD materials. An approximate measure of ash content can be obtained using this procedure.

1. Add a 0.5- to 1.0- g sample to 40 mL of 1 N HCl.
2. Stir the mixture or shake it for 1 hour.
3. Filter the resultant slurry through a Millipore AA tared filter.
4. Dry the resultant filter and solids at 85°C to constant weight.
5. Calculation:

$$\% \text{ Acid Insolubles} = \frac{\text{weight of dried residue}}{\text{weight of sample taken}} \times 100.$$

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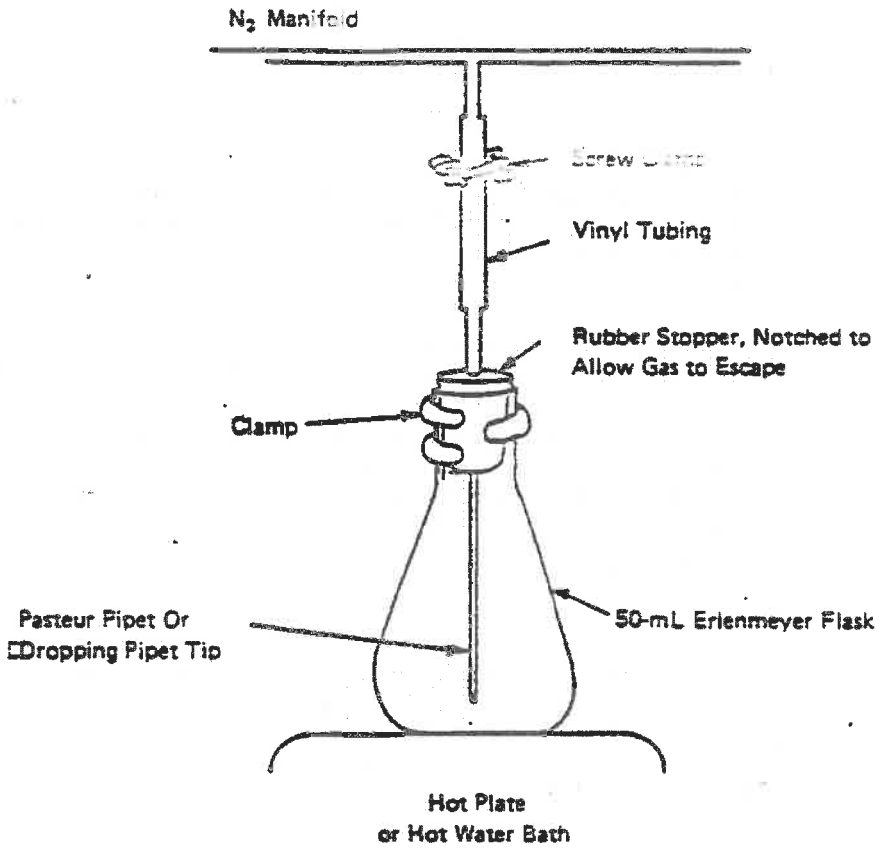
* This corresponds only to that portion of the sample which is insoluble in 1 N HCl.

EXHIBIT D.5-7
PROCEDURES FOR SULFATE ($SO_4^=$) ANALYSES

This method is applicable to solid samples. (Analysis of sulfate in liquid samples will be done by oxidation of the sulfite, measurement of total sulfur by ion chromatography after dilution, and subtracting the TOS originally present in the liquid.)

1. Set up the sparging/boiling apparatus as shown in Figure 1, and add 30 mL of distilled water to the Erlenmeyer flask(s).
2. Heat the water to boiling and purge with a gentle nitrogen flow for 3 minutes to remove dissolved oxygen.
3. Transfer 0.3 to 0.4 g (weighed to ±0.0001 g) of sample to the purged water.
4. Purge with nitrogen for 3 minutes more, then quickly add 10 mL of 1 M perchloric acid (restopper flask quickly) to dissolve sample.
5. When all solids have dissolved, bring to a boil and purge for at least 30 minutes (no less). Then cool solution.
6. Transfer the solution to a 150-mL beaker, add 2 drops bromocresol green indicator, and neutralize (to within 1 drop on the acid, yellow, side) with 1 M NaOH and 1 M $HClO_4$.
7. Add 5 g of washed cation exchange resin, and mix (magnetic stirrer) for 30 minutes.
8. Filter the solution and resin through a 1-inch thick bed of the same resin contained in a sintered glass filter crucible, and wash through with distilled water. The total volume of solution plus washes should be less than 100 mL. Note: This ion-exchange operation can also be carried out on a column containing 10 g of resin.



Source: Arthur D. Little, Inc.

FIGURE 1 APPARATUS FOR SULFATE DETERMINATION

9. Allow to cool and transfer purged solution into a 150-mL beaker. Add 2 drops bromocresol green indicator solution and neutralize solution with 1 N NaOH adding one drop of $HClO_4$ after indicator has turned green.
10. Add 10 mL of 1 M $NaClO_4$ solution and enough methanol to make a 50% (v/v) solution.
11. Under rapid stirring, add 25 mL of standardized (0.1 M) lead perchlorate solution. The amount of lead added should be such that an excess of lead remains in solution. If necessary, readjust pH of solution to 3.5 to 4-5 with $HClO_4$ or NaOH.
12. Back titrate the excess lead with 0.2 M Na_2SO_4 solution using the EMF between the lead-selective specific ion electrode and the double-junction reference electrode to indicate the end point. Titrant increments at the end point should be 0.1 mL. The end point region can be seen from the daily standardization curve, and may vary because of changes in the condition of the lead electrode. The end point can be determined graphically or by means of the second derivative technique.
13. Calculations:

$$\text{Sulfate (millimoles/g)} = \frac{[(\text{mL lead perchl.})(\text{M lead perchl.})] - [(\text{mL } Na_2SO_4)(\text{M } Na_2SO_4)]}{\text{g sample}}$$

EXHIBIT

MEASUREMENT OF RADIOACTIVITY IN VARIOUS SOLID AND LIQUID SAMPLES AND FROM THE SITE

SOLIDS

Radioactivity in the solid phase will be characterized by 226-radium (^{226}Ra) concentration.

Two methods are suggested for ^{226}Ra. The first, involving a considerable amount of wet chemistry, is based on measuring radon emanation from the dissolved sample. This method is specific to ^{226}Ra and so has little or no interference from other nuclides. The second method, based on gamma-ray spectroscopy of the ^{226}Ra daughter products, is somewhat less specific than the radon emanation method, but involves no wet chemistry and so provides major savings in the analysis effort. In addition, the second method uses samples of 0.5 kg, while the first uses 1-g samples.

^{226}Ra by Radon Emanation

Samples containing up to 1 g inorganic matter are used. Treatment follows that of ^{226}Ra analyses of suspended matter as in Reference 7.20, or EPA modification of this method. The procedure includes ashing, grinding, alkaline fushion, acid dissolution of the fushion, sealing the solution for a known period (preferably seven days or longer, for grow-in of ^{222}Ra daughters), de-gassing of the ^{222}Ra into a calibrated alpha particle-sensitive scintillation chamber and alpha counting. Correction is made for grow-in of radon.

^{226}Ra by Sealed Sample Gamma Ray Spectroscopy

Samples containing 50 g matter are sealed in gas-tight thick polyethylene jars or bags for periods of seven days or more. Intensity of the 1.76 MeV gamma ray of ^{214}Bi, a short-lived radioactive daughter product formed in the decay chain of ^{226}Ra,

is measured using a calibrated low-background NaI[Tl] scintillation or [Li] semiconductor detector. Energy range monitored in the NaI:Tl crystal is 1.6 to 1.9 MeV. Background of the counting system with empty jars or bags is subtracted to give net activity of the sample. Correction is made for grow-in of the activity. The method has been routinely used to determine concentrations of ^{226}Ra in soils, rocks, and bones. (See Reference 7.21.)

LIQUIDS

Radioactivity in the liquid phase or in liquid extracts of the solid phase is to be characterized by analysis of ^{226}Ra, ^{228}Ra, total alpha, and total beta activities.

^{228}Ra by Barium Coprecipitation

In order to isolate ^{228}Ra from the nuclides from which it is formed, the ^{228}Ra must be removed from solution. The method is based on barium coprecipitation of all the radium in solution, drying the precipitate to form a thin layer (not to exceed 10 mg dried matter per sq cm of precipitate) on a planchet and measuring the beta activity of the ^{228}Ra daughter product, ^{228}Ac. ^{228}Ra emits only a weak beta particle, but its first daughter ^{228}Ac emits a 1.11 MeV beta. The ^{229}Ac grows into the newly formed radium precipitate with a 6.1-hour half life. A gas flow-through proportional counter with voltage set for beta counting is used to determine the beta activity of the sample. (See Reference 7.15.)

226-Radium by Barium Coprecipitation

The barium coprecipitation of ^{228}Ra carries with it ^{226}Ra. If the precipitate on the planchet does not exceed 5 mg matter per sq cm, the same sample can be used for ^{226}Ra and ^{228}Ra determination. The thinner precipitate is required since ^{226}Ra

emits 4.78 MeV alpha particles. A gas flow-through proport... counter with voltage set for alpha counting is used. (See Reference 7.22.)

An alternative method for ^{226}Ra in water consists of storing

An alternative method for ^{226}Ra in water consists of storing the outgassed water in a radon-tight container for a known time, peferably exceeding seven days. De-gas and measure the ^{222}Rn in an alpha scintillation flask and calculate the ^{226}Ra concentration from the ^{222}Rn grow-in. For water with low specific activity, larger volumes (5-10 L) may be de-gassed onto a cold (2-30°C) activated charcoal radon trap, and the trapped radon then released by warming to 80°C or more into a small alpha scintillation (Lucas-type) flask.

Total (Gross) Alpha and Beta Radioactivity

Evaporate a water sample onto a planchet suitable for use in a gas flow-through proportional counter. Dried solids should not exceed 5 mg/sq cm for alpha counting and not exceed 10 mg sq/cm for beta counting. If one sample is to be used for both alpha and beta, then 5 mg sq/cm should not be exceeded. The precipitated alpha and beta radioactivity on the planchet is measured in a gas flow-through proportional counter. (See Reference 7.23.)

222-Radon Flux at Landfill or Pond Surface

Gaseous diffusion and/or convection across the surface interface can transport ^{222}Rn formed in the decay of ^{226}Ra.

^{222}Rn flux is measured using canisters containing activated charcoal placed at selected locations on the surface of a landfill or pond and at selected locations adjacent to the fill or pond. The canisters are left in place, usually under a protective housing similar to an empty inverted tin can, opened at one end, for several hours to several days, depending on the specific ^{222}Rn flux across the interface. Upon completion of the recorded measurement period, the canisters are put into thick

plastic bags, the bags are sealed and stored for several hours to allow grow-in of the short-lived gamma-emitting radon daughter products, ^{224}Pb and ^{214}Bi. The accumulated gamma ray activity in the canister is measured directly using a calibrated gamma ray detector such as a NaI:Tl crystal. (See Reference 7.24.)

APPENDIX D

APPLICATION OF THE EPA EXTRACTION PROCEDURE AND RADIOACTIVITY MEASUREMENTS TO COAL-FIRED UTILITY WASTES

FULL-SCALE FIELD EVALUATION OF WASTE DISPOSAL FROM COAL-FIRED ELECTRIC GENERATING PLANTS

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ABSTRACT

This report presents the results of radioactivity measurements and trace metal concentrations in extracts obtained using the EPA-Extraction Procedure (EP) for wastes obtained from coal-fired utility plants. Twenty-three waste samples (fly ash and flue gas desulfurization [FGD) wastes) were subjected to the extraction procedure. Thirty-four samples (fly ash, bottom ash, FGD wastes and boiler slag) were analyzed for concentrations of radium-226 using gamma ray spectroscopy. Several samples were also analyzed for radium-228, thorium-228, potassium-40, uranium-238, total uranium and for fractional radon emanation.

In no case did the concentrations of the eight metals determined in the EP extracts of these wastes exceed the one hundred times Interim Primary Drinking Water Standards criteria (100 x) as published in the Federal Register of May 19, 1980. The range of concentrations observed in all the extracts relative to the Interim Primary Drinking Water Standards were As <0.04-8.2x, Ba <0.1-0.7x, Cd <0.2-19x, Cr <0.2-19x, Pb <0.1-0.7x, Hg <1x, Se <0.2-34x and Ag <0.02 times the standard. For none of the samples analyzed did the ^{226}Ra concentration exceed the proposed limit of 5 pCi/g as given in the Federal Register of Dec 18, 1978. The range observed for ^{226}Ra activity for the fly ash samples was 2.0-4.7 ; the bottom ash samples 1.7 - 4.5; boiler slag samples 2.3 to 3.5; and the FGD samples <0.9-3.1 pCi/g.

Concentrations of ^{228}Ra, ^{228}Th, ^{40}K, and ^{238}U in the analyzed ash samples ranged from 2.4-3.6, 2.4-3.0, 8.4 to 28.5 and 4.1-4.5 pCi/g, respectively.

Fractional radon emanation measurements on four fly ash samples and two FGD samples showed no emanation within the accuracy of the measurements, suggesting that the radium is not concentrated on the surface of the ash particles.

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ABBREVIATIONS

EP - EPA Extraction Procedure

FGD - Flue Gas Desulfurization

ml - milliliter

N- normal concentration (equivalents/l)

mm - millimeter

μm - micrometer

nm - nanometer

MeV - Million-electron volt(s)

μg/l - micrograms per liter or parts per billion (ppb)

mg/l - milligrams per liter or parts per million (ppm)

pCi/g - picocuries per gram (10^{-12} Curies/g)

γ - gamma ray

RSD - relative standard deviation

g- grams

cm - centimeter

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1. INTRODUCTION

The U.S. Environmental Protection Agency (EPA) as part of its harzardous waste and consolidated permit regulations under the Resource Conservation and Recovery Act (RCRA) published in the May 19, 1980 Federal Register (1) the EPA Extraction Procedure (EP) which can be used to determine if a waste exhibits the characteristic described as EP-toxicity. Under this regulation a waste exhibits this characterisitc if the extract obtained from a sample of waste using the described procedure contains concentrations of one or more of eight designated metals or of one or more of six designated organics equal to or higher than prescribed limits. In addition, the EPA published proposed regulations in the December 18, 1978 Federal Register which would define the levels of radium-226 in a waste at which it may be considered as having radioactive hazard potential under RCRA (2). Arthur D. Little, Inc. under EPA contract 68-02-3167, is conducting a study to evaluate the overall environmental effects of land disposal of utility waste (fly ash, bottom ash, and flue gas desulfurization wastes) produced by full scale coal fired utility plants. As part of this study grab samples of waste from eighteen plants have been subjected to the EPA-Extraction Procedure and radioactivity tests to obtain preliminary data on these wastes (3). This data from the large number of plants is expected to be useful in providing preliminary indications of the relative impact of wastes from this industry.

2. EXPERIMENTAL PROCEDURES

2.1 Waste Samples

Most of the waste samples studied were obtained during site visits to the plants by members of the Arthur D. Little, Inc. project team, although in a limited number of cases, samples were provided by utility personnel. All samples were single grab samples of a particular waste stream, and thus the experimental results are not necessarily representative of the average wastes produced by a plant over an extended period of time.

Samples were collected in cleaned glass or plastic containers. The samples collected included: twenty fly ash samples (from sixteen plants); seven bottom ash samples (from seven plants); four flue gas desulfurization (FGD) waste samples (from four plants); two boiler slag samples (from two plants) and two combined fly and bottom ash samples (from two plants). A summary of the waste materials studied and the type of tests performed on them is provided in Table 1. The names of the plants and the location of the utility are not identified pursuant to EPA's desire to maintain the generic nature of these analytical efforts.

The EPA-EP procedure was performed only on the fly ash and FGD materials. Radium-226 measurements were performed on most of the samples. Other radioactivity measurements (radium-228, thorium-228, potassium-40 uranium-238, total uranium and fractional radon emanation) were performed on three fly ash samples from three plants, two FGD samples from two plants and one combined ash sample.

2.2 Extraction Procedure (EP)

Samples of fly ash and FGD waste were subjected to the EPA-EP as described in the Federal Register, May 19, 1980 (1). All of the samples had small particle sizes such that the samples passed the 9.5 mm sieve requirement and thus were not subjected to any cutting or grinding.

A schematic of the EP setup is given in Figure 1. The extraction chamber is a one gallon glass jar fitted with a plexiglass cover having various ports for the stirrer, pH electrodes, and a tube for the addition of acetic acid. The pH controller (Horizon Ecology Model 5997-20) was used to control a peristaltic pump (Cole Parmer Masterflex) for the addition of 0.5N acetic acid. The pH control points were set so that acid addition was initiated at pH $\geq$ 5.2 and stopped at pH $\leq$ 5.0. The addition rate of the acetic acid using the pump was approximately 1 mL/min. The acid reservoir was filled with the maximum amount of acid allowed under the EP procedure (e.g., 400 mL of 0.5 N acetic acid for 100 g of solid) so that an excess could not be added even when the controller kept the pump running. Stirring was set at a rate sufficient to suspend all the solid material. The extraction process was carried out for a 24 hour period as specified in the regulations (1).

TABLE 1

Waste Samples Studied

Utility Code	Sample Codes	Type of Sample	Date Sampled	Analyses EP	Analyses Radio-activity
1	EP-1(a),R-1(a)	Fly Ash	July 16, 1980	X	X
1	EP-1(b),R-1(b)	Fly Ash	July 16, 1980	X	X
1	EP-1(c),R-1(c)	Fly Ash	July 16, 1980	X	X
2	EP-2(a),R-2(a)	Fly Ash	July 30, 1980	X	X
2	EP-2(b),R-2(b)	Fly Ash	July 30, 1980	X	X
2	R-2	Bottom Ash	July 30, 1980		X
3	R-3	Bottom Ash	Sept 19, 1980		X
3	EP-3,R-?	Fly Ash	Sept 19, 1980	X	X
4	EP-4(a),R-4(a)	Fly Ash	Sept 5, 1980	X	X
4	R-4(b)	Boiler Slag	Sept 5, 1980		X
5	EP-5(a),R-5(a)	Fly Ash	July 30, 1980	X	X
5	EP-5(b),R-5(b)	Fly Ash	July 30, 1980	X	X
5	R-5(c)	Bottom Ash	July 30, 1980		X
6	EP-6(a),R-6(a)	Fly Ash	Aug 26, 1980	X	X
6	R-6(b)	Boiler Slag	Aug 26, 1980		X
7	EP-7(a),R-7(a)	Fly Ash	Sept 4, 1980	X	X
7	R-7(b)	Bottom Ash	Sept 4, 1980		X
8	EP-8(a),R-8(a)	Fly Ash	Sept 5, 1980	X	X
8	EP-8(b),R-8(b)	FGD	Sept 5, 1980	X	X
9	EP-9(a),R-9(a)	Fly Ash	Sept 11, 1980	X	X
9	R-9(b)	Combined Fly Ash/ Bottom Ash	Sept 11, 1980		X
10	EP-10(a),R-10(a)	Fly Ash	Sept 17, 1980	X	X
10	R-10(b)	Bottom Ash	Sept 17, 1980		X
11	EP-11(a),R-11(d)	Fly Ash	Sept 18, 1980	X	X
11	R-11(b)	Bottom Ash	Sept 18, 1980		X
12	EP-12(a),R-12(a)	Fly Ash	Oct 21, 1980	X	X
12	R-12(b)	Bottom Ash	Oct 21, 1980		X
13	EP-13(a),R-13(a)	Fly Ash	Oct 27, 1980	X	X
13	EP-13(b),R-13(b)	FGD	Oct 27, 1980	X	X
14	EP-14,R-14	Fly Ash	Oct 21, 1980	X	X
15	EP-15(a),R-15(a)	Fly Ash	Sept 11, 1980	X	X
15	R-15(b)	Combined Fly Ash/ Bottom Ash	Sept 11, 1980		X
16	EP-16,R-16	FGD/Fly Ash Mixture	Aug 26, 1980	X	X
17	EP-17	Fly Ash	Jan 20, 1981	X	
18	R-18	FGD	Apr 2, 1981		X

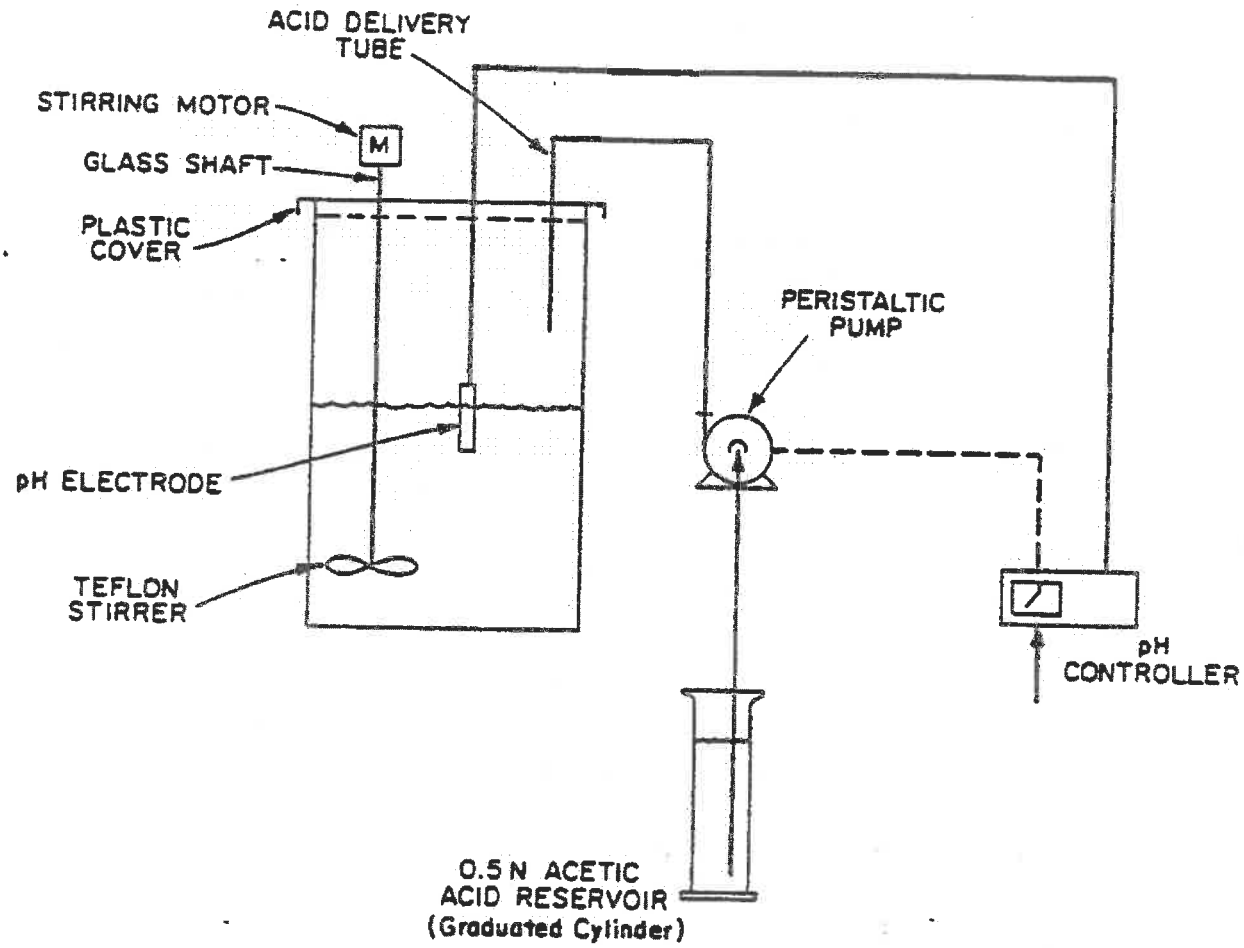

FIGURE 1. EPA-EP APPARATUS.

Dry solid samples were used as received. Approximately 100 g (weighed accurately) of sample was used. Slurry samples were separated using a teflon coated pressure filtration apparatus (Millipore model YT30142HW) and 0.45 μm polycarbonate filters (Millipore HAWP). Pure tank nitrogen was used as the source of pressure. The liquid portion of the filtered slurry was retained and the solid portion extracted. After extraction the slurry was separated using the pressure filtration apparatus. The extract and liquid portion were recombined as specified in the procedure. This mixture was stabilized for metal analysis by addition of 5 mL of concentrated reagent-grade nitric acid. The extracts were analyzed only for the metal species listed in the EP procedure since occurrence of the organic species listed in the prescribed protocol in these utility wastes was considered to be extremely unlikely. More complete details of the extraction procedure can be found in References 1 and 5.

Metals Analysis

A summary of the analysis methods used to measure the eight trace metals (Ag, As, Se, Hg, Cr, Cd, Pb, Ba) is given in Table 2. Arsenic and selenium were measured using the gaseous hydride evolution methods. For arsenic a 10 mL volume of sample was introduced into the hydride generating apparatus and then 5 mL of HCl and 2 mL of 25% aqueous potassium iodide solution were added. The hydride was generated by injection of 2.5 mL of a solution of 5% sodium borohydride in 10% sodium hydroxide solution. Selenium was analyzed similarly to arsenic in that 10 mL volume of sample was introduced into the apparatus followed by 10 mL of HCl and the hydride generated by injection of 2.5 mL of 4% sodium borohydride in 10% sodium hydroxide solution. Mercury was analyzed using the cold vapor technique as described in EPA method 245.1 (5). All of the other elements (silver, chromium, lead, cadmium, barium) were analyzed using graphite furnace atomic absorption techniques using the operating conditions recommended by the instrument manufacturer and guidelines given in the EPA Methods (6). The graphite furnace atomic absorption measurements were carried out on an Instrumentation Laboratories 551 AA Spectrophotometer. Hydride evolution and the mercury cold-vapor analysis methods were performed on a Perkin Elmer 503 AA spectrometer.

2.4 Radioactivity Analysis Methods

The analysis method used for measurement of radium-226 (^{226}Ra) in the samples and the limited studies performed for radon-222 (^{222}Rn) as well as determination of other radioactive species in the samples was gamma-ray spectroscopy (7). Measurements were made of the 0.352 MeV gamma ray of lead-214 (^{214}Pb) and the 0.609 MeV and 1.12 MeV gamma rays of bismuth-214 (^{214}Bi) which are daughter products in the decay of ^{222}Rn which itself is produced by decay of ^{226}Ra. The measurement apparatus consisted of a calibrated high-resolution 10% Ge (Li) detector, (Ortec Inc., Oak Ridge, TN,) a signal amplifier (Ortec 560) and 1024-channel pulse analyzer (Tracor Northern Scientific NS-700).

TABLE 2

Summary of Metal Analysis Methods

Element	Method	Wavelength (nm)	Conditions (°C)			Calibration Range (ppb)
			Dry	Pyrolyze	Atomize	
As	Hydride Evolution	194	-	-	-	0-20
Se	Hydride Evolution	196.5	-	-	-	0-30
Hg	Cold Vapor	253.7	-	-	-	0-6
Ag	Graphite Furnace Atomic Absorption	328.1	150	300	1800	0-20
Ba	Graphite Furnace Atomic Absorption	553.5	150	1100	2250	0-200
Cd	Graphite Furnace Atomic Absorption	228.8	150	2000	-	0-20
Cr	Graphite Furnace Atomic Absorption	357.7	150	900	1850	0-50
Pb	Graphite Furnace Atomic Absorption	383.3	150	600	1900	0-50

Samples of fly ash, bottom ash, boiler slag and FGD waste (37 to 352 g) were dried at 86°C for 22 hours and sealed in flat metal cans (similar to the familiar tuna fish food can) of two different sizes depending on sample size (8.2 cm diameter x 4.3 cm deep and 6.7 cm diameter x 2.3 cm deep). The can tops were sealed using a crimping can sealer and bees-wax was added around the seals of the can to insure retention of radon gas. The end of the can was placed co-axially with the flat end of the the Ge(Li) gamma ray detector housing. The complete system of sample and detector was shielded with lead bricks to give a minimum of stray radiation background. For measurement of ^{226}Ra, the samples contained in the radon-tight cans were stored for 30 days to allow re-equilibration of the natural $^{222}Rn/^{226}Ra$ ratio which was likely to have been perturbed by the sample preparation steps if ^{222}Rn loss occurred.

Gamma ray energies were scanned from 0 to about 2 MeV and other emitting nuclides were identified by the characteristic energies of their emitted gamma-rays. (Calibration plots of gamma ray energy vs channel number and of the detector counting efficiency vs gamma ray energy are included in Appendix B). The gamma ray counting time varied between 9,000 and 429,000 seconds (3 hrs to 5 days) but generally was held in the range of 20,000 to 60,000 seconds.

The activities of ^{214}Pb and ^{214}Bi produced by decay of ^{222}Rn (half life of ^{222}Rn is 3.8 days) are equal considering the half lifes involved and thus these are a measure of the ^{222}Rn content of the sample which in turn is a measure of the ^{226}Ra content. The fractional radon emanation (%) is defined as:

$$\left(\frac{[^{222}Rn]_{30\ days} - [^{222}Rn]_{0\ days}}{[^{222}Rn]_{30\ days}} \right) \times 100$$

Thus measurements of the activity of ^{214}Pb and ^{214}Bi after 30 days and after evacuation of the 30 day old sealed sample (0-days) gives a quantitative measure of the fractional radon emanation from the sample. The 0-day samples were prepared from the 30 day samples by piercing holes in the cans and placing the can in a vacuum chamber. The sample was evacuated and refilled with nitrogen twice, then the short lived γ-emitting daughters were allowed to decay for 3 hours prior to making the measurement of the non-emanated radon.

The activities of ^{228}Ra, ^{228}Th and ^{238}U in the samples were estimated from measurements of the activity of their decay products. Thus, ^{228}Ra activity was determined as ^{228}Ac (0.91 and 0.969 MeV gamma rays), ^{228}Th determined as ^{208}Tl (0.585 MeV gamma ray), ^{238}U as ^{235}U (0.186 MeV gamma minus ^{226}Ra contribution) and total U as ^{235}U (0.186 MeV gamma ray).

2.5 Quality Control Procedures

A number of quality control tests and checks were performed during the course of the extraction procedure. These tests were designed to monitor possible sources of contamination in the various steps of the extraction and to provide an indication of reproducibility of the overall extraction results. A total system blank was run at least once each week. This consisted of distilled water acidified to pH 5.0 with acetic acid which was carried as a sample through the complete extraction and filtration procedure. In addition, contamination arising from the extract storage bottles (bottle blank) and the filters (filter blanks) were also monitored. The results of these "blank" tests are summarized in Table A-1, Appendix A.

Duplicate extractions were performed on three materials to check repeatability of the overall extraction procedure. These results are shown in Table A-3, Appendix A.

All samples were subjected to an initial "survey" measurement for each analyte. Those samples which contained a detectable amount of analyte were subjected to further quantitation using the method of standard additions (8). Samples were spiked to contain an additional 50%, 100% and 150% of the analyte concentration determined during initial survey analysis.

The reproducibility of the analytical measurements was estimated from several replicate measurements of standard solutions. Detection limits, reported in Table A-3, Appendix A were taken as two times the standard deviation of the replicate standard measurements and assume that absolute imprecision at the blank level is the same as that at the measured standard level. It should be noted that the detectabilities of interest in these experiments range in the area of the proposed primary drinking water criteria (9).

The gamma ray spectrometer was calibrated using four National Bureau of Standards (NBS) reference standard sealed glass vials each containing 0.202 μCi of ^{226}Ra placed in a sand matrix contained in a 8.5 cm diameter x 4.3 cm deep metal can. In addition, comparative measurements of a fly ash sample (R-1) by this laboratory and by the Environmental Measurement Laboratory of the Department of Energy (New York City, NY) confirmed the calibration (10). The NBS standard yielded values of 115×10^{-6} counts per second per pCi of ^{226}Ra using the 0.352 MeV γ-ray. This compares well with the independent laboratory measurement of 110×10^{-6} counts per second per pCi of ^{226}Ra at the same energy for a sample of R-1. The respective values for the 0.609 MeV γ-ray were 67.2×10^{-6} and 67.7×10^{-6} counts per second per pCi of ^{226}Ra.

Background counts were monitored weekly at the respective energies used for quantitation and if required appropriate corrections were made.

Precision of the ^{226}Ra analysis was determined by replicate measurement of three samples as well as measurements made using both the 0.352 MeV gamma and the 0.609 MeV gamma (11). These data are summarized in Table B-1, Appendix B.

The results of all the quality control procedures are summarized in the experimental results and discussion section and in Appendices A and B.

3. RESULTS AND DISCUSSIONS

3.1 Extraction Procedure

The results obtained for the analysis of extracts of 20 fly ash samples from 16 plants and three flue gas desulfurization (FGD) waste samples from three plants are summarized in Table 3. Because the single "grab" samples obtained in this study could not be considered representative of the particular plant or facility, the samples were given coded identification numbers. The sum total of the results showing the range and distribution for a number of plants may be taken to give preliminary indications of the general properties and trends of these wastes for the industry.

The range of concentrations observed for these samples and their relationship to the EPA Interim Primary Drinking Water standards are summarized in Table 4. Neither silver nor mercury was detected in any of the fly ash or FGD extracts and very few samples showed any detectable levels of lead. Detectable levels of the other metals were observed but none of them exceeded the proposed RCRA EP Criteria of 100 times Interim Primary Drinking Water Standards as published in the May 19, 1980 Federal Register (1). The FGD samples tended to fall in the lower end of the concentration range found for fly ash samples. The ranges of concentrations observed for these metals in the EP extracts fall within those reported by other studies on utility wastes (12,13).

The quality control data, given in Appendix A, include the data obtained for the various blanks (Table A-1) and the relative standard deviation values obtained for standards which were used to determine detection levels (Table A-2). The data on the various blanks indicate that barium contamination from the filters occurred. Since the level of barium contamination however was about 0.1 times the proposed Primary Drinking Water Criteria (1,000 ppb), no corrective action in the test procedure was taken. However, the detection limit and confidence level of the barium data was adjusted upward to include this contribution of barium by the filters. No contamination from other metals analyzed was observed in any of the steps in the procedure.

The method of standard addition which was used to quantify all samples where detectable levels were observed during preliminary measurements, showed widely varying matrix effects for some samples during measurements of barium and lead. For barium, the slope of the calibration/response line for the standard addition plots varied from 0.5 to 1.5 (with an average of 0.85) times the slope of the independent calibration plots using aqueous standards. For lead, the corresponding ratio of slopes was 0.7 to 2.5 (average 0.89). Other elements (As, Se, Cd) showed only minor matrix effects for the samples studied. The range for the ratio of slopes for these elements was 0.81-1.02 (average 0.92), 0.78-0.94 (average 0.86), and 0.74-1.2 (average 0.94) for As, Se and Cd, respectively. No standard addition was performed for the mercury and silver analyses.

TABLE 3

Summary of Extraction Procedure Data for FGC Waste Samples
From Various Coal Fired Power Plants

Sample[a]	Concentration in Extract[b]							
	As (µg/l)	Cd (µg/l)	Cr (µg/l)	Pb (µg/l)	Hg (µg/l)	Se (µg/l)	Ag (µg/l)	Ba (mg/l)
Fly Ash Samples:								
EP-1(a)	39±10	10±3	23±8	<6	<2	7±2	<1	<0.16
EP-1(b)	63±10	5±3	<8	<3	<2	8±2	<1	0.36±0.16
EP-1(c)[c]	98±20	16±3	12	<3	<2	52±7	<1	0.51±0.16
EP-2(a)[c]	<5	<2	240±37	<3	<2	17±3	<1	1.2±0.16
EP-2(b)	<5	11±3	430±73	<3	<2	<5	<1	0.4±0.1
EP-3(a)	<2	6±2	19±13	<4	<2	10±2	<1	0.34±0.15
EP-4(a)	<2	63±5	<9	<5	<2	34±9	<1	<0.11
EP-5(a)	<6	6±2	<57	<3	<2	21±3	<1	<0.15
EP-5(b)	<6	<2	445±37	<4	<2	25±3	<1	0.17±0.10
EP-6(a)	<24	90±32	320±73	<36	<2	13±2	<1	<0.3
EP-7(a)	<24	193±32	110±37	<3	<2	5±2	<1	-
EP-8(a)	30±10	135±32	56±15	<3	<2	59±7	<1	0.3±0.1
EP-9(a)	410±41	16±2	<13	<4	<2	340±43	<1	0.4±0.10
EP-10(a)	14±2	26±5	930±558	<5	<2	160±43	<1	0.30±0.10
EP-11(a)	19±2	19±4	480±280	23±5	<2	60±17	<1	0.7±0.3
EP-12(a)	310±41	4±2	<11	<5	<2	<2	<1	0.33±0.15
EP-13(a)	5±2	5±2	<11	24	<2	<2	<1	<0.1
EP-14	200±41	8±2	<8	<3	<2	73±17	<1	0.20±0.1
EP-15(a)	340±41	30±4	<19	10±5	<2	83±17	<1	0.28±0.1
EP-17[c]	6±2	<2	14±3	<3	<2	9±2	<1	<0.5
FGD Samples:								
EP-8 (b)	<2	<2	<11	<5	<2	9±2	<1	0.16±0.1
EP-13(b)	65±8	<2	<11	-	<2	49±17	<1	<0.15
EP 16	<5	20±3	26±15	<3	<2	8±2	<1	0.23±0.11

[a] Samples are listed according to a code given to the various plants

[b] Error limits as well as detection limits were calculated using twice the standard deviation of replicate standard solutions and dilution factors (see text).

[c] Performed in duplicate. Value reported is highest of two observed. See Table A-3.

TABLE 4

Range of Concentrations of Metals in EP Extracts of Fly Ash and FGD Samples Compared to Interim Primary Drinking Water Standards

Metal	Overall Range Observed(A)	Interim Primary Drinking Water Standards(B)	Ratio of A to B
As	<2 - 410 µg/l	50 µg/l	<0.04 to 8.2
Ba	<0.1-0.7 mg/l	1.0 mg/l	<0.1 to 0.7
Cd	<2 - 193 µg/l	10 µg/l	<0.2 to 19.3
Cr	<8 - 930 µg/l	50 µg/l[a]	<0.16 to 18.6[b]
Pb	<3 - <36 µg/l	50 µg/l	<0.06 to 0.72
Hg	<2 µg/l	2 µg/l	<1
Se	<2 - 340 µg/l	10 µg/l	<0.2 to 34
Ag	<1 µg/l	50 µg/l	<0.02

[a] The Federal Register of Thursday Oct. 30, 1980 pp 72024-41 contained an amendment to the chromium criteria for the EP revising it from total chromium to Cr(VI).

[b] Since total chromium values are measured by the AA analysis method, these are upper limits for the Cr(VI) values.

3.2 Radioactive Measurements

Naturally occurring uranium (U) and thorium (Th), the isotopes of which are all radioactive, initiate a long decay series of radioactive nuclides. Among these nuclides are ^{226}Ra (from the U series) and ^{226}Ra (from the Th series). Typical concentrations of ^{226}Ra and ^{228}Ra in sedimentary rocks (assuming equilibrium with parent nuclides) are 1 pCi/g and 0.4 pCi/g, respectively (14).

Coals also contain concentrations of these radionuclides. Following combustion of coal, the naturally occurring U, Th, ^{226}Ra and ^{228}Ra are likely to be found in the non-volatile combustion products (e.g., bottom and fly ash). As a result of this ashing process the concentration of these species in the ash will be increased relative to those in the coal since the combustion products of these species are not likely to be sufficiently volatile to be lost in the gaseous products. Such an increase in concentration for other elements has been reported. Three to ten-fold increases in concentrations of these species in ash by-products of a limited number of coals were noted and in some cases small particle fractions of fly ash had concentrations greater than 5 pCi/g of ^{226}Ra (15).

Another study which investigated a large number of ash samples (from 55 different coal sources) reported that about 36% of the national coal reserves were expected to produce levels of ^{226}Ra in excess of 5 pCi/g (16). It should be noted that these investigators determined the ^{226}Ra concentrations by extrapolation from the ^{238}U concentration (parent of ^{226}Ra) and by assuming that the two nuclides were in radioactive "secular equilibrium." This assumption may not be accurate since the long half-life of ^{226}Ra (1,600 years) and the period in excess of 10^9 years required for decay from ^{238}U to produce measurable amounts of ^{226}Ra coupled with the very different geochemistry of radium (an alkaline earth) from that of uranium (a member of the actinide series) may well allow ample opportunity for dislocation (e.g., leaching, recrystalization) of ^{226}Ra from the host rock and coal minerals.

The EPA in the Federal Register of December 18, 1978, has listed a level of 5 pCi/g of ^{226}Ra in the proposed guidelines for evaluating radioactivity in solid wastes. In summary these proposed guidelines state that a solid waste (as defined in the proposed guidelines) would be declared a hazardous waste if: 1) it is not a "source material," "special nuclear material," or "by-product material" as defined by the Atomic Energy Act of 1954 and if, 2) a representative sample of the waste has either an average concentration of ^{226}Ra exceeding 5 pCi/g in a solid or 50 pCi/liter of ^{226}Ra and ^{228}Ra for liquids or a total ^{226}Ra activity equal to or exeeding 10 μCi for any single discrete source.

Other considerations with regard to the possible effects of radium nuclides in utility wastes are: 1) the relative availability of the ^{226}Ra for leaching from the ash and subsequent migration into groundwaters and; 2) the production of ^{222}Rn gas which is often associated with elevated

levels of ^{226}Ra. Radon-222, the radioactive noble gas daughter product of ^{226}Ra itself decays to produce a series of non-gaseous alpha-emitting nuclides of polonium (Po), and beta-emitting nuclides of bismuth (Bi) and lead (Pb).

For some volatile elements (e.g., As, Se), volatilization-condensation processes in the combustion process have been invoked to account for the relatively higher concentrations of such species on the finer fractions (small particles with high surface areas) of the ash. While such processes are speculative for the heavy nuclides, they cannot necessarily be ruled out (1). Thus, higher concentrations of species at the surface of the particles would lead to greater leachability of these species and for ^{222}Rn (a product of the ^{226}Ra decay), greater opportunity for leaving the ash particle as a gas. The process of separation of the radon from the radon-bearing solids is termed "radon emanation." A study of the radon emanation quantity would aid in determining whether the ^{226}Ra is concentrated on the surface of the particle or distributed within it and would, in addition, provide additional information of possible gas emanation problems. A previous study of some 21 coal fly ash and related samples has suggested a value of about 40% for the radon emanation (19). However, the calculations upon which this value was based had a fundamental error in assuming that the 0.185 MeV γ-ray of ^{235}U causes a <20% error in the determination of Ra-226, whereas in reality the values may nearly be 100% error*.

The data obtained in this study for the ^{226}Ra content of 20 fly ash, eight bottom ash, four FGD, two combined fly and bottom ash and two boiler slag samples are shown in Table 5. The ^{226}Ra activity in pCi/g ranged from 1.8 to 4.7 for the fly ash samples, and 1.7 to 4.5 for the bottom ash. The combined bottom and fly ash and boiler slag samples were similarly within these ranges. The three FGD samples had a ^{226}Ra activity in the range of 0.9 to 3.1 pCi/g. A summary of the sample size, count time and comparison of the data obtained using the intensities of the 0.352 MeV gamma ray versus the 0.609 MeV gamma ray are given in Table B-1 in Appendix B. Measurement of both gamma rays provides greater confidence in the low level activities observed. In general, relatively good agreement was observed for the replicates as well as the values obtained using the two different gamma rays.

*Both ^{235}U and ^{226}Ra emit gamma rays in the 185$\pm$1 KeV energy range. The total counts observed at this energy can be nearly 50% due to ^{226}Ra and 50% due to ^{235}U. Thus, if one assumes no contribution from ^{235}U, the calculated ^{226}Ra activity based on the measured counts at this energy would be twice the activity of only the ^{226}Ra in the sample.

TABLE 5

Radium-226 Concentrations in Sealed Samples of Fly Ash, Bottom Ash, Boiler Slag and FGD Wastes

Sample[a]	^{226}Ra Concentrations (pCi/g)[b]
Fly Ash:	
R-1(a)	3.5±0.3
R-1(b)	4.2±0.4
R-1(c)	4.3±0.3
R-1(d)	4.3±0.3
R-2(a)	2.9±0.1
R-2(b)	3.9±0.5
R-3(a)	3.4±0.1
R-4(a)	4.7±0.5
R-5(a)	3.4±0.3
R-5(b)	3.1±0.1
R-6(a)	4.7±0.3
R-7(a)	4.1±0.2
R-8(a)	4.1±0.1
R-9(a)	3.9±0.5
R-10(a)	2.9±0.3
R-11(a)	3.8±0.3
R-12(c)	4.0±0.[illegible]
R-13(a)	2.0±0.[illegible]
R-14	4.5±0.[illegible]
R-15(a)	3.8±0.5
Bottom Ash:	
R-2 (c)	1.7±0.2
R-3 (b)	1.9±0.2
R-5 (c)	4.1±0.6
R-7 (b)	3.2±0.3
R-10(b)	2.8±0.5
R-11(b)	1.9±0.1
R-12(a)	4.2±0.5
R-12(b)	6.5±0.2
Boiler Slag:	
R-4 (b)	2.3±0.4
R-6 (b)	3.5±0.1
Combined (Fly Ash - Bottom Ash)	
R-9 (b)	3.6±0.5
R-15(b)	3.1±0.2
FGD (with/without ash)	
R-8 (b)	0.9±0.6
R-13(b)	<1.3
R-16	3.1±0.2
R-18	0.3±0.1

[a] Samples are listed according to code given to the various plants

[b] Gamma Ray Spectroscopy - Errors quoted are one standard deviation calculated based on procedures given in Reference 11. See Table B-1 for additional data.

Table 6 provides a listing of the gamma ray energy spectrum observed for most of the fly ash and bottom ash samples. Included in the table are the emitting nuclide and relative peak intensity in the spectrum of a representative sample. Essentially all of the photopeaks observed may be related to the naturally occurring radioactive decay series of ^{235}U, ^{238}U, ^{232}Th and ^{40}K.

Table 7 provides data on nuclide concentrations (pCi/g) of ^{228}Ra (using the ^{228}Ac product), ^{228}Th (using ^{208}Tl product), ^{40}K, ^{238}U (using ^{235}U minus contribution from ^{226}Ra at 0.186 MeV) and total uranium in ppm. Three fly ash, one bottom ash and two FGD samples were analyzed in these experiments. Data for fractional radon-222 emanation in percent are given in Table 8.

The three total uranium values (range of 12.3 to 13.6 ppm) are very similar to that reported by other investigators for a Bull Run sample of fly ash (20). The ^{40}K data are in agreement with the generally observed total concentration of potassium in these samples. Recalling that 7.10 pCi/g of ^{40}K represents 1 ppm and that 1 ppm of ^{40}K represents 8,400 ppm of total K, the total K content observed for the fly ash and bottom ash samples range from 9,900 to 32,000 ppm (0.99 to 3.2%) and 6,600 ppm (0.66) for one FGD sample. These values are in the range previously reported for these types of samples (21).

Radium-228 concentrations in the fly ash and bottom ash samples were in the 2.6 to 3.6 pCi/g range. Thorium-228 concentrations were in the 2.4 to 3.0 pCi/g for the ash samples and 0.9 to 1.9 for the two FGD samples studied. It should be noted that one of the samples of FGD material studied contained ash [sample R-16] while the other did not. Uranium-238 levels were in the 4.1 to 4.5 pCi/g range for the ash samples studied.

Fractional emanation measurements for all the samples studied showed no emanation within the accuracy of the measurements (Negative values in the table indicate that the measured 0-day sample value exceeded the measured 30-day sample value).

The low fractional emanation for the ash particles suggests that the radium is not preferentially concentrated at the surface of the particle. Assuming that the ^{226}Ra (radioactive parent of radon-222), is uniformly distributed throughout the fly ash particles; emanation of radon from an average 30 μm diameter particle would be less than 1% of the radon-222 (16,22). This is because the recoil associated with the emission of a 4.6 to 4.8 MeV alpha particle, which occurs when ^{222}Rn is formed, causes the ^{222}Rn atom to travel about 0.06 μm. By contrast, radon emanation from 1 μm size particles would be expected to be 5 to 10%. The observed radon emanation data suggests that preferential concentration of ^{226}Ra on surfaces of smaller particles does not occur during the coal combustion process and that it is distributed throughout the particles.

TABLE 6

TYPICAL GAMMA RAY ENERGY SPECTRUM OBSERVED FOR FLY ASH AND BOTTOM ASH SAMPLES[a]

Gamma ray[c] Energy (MeV)	Emitting Nuclide	Gamma Abundance (% gamma/decay)	Relative Peak Intensity[b] Observed In Spectra
0.08	^{214}Pb x-rays, etc.	---	M
0.09	^{214}Pb x-rays, etc.	---	M
0.14	^{235}U	12 %	S
0.185	^{235}U	55 %	I
0.185	^{226}Ra	3 %	---[d]
0.21	^{228}Ac	3.5%	S
0.21	^{239}Np	3 %	---
0.21	^{227}Th	<1 %	---
0.24	^{214}Pb	4 %	M
0.24	^{224}Ra	4 %	---
0.24	^{212}Pb	47 %	---
0.24	^{227}Th	15 %	---
0.27	^{219}Rn	9 %	S
0.27	^{223}Ra	10 %	---
0.30	^{214}Pb	19 %	M
0.30	^{212}Pb	3 %	---
0.30	^{231}Pa	6 %	---
0.30	^{227}Th	8 %	---
0.34	^{228}Ac	15 %	I
0.34	^{223}Ra	6 %	---
0.352	^{214}Pb	36 %	M
0.352	^{211}Bi	14 %	---

TABLE 6 (continued)

Gamma ray[c] Energy (MeV)	Emitting Nuclide	Gamma Abundance (% gamma/decay)	Relative Peak Intensity[b] Observed In Spectra
0.463	^{228}Ac	3.7%	i
0.511	Annihilation (β^--β^+) peak		i-M
0.511	^{208}Tl	23 %	M
0.583	^{208}Tl	86% γ abundance x 36% α-β branching at ^{212}Bi = 31%	M
0.609	^{214}Bi	47 %	M
0.665	^{214}Bi	---	S
0.727	^{212}Bi	7 %	S
0.77	^{214}Bi	5 %	S
0.83	^{211}Pb	3.4%	S
0.86	^{208}Tl	12 %	S
0.91	^{228}Ac	25 %	i
0.93	^{214}Bi	3 %	S
0.969	^{228}Ac	20 %	i
1.120	^{214}Bi	17 %	i
1.24	^{214}Bi	6 %	S
1.38	^{214}Bi	5 %	S
1.4-1.41	^{214}Bi	4 %	S
1.46	^{40}K	11 %	M
1.50	? (possible random sum peak)	---	S
1.51	^{214}Bi	2.1%	S

TABLE 7

CONCENTRATIONS OF SEVERAL NATURALLY OCCURRING RADIOACTIVE NUCLIDES
IN SAMPLES OF FLY ASH, COMBINED ASH AND FGD WASTES

Sample	Sample Container Number	Sample Type	Gamma Analysis Time(Sec)	Nuclide Concentrations (pCi/g)[a] ^{228}Ra[b] (as ^{228}Ac) 0.91 MeVγ	^{228}Ac 0.96 MeVγ	^{228}Th[b] (as ^{208}Tl) 0.585 MeVγ	^{40}K 1.46 MeVγ	^{238}U (as ^{235}U) 0.186 MeVγ (minus ^{226}Ra Contribution)	Total U(ppm) (as ^{235}U)
R-11 (a)	2	fly ash	65,300	2.8	2.7	2.6	8.4		
R-11 (a)	2	fly ash	85,000	2.9	2.4	3.0	8.4	4.4	13.3
R-1(d)	23	fly ash	68,700			3.0	27.6		
R-1(d)	23	fly ash	77,000	3.6	3.2	3.0	26.7		
R-1(d)	23	fly ash	240,700	3.5	2.7	2.9	24.3	4.1	12.3
R-9 (b)	6	Combined ash	58,900			2.4	9.2		
R-9 (b)	6	Combined ash	86,513	2.7	3.0	2.4	9.2		
R-9 (b)	6	Combined ash	313,000	2.9	2.6	2.5	9.3	4.5	13.6
R-18	39	FGD	74,000	N.A.	N.A.	0.5±0.6	<5	N.A.	N.A.
R-18	39	FGD	77,000	N.A.	N.A.	0.2±0.3	0	N.A.	N.A.
R-16	32	FGD with ash	79,300	N.A.	N.A.	1.9	5.6	N.A.	N.A.
R-16	32	FGD with ash	75,800	N.A.	N.A.	1.7	5.6	N.A.	N.A.

[a] Accuracy is ±10% (estimated from calibration data) except as noted for the Sample R-18 which had very low activity and, hence, inferior statistical certainty to the data.

[b] These nuclides occur in the decay chain initiated by ^{232}Th decay. ^{232}Th activity will be similar to these activities if equilibirum exists.

[c] Not Analyzed

TABLE 8

FRACTIONAL RADON-222 EMANATION (%) IN ASH AND FGD WASTE SAMPLES

Sample	Container Number	Sample Type	Gamma Analysis Time(sec)	Fractional Radon Emanation(%)[a]	
				0.352 MeV$_\gamma$	0.609 MeV$_\gamma$
R-11 (a)	2	fly ash	65,300-85,000	5 ± 15	(8 ± 15)[c]
R-1(d)	23	fly ash	68,700-240,700	(4 ± 8)	(2 ± 6)
R-2(a)[d]	11	fly ash	60,000	6 ± 9	-
R-9(a)	6	combined fly and bottom ash	58,900-313,000	14 ± 23	2 ± 25
R-18	39	FGD	74,000-77,000	13 ± 69[b]	(66 ±178)[b]
R-16	32	FGD(with ash)	75,800-79,300	7 ± 14	12 ± 18

[a] As changes in counts, at the respective energies, of ^{241}Pb and ^{214}Bi between 30 day samples and the same sample (termed "zero" days) following flush of interstitial gases.

[b] These samples had very low initial activities and thus, large relative errors associated with each measurement

[c] Value in parenthesis indicates value for "zero day" sample was larger than 30 day old sample. See note b,

[d] Performed by DOE laboratory (Ref 10) using Marinelli flask. Sample showed no radon growth within experimental error.

The relative concentrations of ^{228}Ra and ^{228}Th (products of ^{232}Th decay) may be used to indicate whether selective pyrochemical separation of Th and Ra occurs as coal is converted to the ash. If some pyrochemical separation occurs the activity ratio of radium to thorium in the ash would be in disequilibrium (unequal) relative to the equilibrium state in the coal. This assumes that the entire decay chain of Th-232 is in equilibrium (all have half-lives of less than 7 years) and that no leaching of thorium versus radium occured in the coal over the last 35 years. Given these assumptions, the data in Table 7 suggest that within the variations observed in the data the ratios in the ash are similar to those that would have existed in coal.

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APPENDIX A

Extraction Procedure Measurements Supplemental Data

Table A-1: Summary of Quality Control Experiments: Data for Blanks

Table A-2: Calculation of Detection Limits

Table A-3: Replicate Extraction Data

TABLE A-1: Summary of Quality Control Experiments Data for Blanks[a]

Sample	Description	No of Samples	As	Ba	Cd	Cr	Hg	Pb	Se	Ag
Total System Blank	pH 5 H_2O carried through complete procedure	6	<2	110	<2	<8	<2	<3	<2	<1
Total Extraction Blank	Total System Blank without final filtration	2	<2	<30	<2	<8	<2	<3	<2	<1
Filter Blank	0.125 N Acetic Acid passed through filters	3	<2	75	<2	<8	<2	<3	<2	<1
Bottle Blank	0.125 N Acetic Acid added to containers used to store extracts	3	<2	<30	<2	<8	<2	<3	<2	<1
Distilled Water Rinse	Final Rinse of Extraction Container prior to initiation of extraction	3	<2	<30	<2	<8	<2	<3	<2	<1

[a]All concentrations in µg/L (ppb).

TABLE A-2

Calculations of Detection Limits

Element	Concentration of Standard (ppb)	RSD[a] of Replicate (%)	Detection Level[b] Estimate (ppb)
Ba	200	8.1	<40[c]
	200	7.5	<30
Cr	25	14.6	<8
	75	4.3	<7
As	20	6.8	<3
	20	4.3	<2
Ag	6	5.0	<1
	6	2.6	<1
Pb	6	2.4	<3
	10	5.8	<2
Cd	6	10.7	<2
	10	3.8	<1
Hg	6	9.7	<2
	8	11	<2
Se	20	3.5	<2
	6	9.6	<2

[a] RSD - Relative Standard Deviation of replicates (at least 3)

[b] Detection Limit = 2 x RSD x Concentration of Standard

[c] Detection Limit of 100 ppb was used due to filter blank values. See text.

TABLE A-3: Replicate Extraction Data

Sample	Concentration (ug/l)							
	Ag	As	Ba	Cd	Cr	Hg	Pb	Se
Fly Ash:								
EP-1c	<1	98	510	16	8	<2	<3	39
EP-1c (replicate)	<1	98	240	16	12	<2	<3	52
EP-2a	<1	<5	750	<2	240	<2	<3	20
EP-2a (replicate)	<1	<5	1200	<2	220	<2	<3	20
EP-17	<1	6	500	<2	14	<2	<3	5
EP-17 (replicate)	<1	6	460	<2	8	<2	<3	9

APPENDIX B

Radioactivity Measurements

Supplemental Data

Table B-1: ^{226}Ra Concentrations based on 0.352 MeV and 0.609 MeV gamma rays

Figure B-1: Gamma Ray Energy vs Channel Number Calibration

Figure B-2: Absolute Counting Efficiency vs Gamma Ray Energy Calibration

TABLE B-1

Radium-226 Concentration in Sealed Fly Ash, Bottom Ash and FGD Samples Based on High Resolution Gamma Spectroscopy of the 0.352 MeV Gamma Ray (^{214}Pb) and the 0.609 MeV Gamma Ray (^{214}Bi).

Sample Type	Container Number	Sample[a]	Sample Net Wt. (g)	Gamma Ray Analysis Time(sec)	^{226}Ra Concentration (pCi/g sample)[b] Based on 0.352 MeV gamma	Based on 0.609 MeV gamma	Average
Fly Ash:	2	R-11(a)	263.8	13,400	3.7 ± 0.4	3.8 ± 0.4	3.8 ± 0.3
	5	R-7 (a)	244.3	77,400	4.1 ± 0.2	4.0 ± 0.3	4.1 ± 0.2
	7	R-5(b)	256.2	58,503	2.6 ± 0.2	2.9 ± 0.3	3.1 ± 0.1
	7	R-5(b)	256.2	251,000	3.5 ± 0.1	3.6 ± 0.1	
	8	R-8(a)	258.5	241,500	4.9 ± 0.1	4.8 ± 0.1	4.1 ± 0.1
	9	R-15(a)	214.4	8,452	3.5 ± 0.7	4.0 ± 0.6	3.8 ± 0.5
	10	R-9 (a)	248.0	6,080	3.9 ± 0.7	3.8 ± 0.6	3.9 ± 0.5
	11	R-2(a)	266.7	59,000	3.0 ± 0.2	2.8 ± 0.2	2.9 ± 0.1
	12	R-2(b)	189.5	8,000	3.8 ± 0.6	3.9 ± 0.8	3.9 ± 0.5
	20	R-2(a)	279.7	74,300	2.8 ± 0.2	3.2 ± 0.3	2.9 ± 0.1
	20	R-2(a)	279.7	57,380	2.9 ± 0.2	2.9 ± 0.2	
	21	R-2(a)	290.4	429,195	2.8 ± 0.1	2.6 ± 0.1	
	21	R-2(a)	290.4	57,510	3.3 ± 0.3	3.2 ± 0.2	
	21	R-2(a)	290.4	15,800	2.7 ± 0.4	2.5 ± 0.4	
	22	R-14	214.9	24,000	4.3 ± 0.4	4.6 ± 0.5	4.5 ± 0.3
	23	R-1(d)	144.7	27,600	N.A.	4.3 ± 0.3	4.3 ± 0.3
	24	R-6 (a)	129.1	26,400	4.8 ± 0.4	4.5 ± 0.5	4.7 ± 0.3
	25	R-5(a)	85.5	57,200	3.0 ± 0.3	3.7 ± 0.4	3.4 ± 0.3
	26	R-13(a)	140.7	54,430	1.9 ± 0.3	1.7 ± 0.3	1.8 ± 0.2

TABLE B-1 (Continued)

Sample Type	Container Number	Sample[a]	Sample Net Wt. (g)	Gamma Ray Analysis Time(sec)	^{226}Ra Concentration (pCi/g sample)[b] Based on 0.352 MeV gamma	Based on 0.609 MeV gamma	Average
Fly Ash (Cont)	27	R-4 (a)	66.9	26,900	4.6 ± 0.7	4.8 ± 0.8	4.7 ± 0.5
	28	R-1(a)	115.3	57,800	3.2 ± 0.3	3.8 ± 0.5	3.5 ± 0.3
	29	R-12(c)	174.5	56,400	3.9 ± 0.3	4.1 ± 0.4	4.0 ± 0.3
	30	R-1(b)	175.2	23,400	4.4 ± 0.5	4.0 ± 0.5	4.2 ± 0.4
	31	R-1(c)	195.0	62,300	4.2 ± 0.3	4.4 ± 0.4	4.3 ± 0.3
	38	R-13(a)	241.0	27,550	2.2 ± 0.3	1.8 ± 0.3	2.0 ± 0.2
	15	R-3 (a)	219.5	57,200	3.3 ± 0.2	3 4 ± 0.2	3.4 ± 0.1
	16	R-10(a)	202.2	8,000	2.6 ± 0.8	3.0 ± 0.6	2.9 ± 0.3
	16	R-10(a)	202.2	16,000	2.8 ± 0.7	3.0 ± 0.6	
Bottom Ash	1	R-7(b)	352.7	59,700	3.0 ± 0.4	3.4 ± 0.3	3.2 ± 0.3
	3	R-10(b)	158.6	9,300	2.4 ± 0.7	3.1 ± 0.6	2.8 ± 0.5
	14	R-5(c)	134.2	6.610	3.9 ± 0.8	4.3 ± 1.0	4.1 ± 0.6
	18	R-12(a)	202.0	57,000	4.4 ± 0.2	4.5 ± 0.3	4.5 ± 0.2
	19	R-12(b)	140.9	18,600	4.1 ± 0.5	4.2 ± 0.8	4.2 ± 0.5
	33	R-3 (b)	203.0	58,700	1.7 ± 0.3	2.0 ± 0.3	1.9 ± 0.2
	34	R-11 (b)	195.0	241.620	1.8 ± 0.2	2.0 ± 0.2	1.9 ± 0.1
	35	R-2(c)	334.7	58,500	1.7 ± 0.3	1.6 ± 0.3	1.7 ± 0.2

TABLE B-1 (Continued)

Sample Type	Container Number	Sample[a]	Sample Net Wt. (g)	Gamma Ray Analysis Time(sec)	^{226}Ra Concentration (pCi/g sample)[b] Based on 0.352 MeV gamma	Based on 0.609 MeV gamma	Average
Combined Fly and Bottom Ash	4	R-15(b)	168.5	54,500	2.9 ± 0.3	3.2 ± 0.3	3.1 ± 0.2
	6	R-9 (b)	231.9	8,300	3.7 ± 0.6	3.4 ± 0.9	3.6 ± 0.5
Boiler Slag	13	R-4 (b)	298.4	7,200	2.4 ± 0.4	2.1 ± 0.8	2.3 ± 0.4
	17	R-6 (b)	275.5	59,500	3.6 ± 0.2	3.4 ± 0.2	3.5 ± 0.1
FGD	32	R-16	73.2	243,230	2.9 ± 0.3	3.3 ± 0.3	3.1 ± 0.2
	36	R-8 (b)	37.5	16,000	0.8 ± 0.8	1.0 ± 1.0	0.9 ± 0.6
	37	R-13(b)	42.2	52,660	0.6 ± 1.6	0.4 ± 0.6	<1.3
	39	R-18	40.1	74,000	0.4 ± 0.2	0.2 ± 0.1	0.3 ± 0.1

[a]Samples listed according to code given to various plants

[b]Error (± 1 standard deviation) based on gamma ray counting statistics (See reference 11).

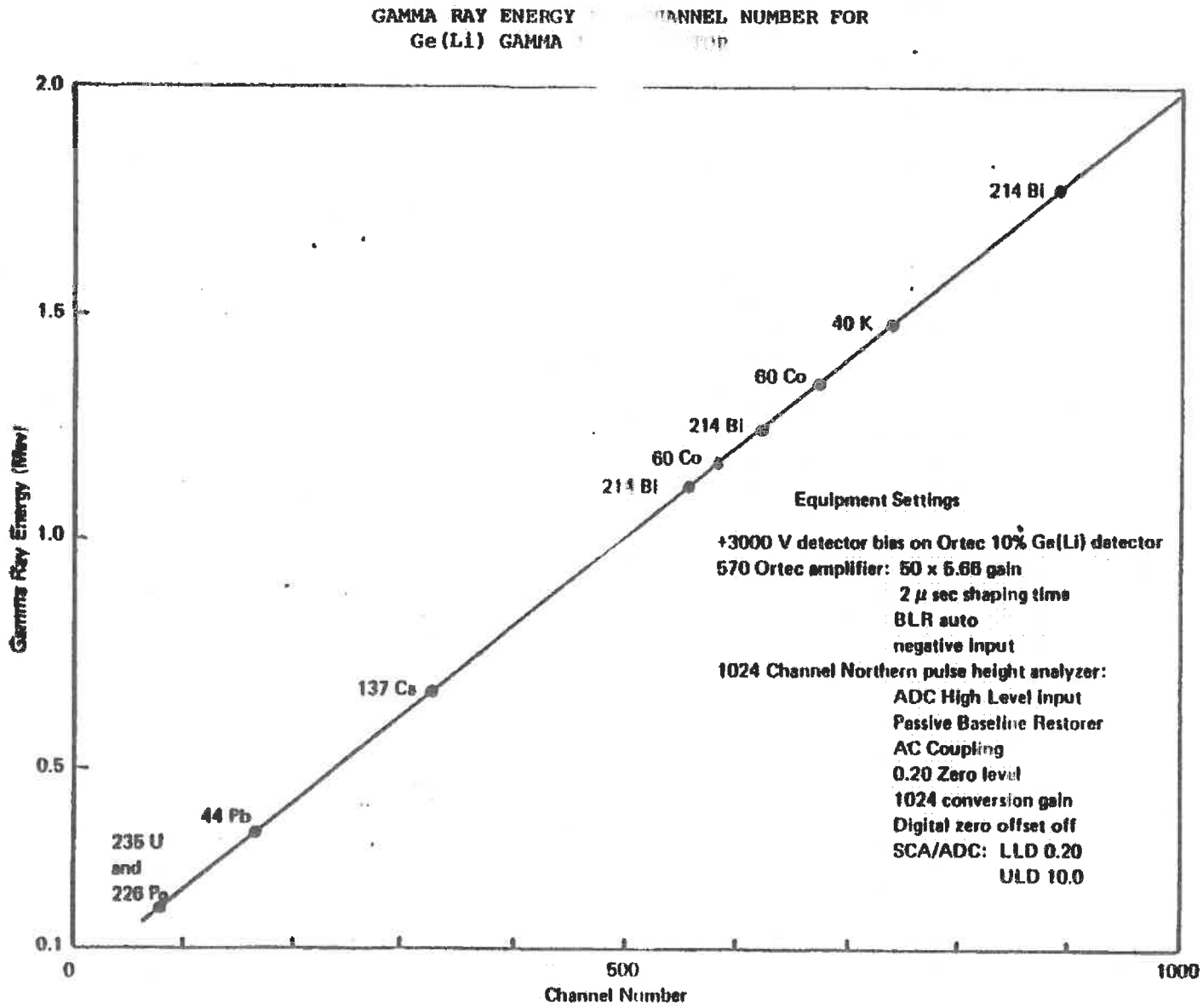
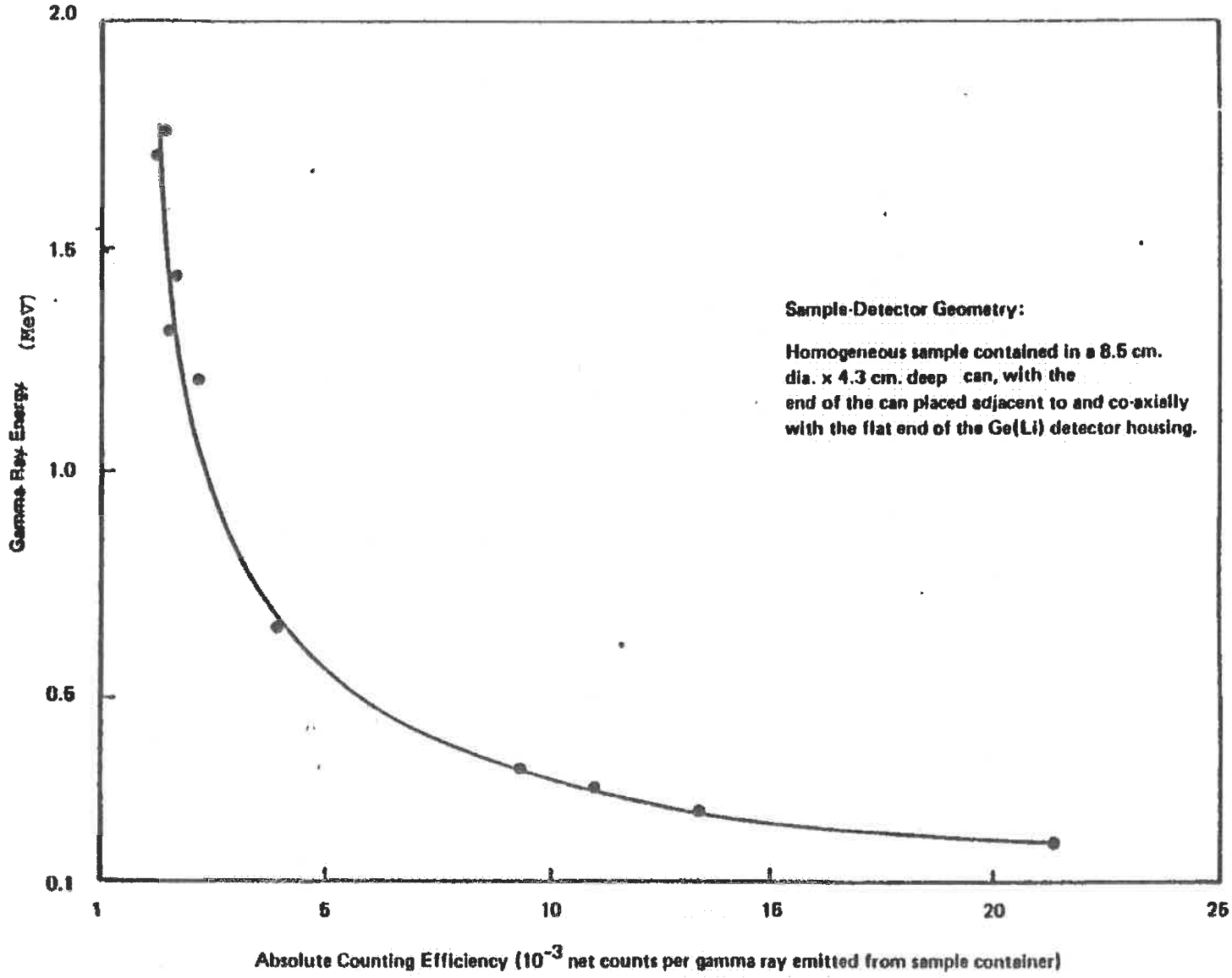

GAMMA RAY ENERGY
Ge(Li) GAMMA
Gamma Ray Energy (Mev)
2.0
1.5
1.0
0.5
0.1
0
500
1000
Channel Number
214 Bi
40 K
60 Co
214 Bi
60 Co
214 Bi
137 Cs
44 Pb
235 U
and
226 Ra
Equipment Settings
+3000 V detector bias on Ortec 10% Ge(Li) detector
570 Ortec amplifier: 50 x 5.66 gain
2 μ sec shaping time
BLR auto
negative input
1024 Channel Northern pulse height analyzer:
ADC High Level Input
Passive Baseline Restorer
AC Coupling
0.20 Zero level
1024 conversion gain
Digital zero offset off
SCA/ADC: LLD 0.20
ULD 10.0

FIGURE B-1

ABSOLUTE COUNTING EFFICIENCY AS A FUNCTION OF THE GAMMA RAY ENERGY FOR A FIXED SAMPLE/DETECTOR GEOMETRY



FIGU -2

APPENDIX E

PHYSICAL SAMPLING AND ANALYSIS DATA

FULL-SCALE FIELD EVALUATION OF WASTE DISPOSAL FROM COAL-FIRED ELECTRIC GENERATING PLANTS

By

Chakra J. Santhanam
Armand A. Balasco
Itamar Bodek
Charles B. Cooper
John T. Humphrey (Haley & Aldrich, Inc.)
and
Barry K. Thacker (Bowser-Morner Testing Laboratories)

Arthur D. Little, Inc.
Acorn Park
Cambridge, Massachusetts 02140

EPA Contract 68-02-3167

EPA Project Officer: Julian W. Jones
Industrial Environmental Research Laboratory*
Office of Environmental Engineering and Technology
Research Triangle Park, North Carolina 27711

Prepared For

U.S. Environmental Protection Agency
Office of Research and Development
Washington, DC 20460

(*) Now, Air and Energy Engineering Research Laboratory

APPENDIX E

Physical Sampling and Analysis Data

This appendix provides the physical sampling and analysis data as discussed in the main body of the report. This appendix contains data in the following areas for each site.

- site map
- QA/QC results
- permeability data (constant head)
- void ratio vs pressure
- extended permeability tests (limited number of sites)
- unconsolidated - undrained triaxial tests (limited number of sites)
- specific gravity
- soil classifications
- data summary sheets

These data are reported by site in the following sections.

	Page
• Allen	E-3
• Elrama	E-43
• Dave Johnston	E-114
• Sherco	E-153
• Smith	E-191
• Powerton	E-226

Allen Duke Power

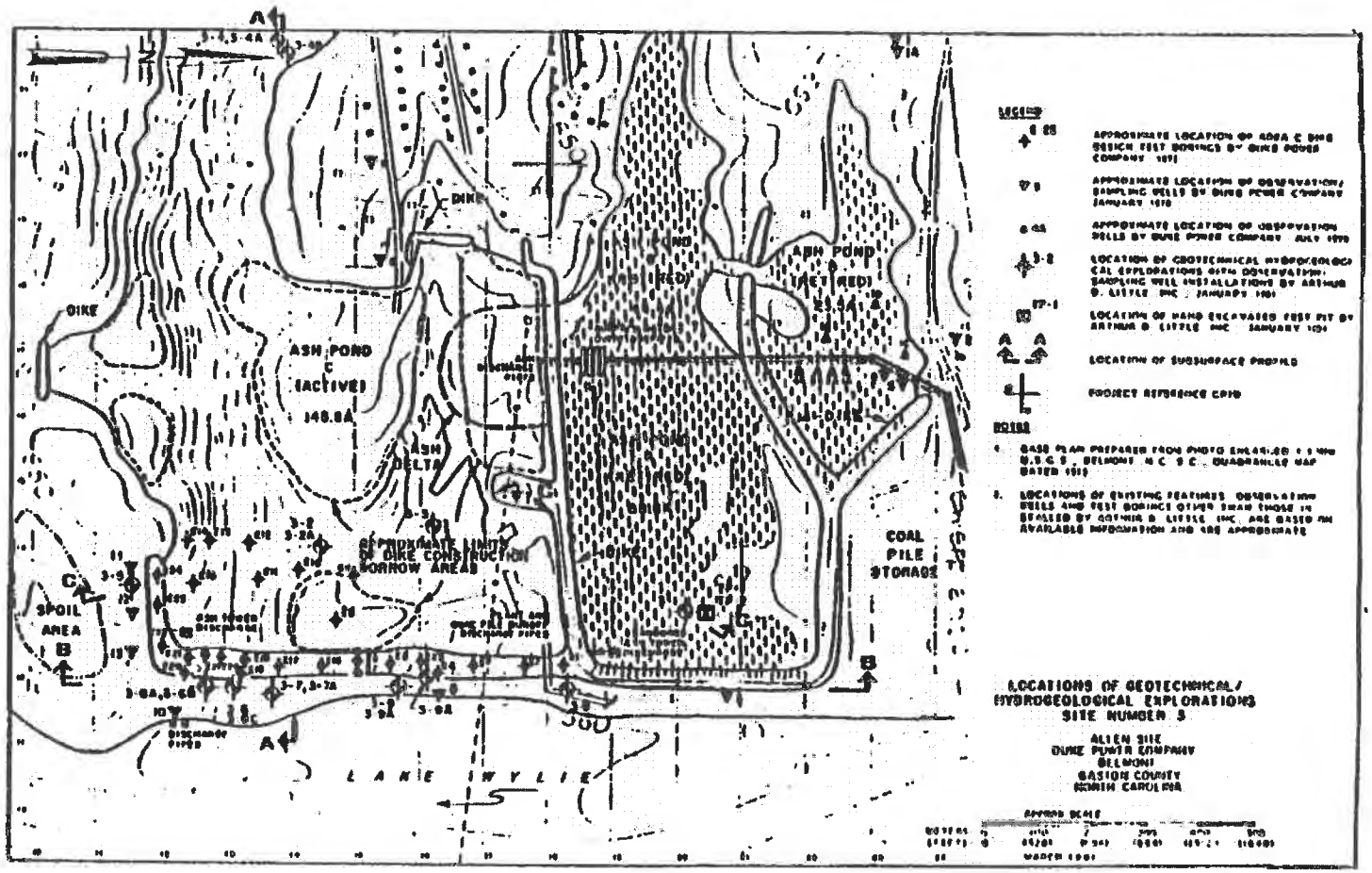

DIKE
ASH POND C (ACTIVE)
ASH DELTA
APPROXIMATE LIMITS OF DIKE CONSTRUCTION BORROW AREAS
ASH POND (INACTIVE)
COAL PILE STORAGE
SPOIL AREA B
LAKE WYLIE
LOCATIONS OF GEOTECHNICAL/ HYDROGEOLOGICAL EXPLORATIONS SITE NUMBER 3
ALLEN SITE
DUKE POWER COMPANY
BELMONT
GASTON COUNTY
NORTH CAROLINA

FIGURE 9.4

EPA CONTRACT 68-02-3167

ADL CASE 84000

PHYSICAL TESTING RESULTS

1.0	ALLEN	DUKE POWER
2.0	ELRAMA	DUQUESNE LIGHT & CSI
3.0	DAVE JOHNSTON	PACIFIC POWER & LIGHT
4.0	SHERCO	NORTHERN STATES POWER
5.0	POWERTON	COMMONWEALTH EDISON
6.0	LANSING SMITH	GULF POWER

UNIVERSITY OF LOUISVILLE
LOUISVILLE, KENTUCKY 40292

SPEED SCIENTIFIC SCHOOL
JAMES BRECKENRIDGE SPEED FOUNDATION
DEPARTMENT OF CIVIL ENGINEERING

September 23, 1981

MEMORANDUM TO: C. J. Santhanam, ADL

FROM.....: C. R. Ullrich, UL CRUllrich

SUBJECT.....: QA/QC Physical Property Tests

Please find attached a summary of results of QA/QC tests performed at the University of Louisville on samples from the Allen Plant. All samples tested consisted of ash materials, thus unconfined compression tests could not be performed. Test results are reported for permeability tests performed on remolded, compacted samples representing three depth intervals.

QA/QC physical property tests on Shelby tube samples and jar samples from Sherco are under way. We will provide results to you when testing is completed.

lw

SUMMARY OF RESULTS

QA/QC PHYSICAL PROPERTY TESTS

ALLEN PLANT

Boring No.: 3-1

Sample No.: 5C

Depth: 20'0" - 22'0"

Date of sampling: January 22, 1981

*Results of permeability tests on remolded, compacted samples:

Depth Interval (ft.)	Material	Water Content (%)	Moist Density (pcf)	Dry Density (pcf)	Coefficient of Permeability (cm/sec)
20'0"-20'8"	ash	5.0	110.4	104.8	4.27 x 10^{-3}
20'8"-21'2"	ash	6.0	116.1	109.2	2.29 x 10^{-3}
21'2"-22'0"	ash	35.8	104.2	76.5	2.00 x 10^{-3}

CONSTANT HEAD
PERMEABILITY TEST
LABORATORY COMPACTED

Project:	Allen Disposal Site
Material Description:	Flyash
Method of Compaction:	Puddled into mold

SPECIMEN DATA

Compaction:	
Maximum Dry Unit Weight:	63.7 pcf
Optimum Moisture Content:	14.5%
Test Method:	ASTM-D698-70-Method "C" Standard
Dimensions:	
Height:	4.002"
Diameter:	4.505"
Weight:	
Initial:	3.00 lbs.
Moisture Content:	
Initial:	55.6%
Final:	57.5%
Wet Unit Weight:	
Initial:	81.3 pcf
Final:	82.2 pcf
Dry Unit Weight:	
Initial:	52.2 pcf
% Compaction:	81.9
Back Pressure Saturation:	
Pressures:	5.0 psi
Permeability:	
k =	2×10^{-4} cm/sec

Calculations:

Formula: $k=\frac{QLC}{thD^2}$

Where for lost reading:

Q=161 cc
L=4.505"
t=378 seconds
h=5.0 psi
D^2=16.016 $inches^2$
C=0.0071297
k=2×10^{-4} cm/sec

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Testing Laboratories, Inc.

Constant Head

Permeability Test

Project:	Allen Disposal Site
Boring No.:	3-1A
Sample No.:	1B
Depth Interval of Sample:	4.0' - 5.5'
Depth Interval of Test Specimen:	4.5' - 5.0'

SPECIMEN DATA:

Dimensions, inches,	
Height:	5.968"
Diameter:	2.931"
Weight, lbs.,	
Initial:	1.85
Moisture Content, %:	
Initial:	35.6
Final:	43.9
Wet Unit Weight, pcf,	
Initial:	79.4
Final:	84.3
Dry Unit Weight, pcf,	
Initial:	58.6
Back Pressure Saturation, psi,	
Pressures:	10.0
Material Description:	Gray Flyash
Permeability, cm/sec,	
k:	9×10^{-6}

Calculations:

Formula: $k = \frac{QLC}{thD^2}$

Where for last reading:

Q=53.1 cc
L=5.968"
t=2940 seconds
h=10.0 psi
D^2=8.590 $inches^2$
C=0.0071297
k=9×10^{-6} cm/sec

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Testing Laboratories, Inc

Constant Head

Permeability Test

Project:	Allen Disposal Site
Boring No.:	3-ITPI
Sample No.:	SC
Depth Interval of Sample:	1.5' - 3.0'
Depth Interval of Test Specimen:	1.5' - 2.0'

SPECIMEN DATA:

Dimensions, inches,	
Height:	5.953
Diameter:	2.854
Weight, lbs.,	
Initial:	2.20
Moisture Content, %:	
Initial:	36.3
Final:	35.4
Wet Unit Weight, pcf,	
Initial:	99.8
Final:	99.1
Dry Unit Weight, pcf,	
Initial:	73.2
Back Pressure Saturation, psi,	
Pressures:	10.0
Material Description:	Gray Flyash
Permeability, cm/sec,	
k:	2×10^{-5}

Calculations:

Formula: $k = \frac{QLC}{thD^2}$

Where for Last Reading:

Q=47.7 cc
L=5.953"
t=1500 seconds
h=10.0 psi
D^2=8.145 $inches^2$
C=0.0071297
k=2×10^{-5} cm/sec

PERMEABILITY TEST
LABORATORY COMPACTED

Project:	Allen Disposal Site
Material Description:	Flyash
Method of Compaction:	Static

SPECIMEN DATA

Compaction:	
Maximum Dry Unit Weight:	63.7 pcf
Optimum Moisture Content:	14.5%
Test Method:	ASTM-D698-70-Method "C" Standard
Dimensions:	
Height:	1.978"
Diameter:	2.684"
Weight:	
Initial:	0.47 lbs.
Moisture Content:	
Initial:	18.2%
Final:	42.1%
Wet Unit Weight:	
Initial:	72.6 pcf
Final:	87.2 pcf
Dry Unit Weight:	
Initial:	61.4 pcf
% Compaction:	96.4
Back Pressure Saturatio.	
Pressures:	10.0 psi
Permeability:	
K =	1×10^{-7} cm/sec

Calculations:

Formula:	$k=\frac{QLC}{thD^2}$
Where at last reading:	Q=17 cc L=1.978" t=25200 seconds h=10.0 psi D^2=7.204 inches^2 C=0.0071297 k=1 x 10^{-7} cm/sec

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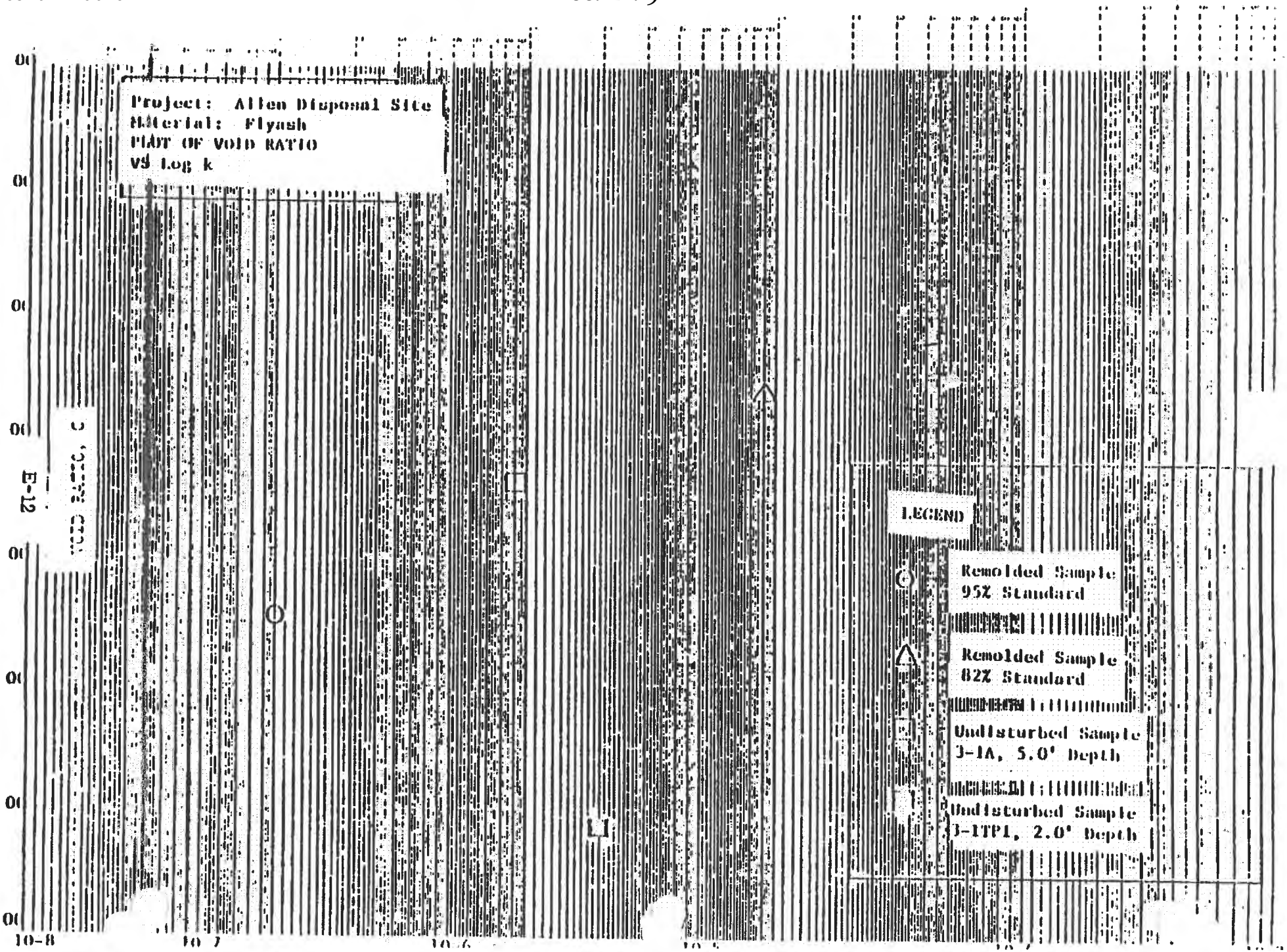
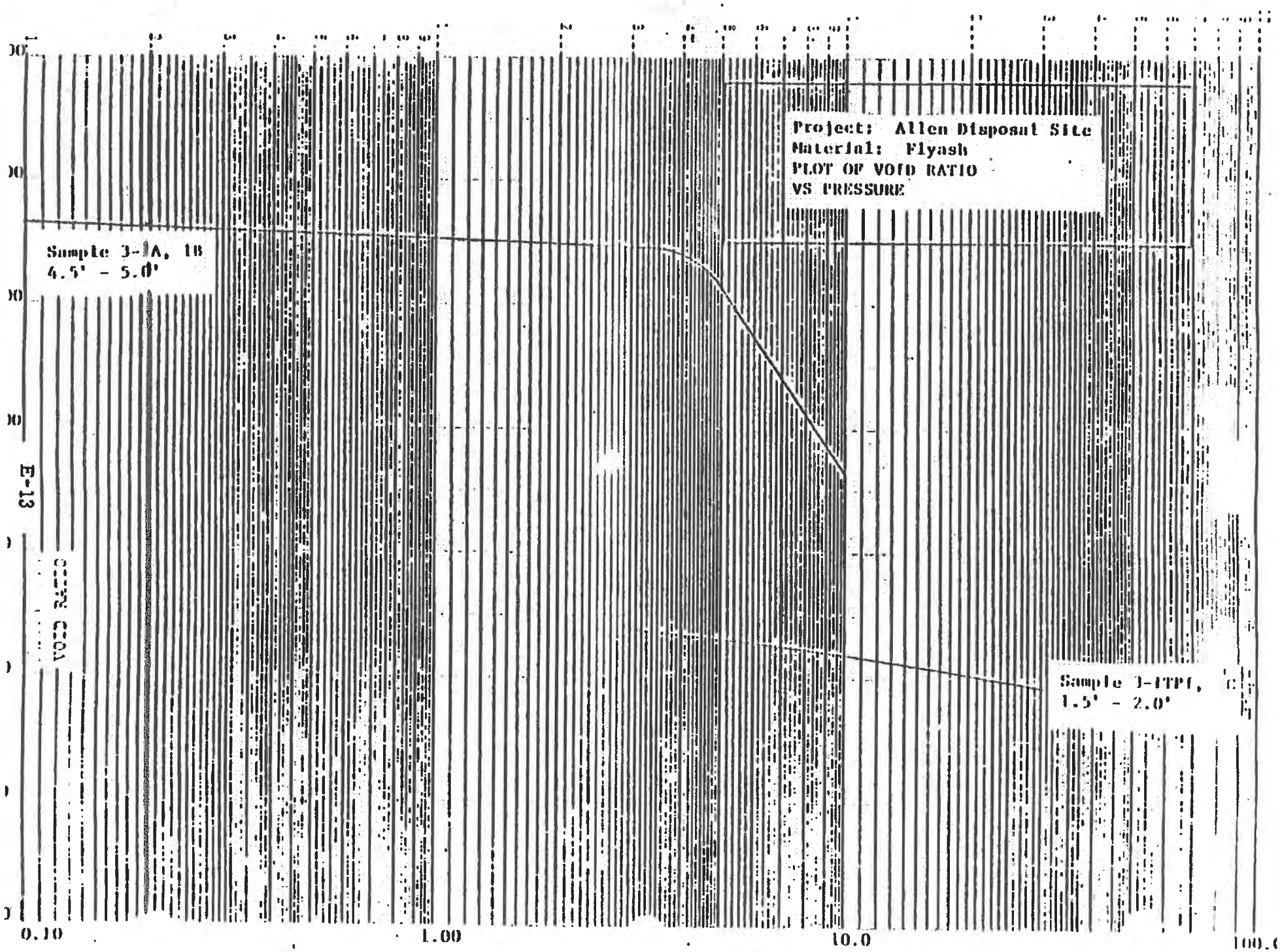

Project: Allen Disposal Site
Material: Flyash
PLOT OF VOID RATIO
vs Log k
LEGEND
Remolded Sample
95% Standard
Remolded Sample
82% Standard
Undisturbed Sample
3-1A, 5.0' Depth
Undisturbed Sample
3-1TP1, 2.0' Depth
10-8
10-7
10-6

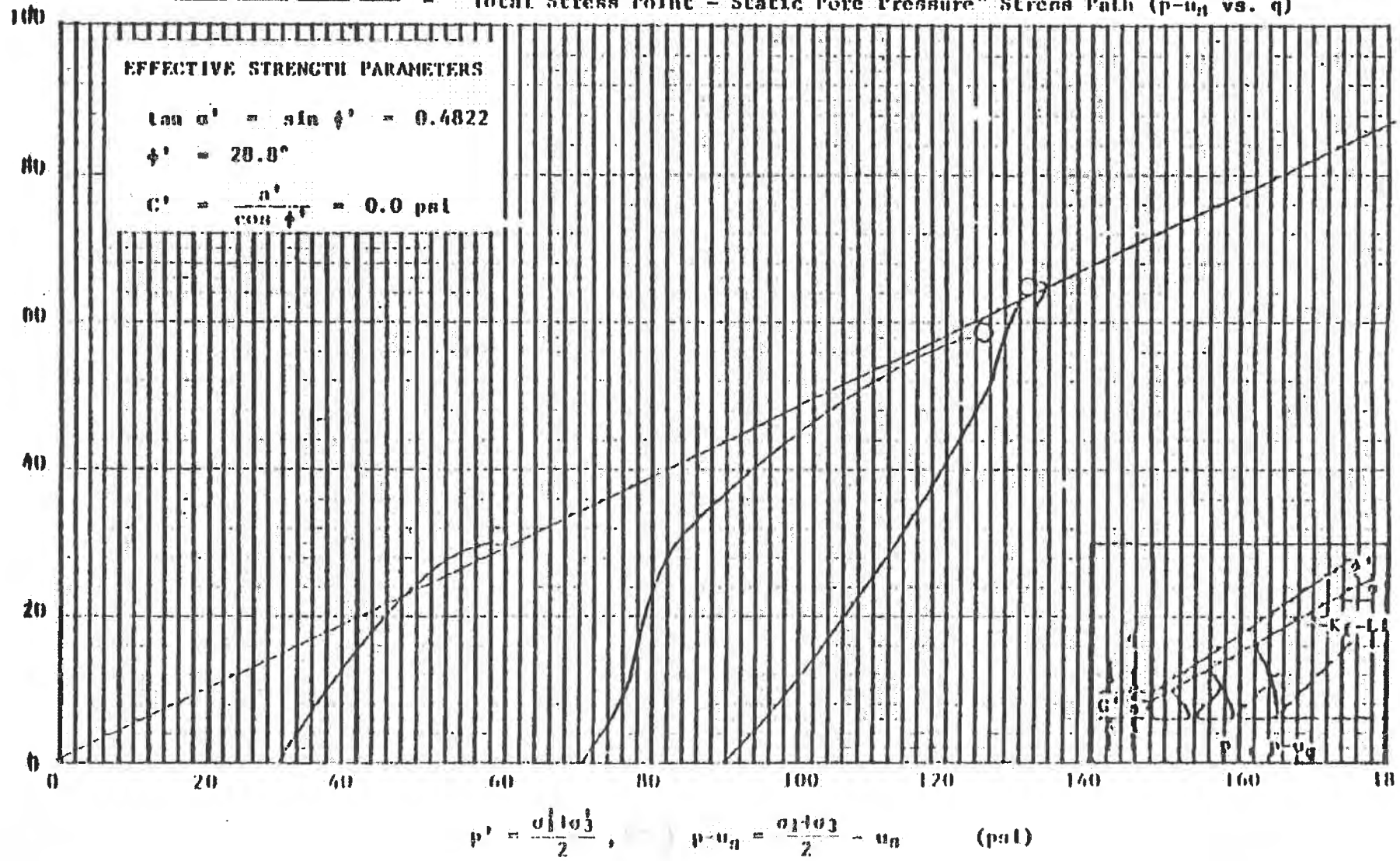

Project: Allen Disposal Site
Material: Flyash
PLOT OF VOID RATIO
VS PRESSURE
Sample B-1A, 1B
4.5' - 5.0'
Sample B-1TP1,
1.5' - 2.0'
E-13
0.10
1.00
10.0

CONSOLIDATED-UNDRAINED TRIAXIAL STRESS PATHS

TEST NO. 1

Project: Arthur D. Little, Allen Disposal Site
Material: Fill of dark gray flyash, source; 3-ITP-1, 5C; 3-1A, 1B

0 = Maximum Principal Effective Stress Ratio
——— = Effective Stress Path (p' vs. q)
— — — = "Total Stress Point - Static Pore Pressure" Stress Path ($p-u_a$ vs. q)



E-14

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CON- UNDRAINED TRIAXIAL TEST SUMMARY

SAMPLE CONDITIONS

	Test Sample 1	Test Sample 2	Test Sample 3	Test Sample 4	Test Sample 5
Sample Preparation:		- Undisturbed -			
Material:		Fill of Gray Flyash			
Boring No.:		3-IIPI	3-IIPI	3-1A	
Sample No.:		5C	5C	1B	
Depth (ft):		2.0-2.5	1.5-2.0	4.5-5.0	
Lateral Pressure (psi),					
Saturation Phase:		15.0	15.0	15.0	
Consolidation Phase:		40.0	70.0	100.0	
Back Pressure (psi),					
Saturation Phase:		10.0	10.0	10.0	
Consolidation Phase:		10.0	10.0	10.0	
Effective Consolidation Pressure (psi):		30.0	60.0	90.0	
Skempton B-Value at Initiation of Consolidation Phase:		0.37	1.00*	1.00*	
Deformation Rate, (Inches Per Minute):		0.01	0.01	0.01	
Specimen Weight (lbs):		2.04	2.20	1.85	
Specimen Height (in),					
Initial:		5.930	5.953	5.968	
Consolidated:		5.664	5.928	5.904	
End of Test:		4.531	4.742	4.723	
Specimen Diameter (in),					
Initial:		2.838	2.854	2.838	
Consolidated:		2.711	2.842	2.808	
Moisture Content (%),					
Initial:		43.6	36.3	35.6	
Final:		45.0	38.7	48.8	
Wet Unit Weight (pcf),					
Initial:		94.0	99.8	84.3	
Consolidated:		111.1	102.9	95.6	
Dry Unit Weight (pcf),					
Initial:		65.5	73.2	62.2	
Consolidated:		75.1	74.2	64.2	
Specific Gravity:			2.18		
Degree of Saturation (%),					
Initial:		88.0	92.3	65.2	
Final:		100.0	100.0	95.3	
At Maximum Principal Effective Stress Ratio,					
$p' = (\sigma'_1 + \sigma'_3)/2$, (psi):		58.5	124.6	130.5	
$q' = (\sigma'_1 - \sigma'_3)/2$, (psi):		30.1	55.3	64.6	

*Saturated before consolidation

Measured Strength Parameters:

Effective ϕ' (°) = 28.6°

C' (psi) = 0.0

2AM9S

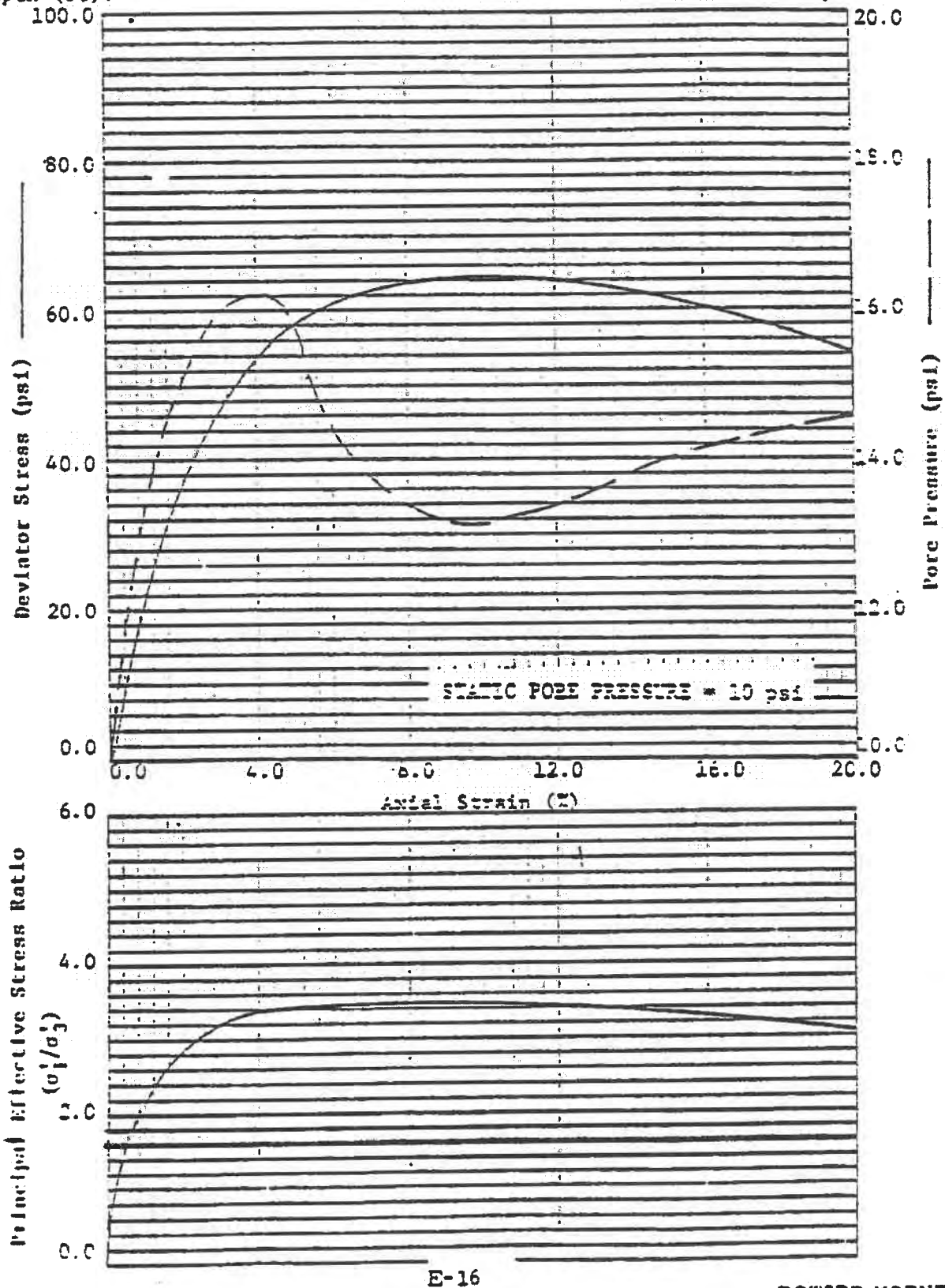
CONSOLIDATED-UNDRAINED TRIAXIAL TEST

TEST NO. 1
SAMPLE NO. 1

Project: Arthur D. Little, Allen Disposal Site
Material: Fill of Gray Flyash

Boring No: B-[illegible]
Sample No: SC
Depth (ft): 2.0 - 2.5

Lateral Pressure (psi): 40.0
Back Pressure (psi): 10.0
Effective Consolidation Pressure (psi): 30.0



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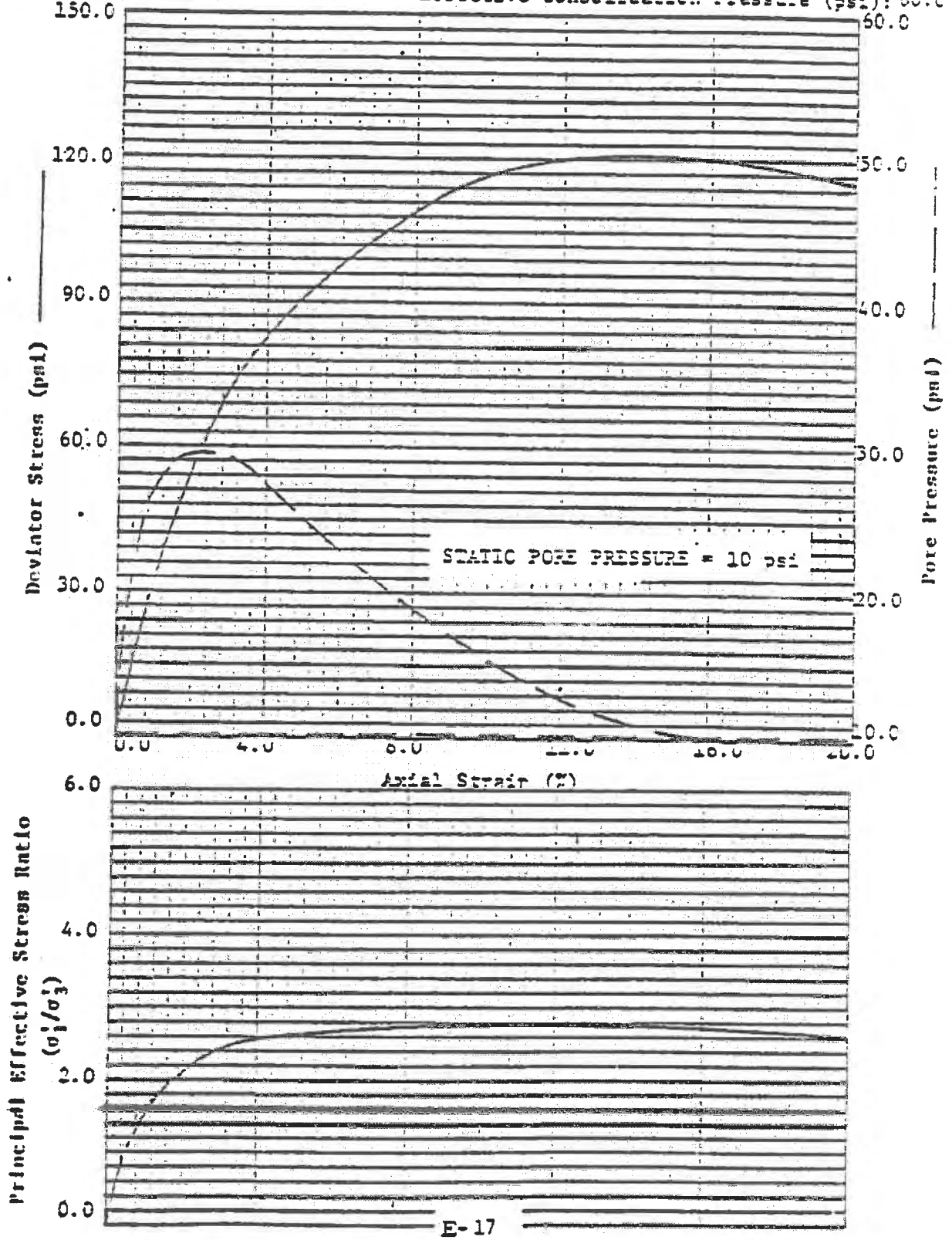
CONSOLIDATED-UNDRAINED TRIAXIAL TEST

TEST NO. 1
TRIP NO. 2

Project: Arthur D. Little, ... n Disposal Site
Material: Fill of Gray Flyash

Boring No: 3-ITPI
Sample No: 5C
Depth (ft): 1.5 - 2.0

Lateral Pressure (psi): 70.0
Back Pressure (psi): 10.0
Effective Consolidation Pressure (psi): 60.0



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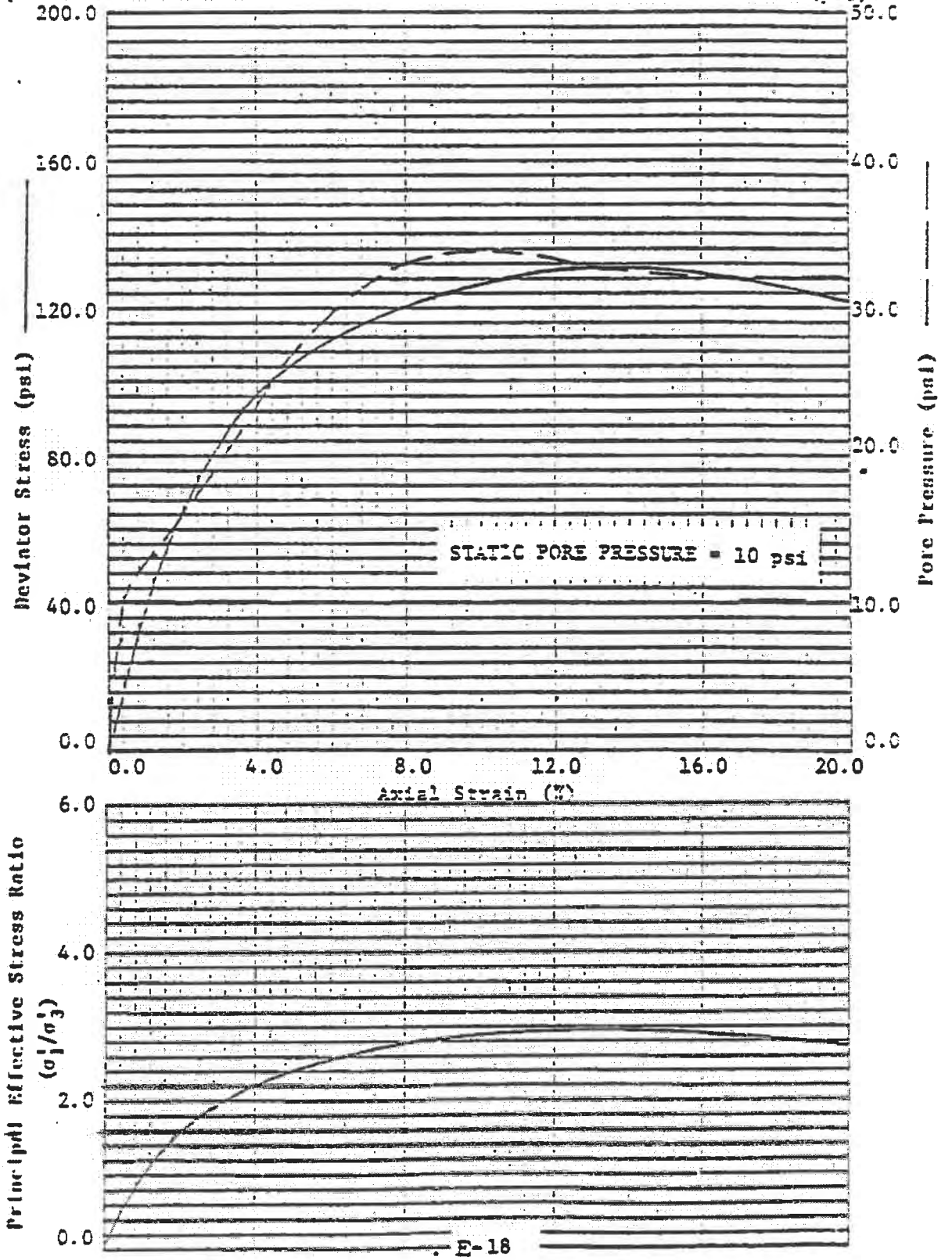
CONSOLIDATED-UNDRAINED TRIAXIAL TEST

TEST NO. 1
SAMPLE NO. 3

Project: Arthur D. Little, Allen Disposal Site
Material: Fill of Gray Flyash

Boring No: B-2A
Sample No: 1B
Depth (ft): 4.5 - 5.0

Lateral Pressure (psi): 100.0
Back Pressure (psi): 10.0
Effective Consolidation Pressure (psi): 90.0



E-18

BOWSER-MORNER

SPECIFIC GRAVITY OF SOILS

Project: Arthur D. Little, Allen Disposal Site

Boring #	Sample #	Specific Gravity
3-1A	1B	2.18
3-2	5A-1	1.96
3-2	8A-1	2.09
3-3	1A-1	2.20
3-3	4A-1	2.02
3-ITPI	5C	2.15
Bag Sample		2.08
	Average	2.10

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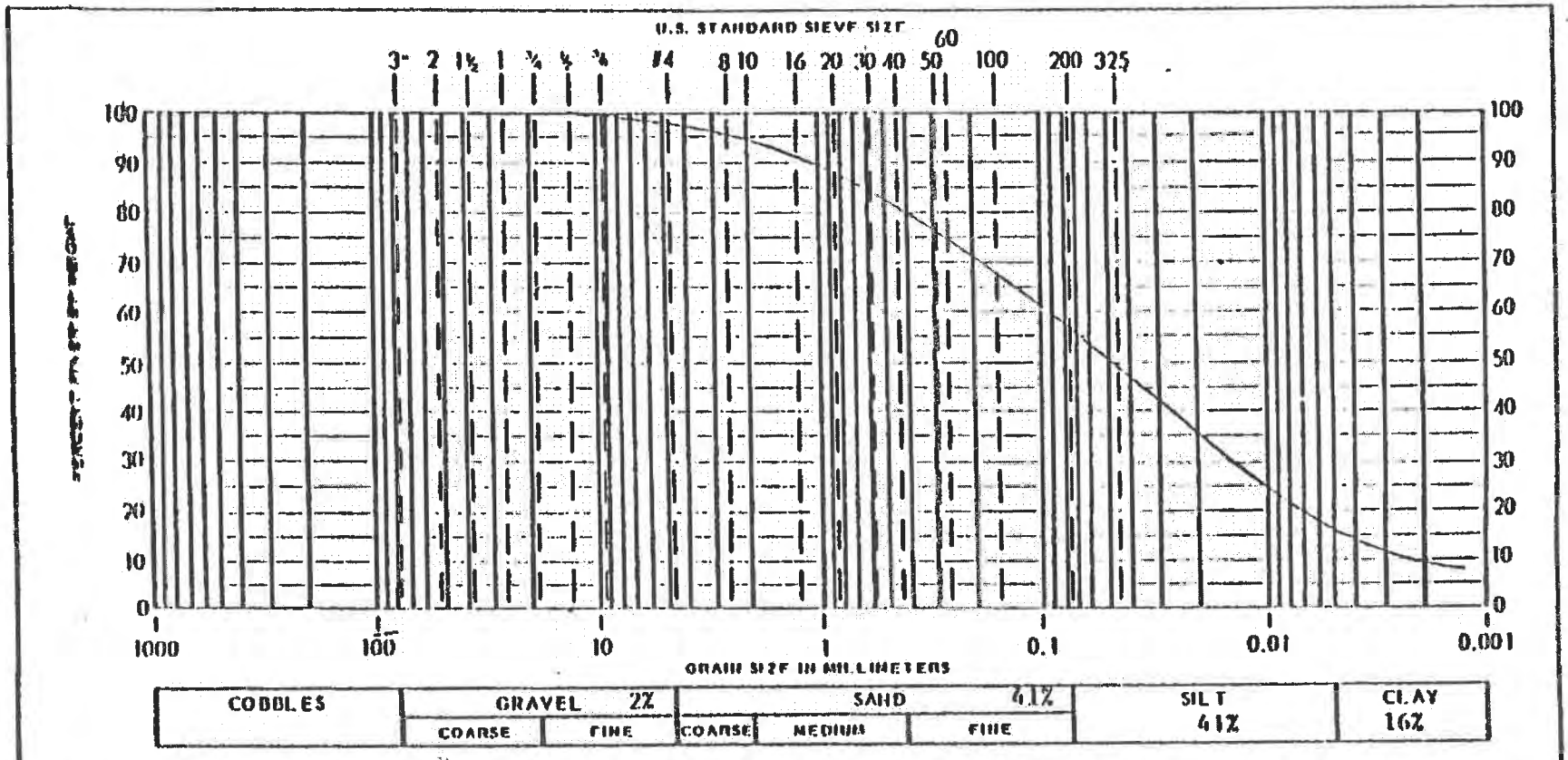
Testing Laboratories, Inc

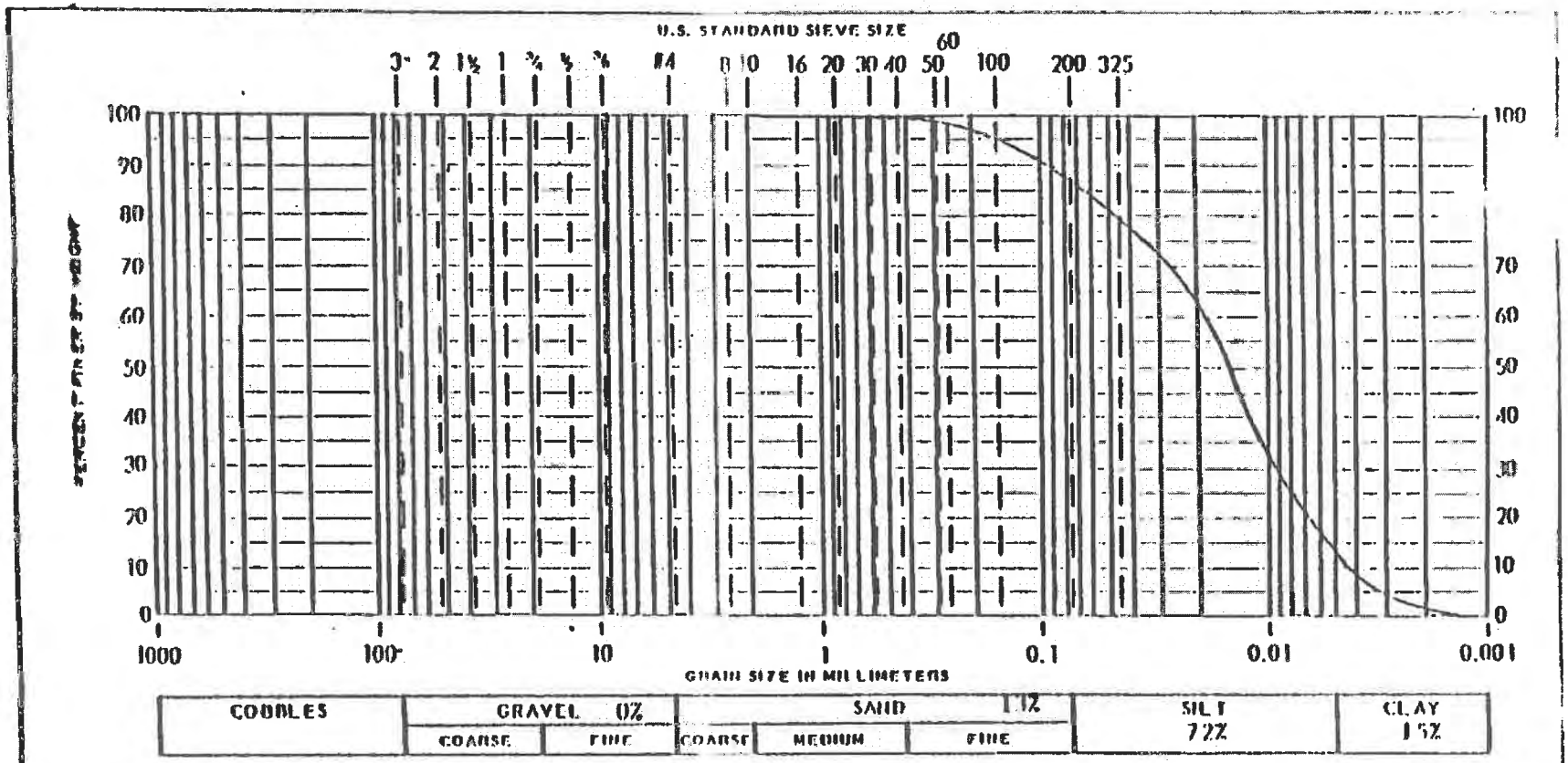
SOIL CLASSIFICATION SHEET



PROJECT	Arthur D. Little Allen Disposal Site	NATURAL % MOISTURE	29.4
BORING NO.	3	LIQUID LIMIT	Tested
SAMPLE NO.	3A	PLASTIC LIMIT	Non
DEPTH	16.0' - 18.0'	PLASTICITY INDEX	Plastic
CLASSIFICATION	"ML" Sandy Silt	COLOR	Gray
		REMARKS	"U.S.C.S."

DOWSER-MORNER
TESTING LABORATORIES, INC.

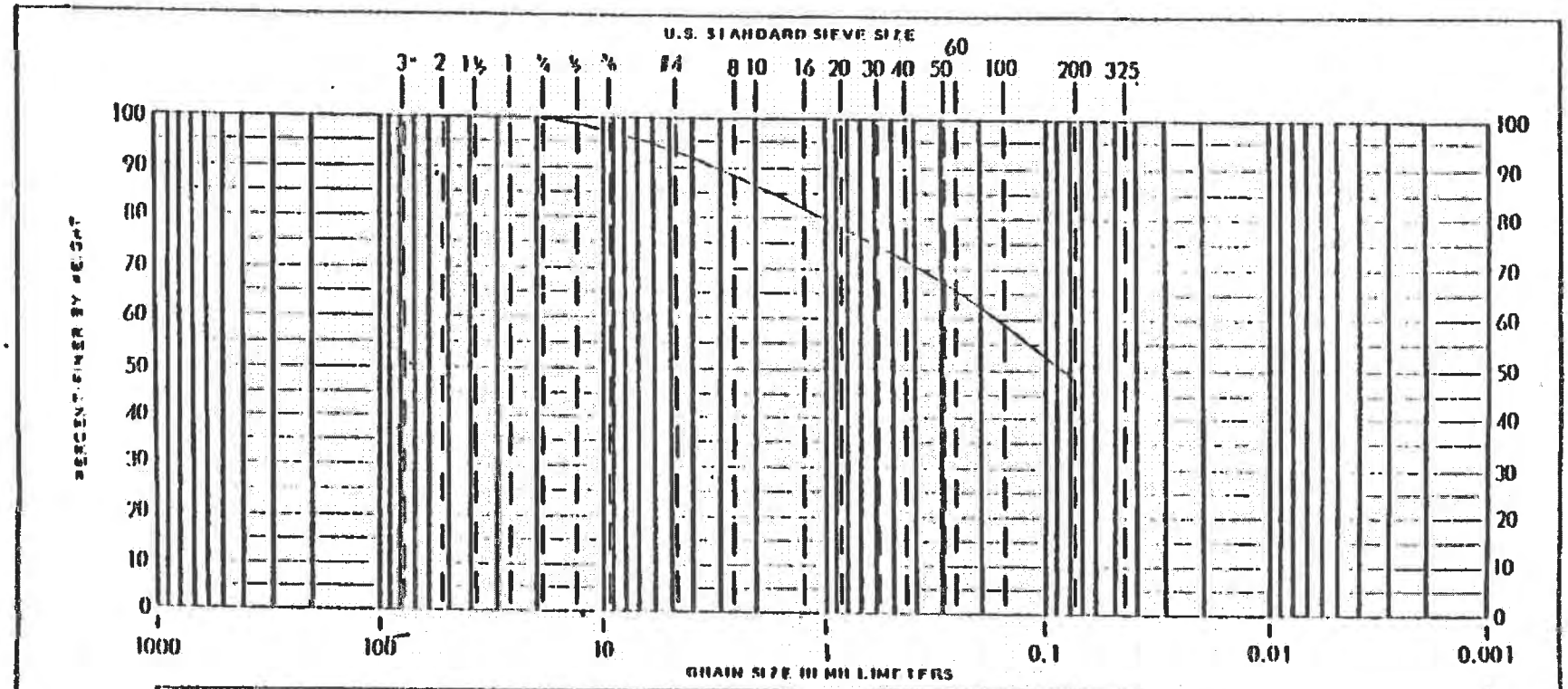
SOIL CLASSIFICATION SHEET



PROJECT	Arthur D. Little Allen Disposal Site	NATURAL % MOISTURE	Saturated
BORING NO.	B-1TPI	LIQUID LIMIT	Tested
SAMPLE NO.	SC	PLASTIC LIMIT	Non
DEPTH	1.5' - 3.0'	PLASTICITY INDEX	Plastic
CLASSIFICATION	"ML" Sandy "SILT"	COLOR	Gray
		REMARKS	"U.S.C.S."

BOWSER-MORNER
TESTING LABORATORIES, INC.

SOIL CLASSIFICATION SHEET



project	Arthur D. Little Allen Dinpoint Site	NATURAL % MOISTURE	Saturated
		LIQUID LIMIT	Visually
nothing no.	3-1	PLASTIC LIMIT	Non
sample no	5A	PLASTICITY INDEX	Plastic
depth	30.0' - 31.5'	COLOR	Gray
CLASSIFICATION	"SM" Silty Sand	REMARKS	"U.S.C.S."

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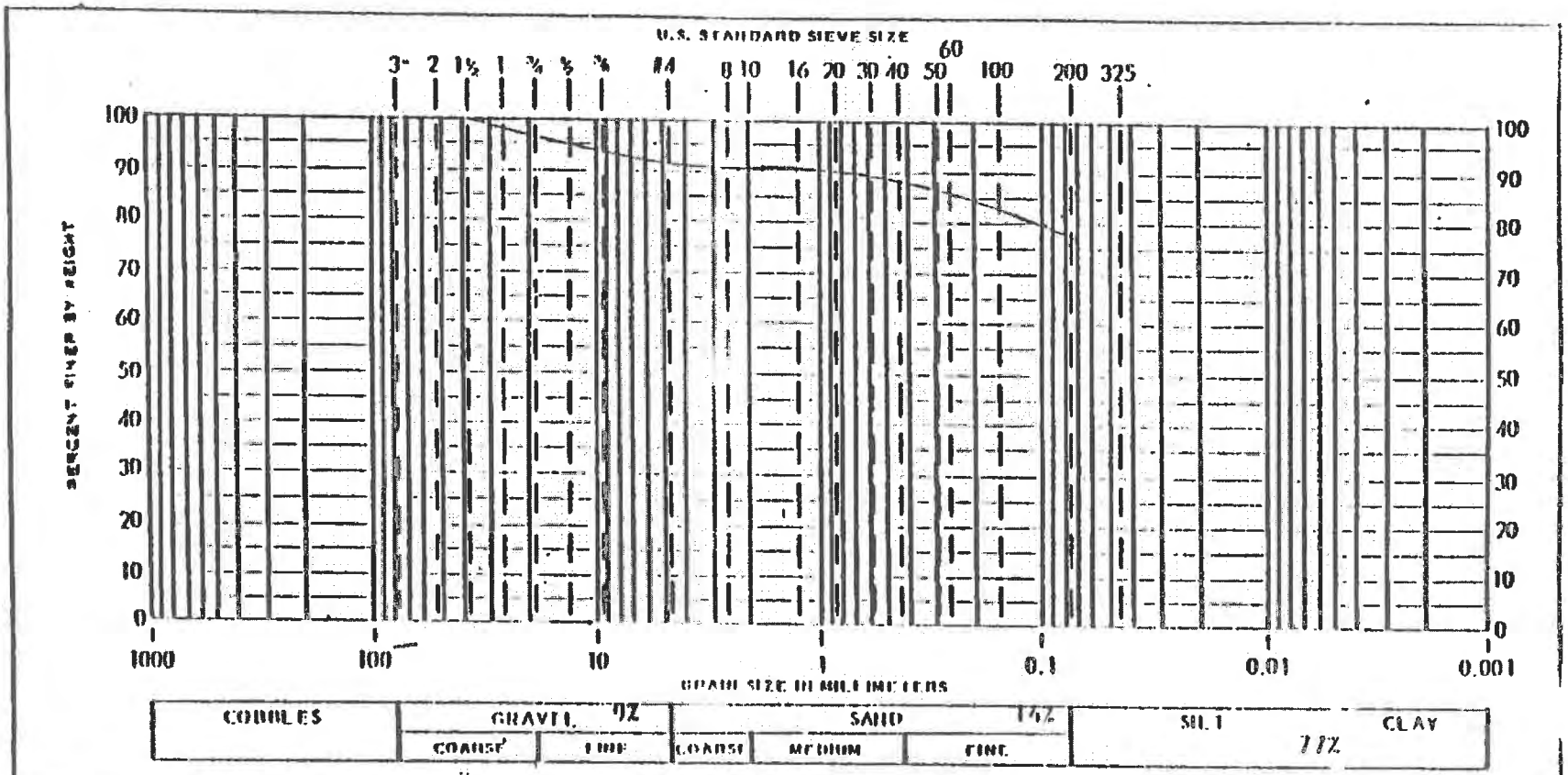
TESTING LABORATORIES, INC.

3-22

SOIL CLASSIFICATION SHEET

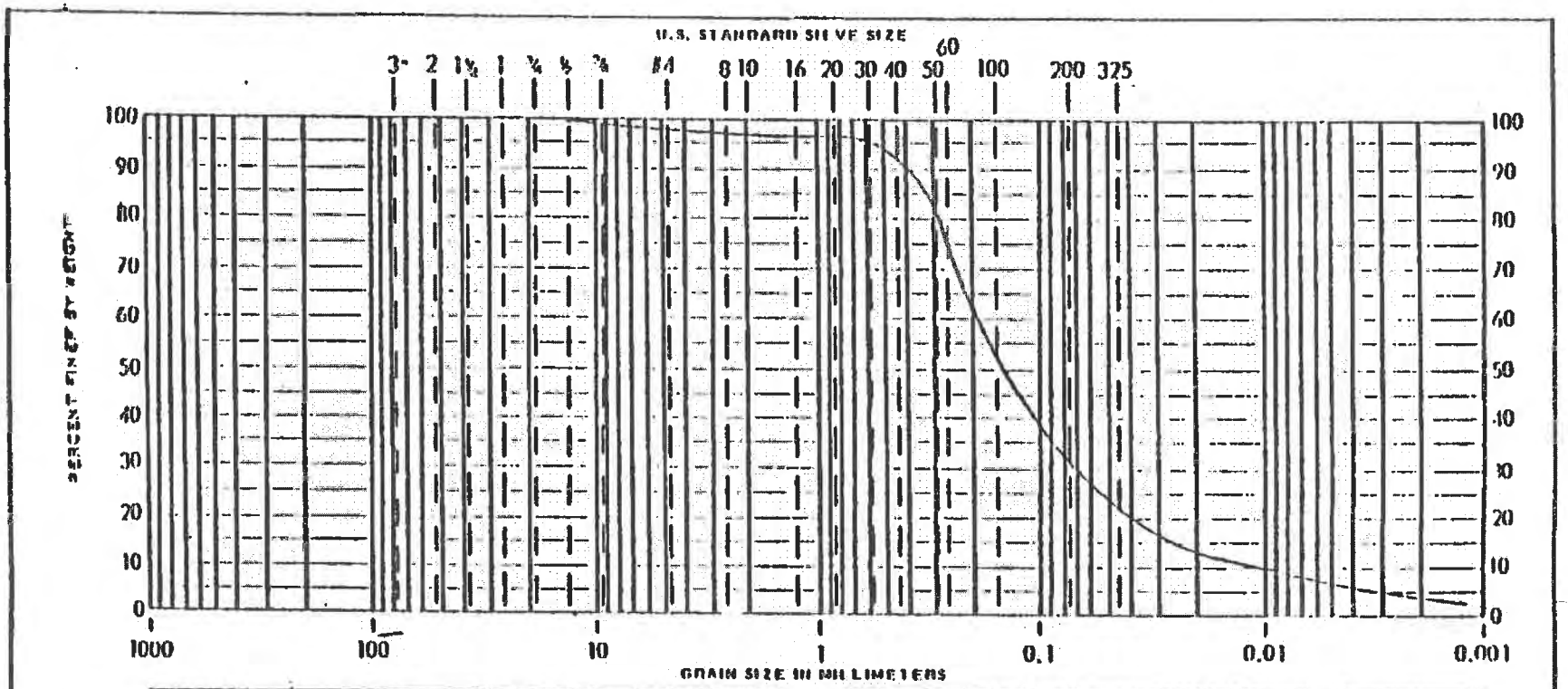


PROJECT	Arthur D. Little Allen Disposal Site	NATURAL % MOISTURE	Saturated
BORING NO.	3-1	LIQUID LIMIT	Visually
SAMPLE NO.	9A	PLASTIC LIMIT	Non
DEPTH	55.0' - 56.5'	PLASTICITY INDEX	Plastic
CLASSIFICATION	"ML" Sandy Silt	COLOR	Gray
		REMARKS	"U.S.C.S."

BOWSER-MORNER
TESTING LABORATORIES, INC.

E- 23

SOIL CLASSIFICATION SHEET

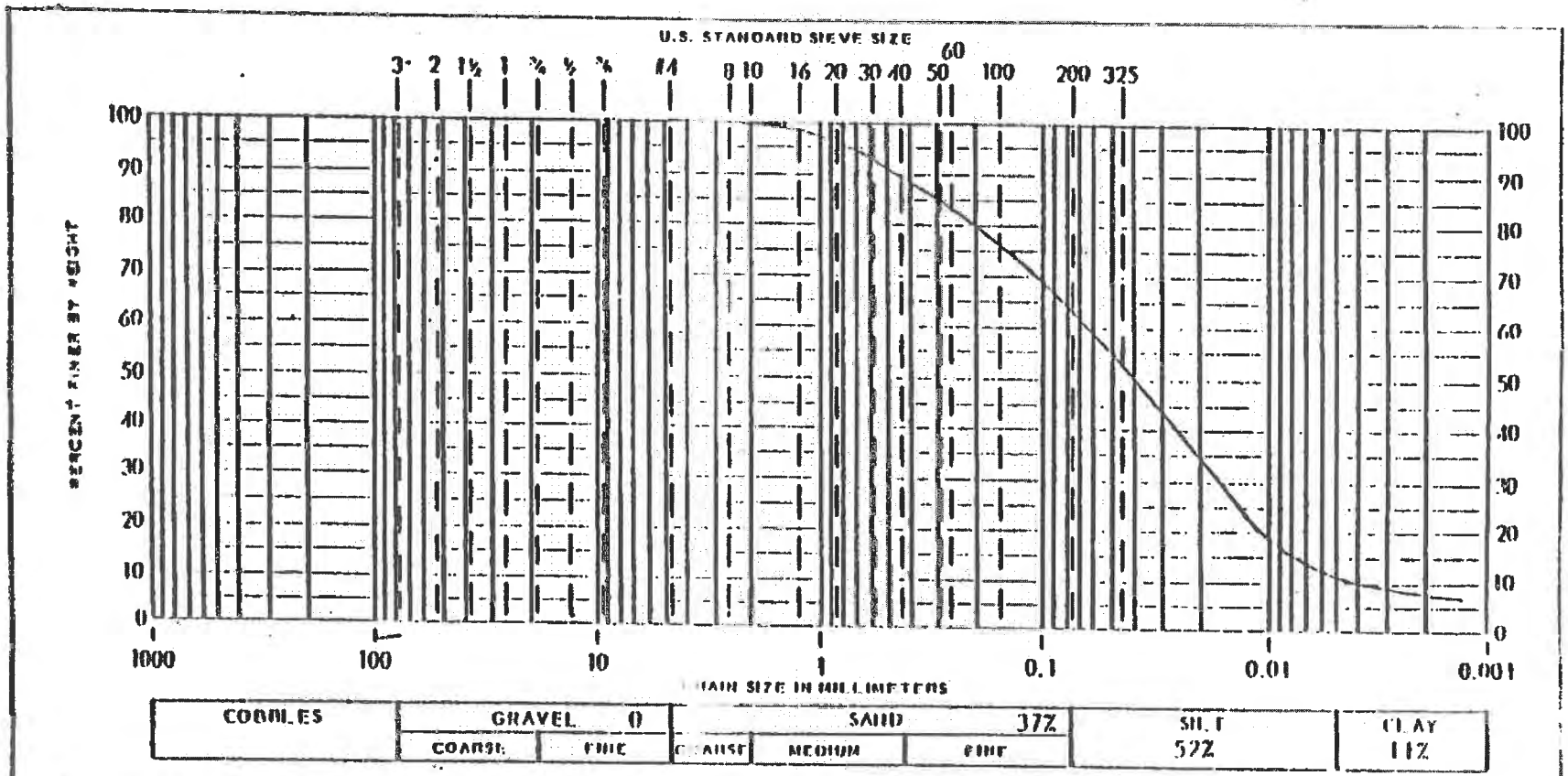


PROJECT	Arthur D. Little Allen Disposal Site	NATURAL % MOISTURE	43.7%
BORING NO.	B-2	LIQUID LIMIT	Tested
SAMPLE NO.	4A	PLASTIC LIMIT	Non
DEPTH	18.0' - 20.0'	PLASTICITY INDEX	Plastic
CLASSIFICATION	"SM" Silty sand	COLOR	Gray
		REMARKS	"U.S.C.S."

BOWSER-MORNER
TESTING LABORATORIES, INC.

Ex. 24

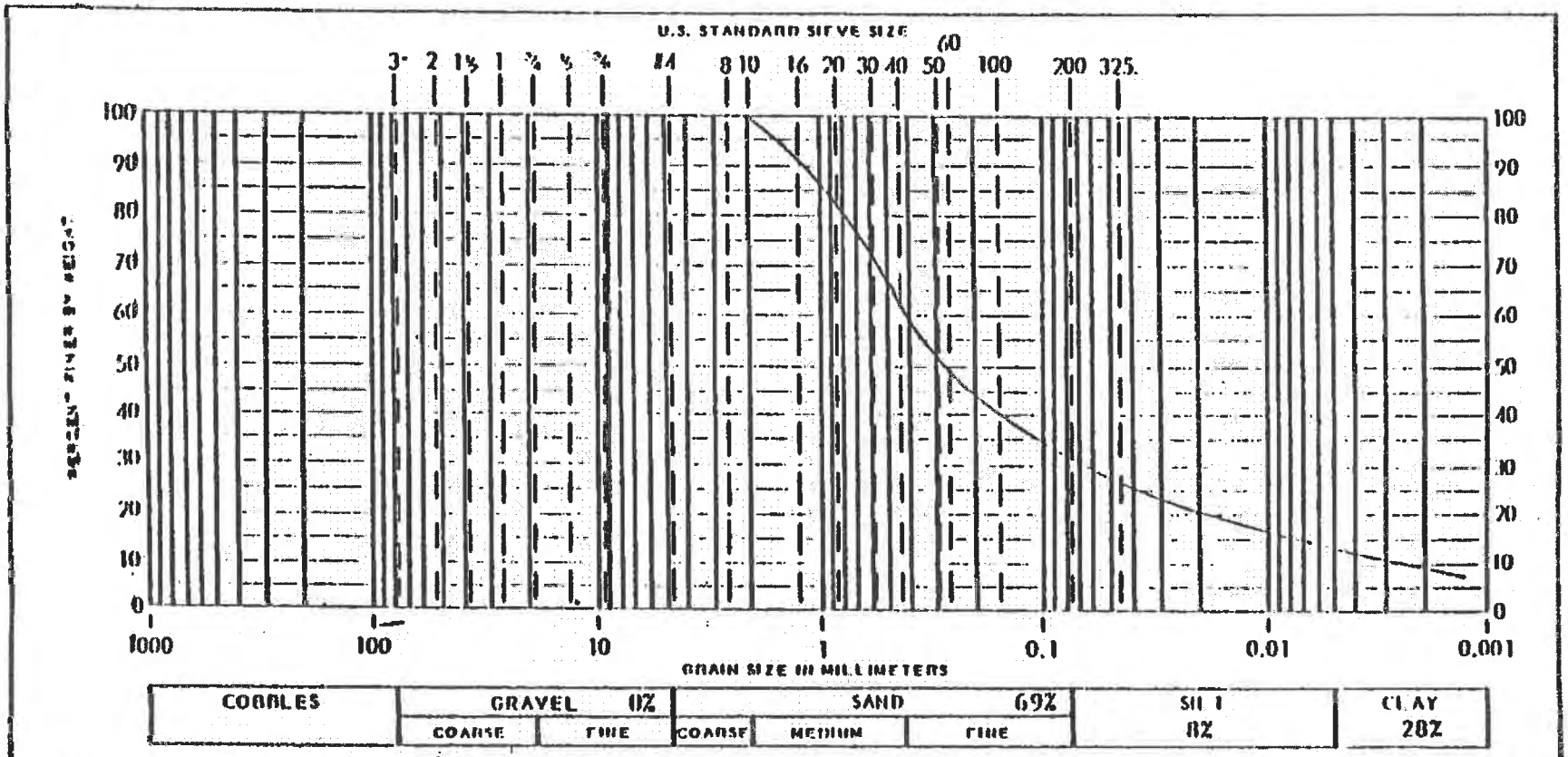
SOIL CLASSIFICATION SHEET



PROJECT	Arthur D. Little Allen Disposal Site	NATURAL % MOISTURE	49.5
BORING NO.	B-7	LIQUID LIMIT	Tested
SAMPLE NO.	7A	PLASTIC LIMIT	Non
DEPTH	36.6' - 38.0'	PLASTICITY INDEX	Plastic
CLASSIFICATION	"ML" Sandy, Silt	COLOR	Gray
		REMARKS	"U.S.C.S."

BOWSER-MORNER
TESTING LABORATORIES, INC.

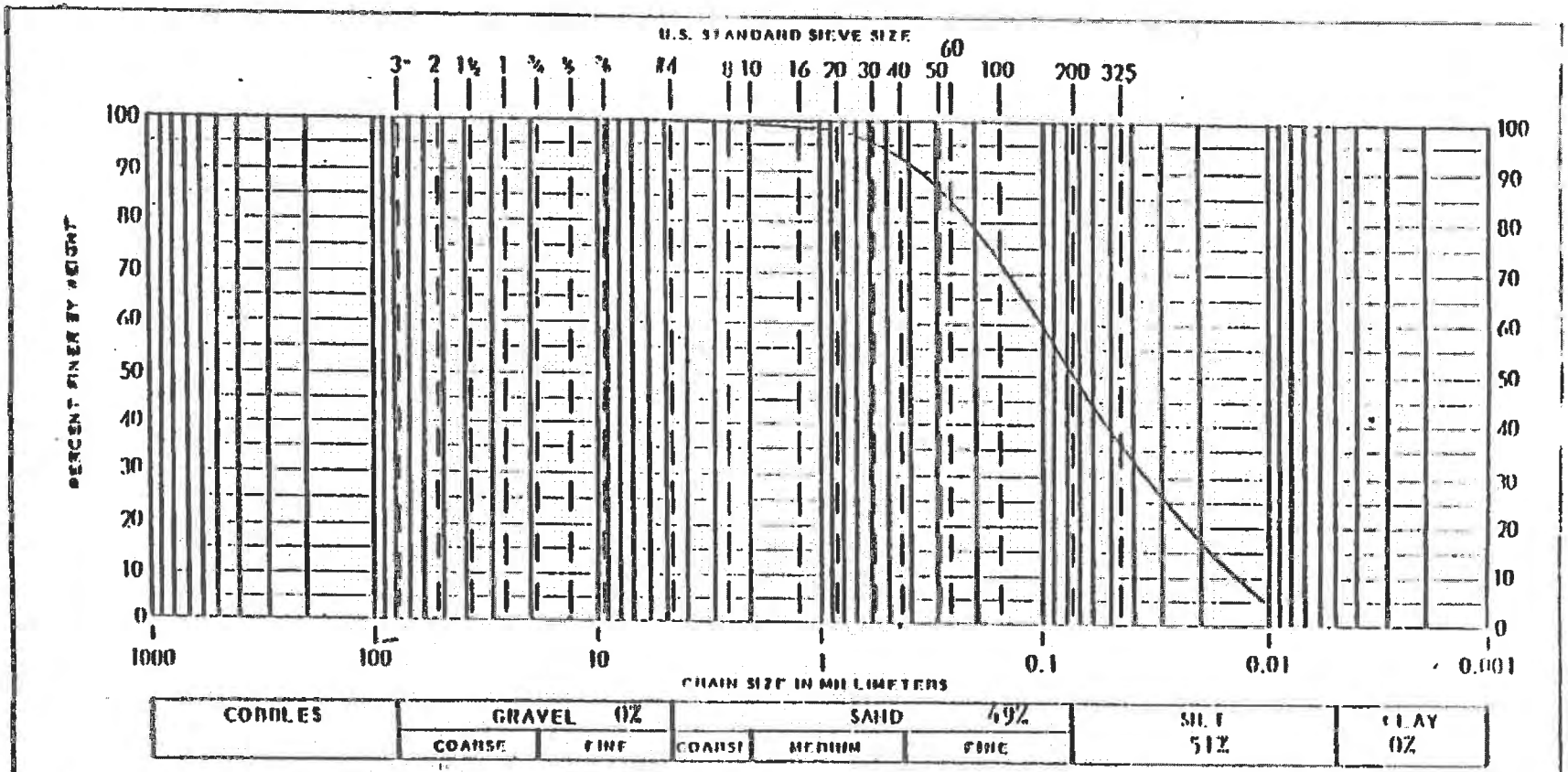
SOIL CLASSIFICATION SHEET



PROJECT	Arthur D. Little Allen Disposal Site	NATURAL % MOISTURE	22.21
BORING NO.	B-2	LIQUID LIMIT	39
SAMPLE NO.	11A	PLASTIC LIMIT	26
DEPTH	52.0' - 54.0'	PLASTICITY INDEX	13
CLASSIFICATION	"SM" Silty Sand	COLOR	Brown and Gray
		REMARKS	"U.S.C.S."

BOWSER-MORNER
TESTING LABORATORIES, INC.

SOIL CLASSIFICATION SHEET

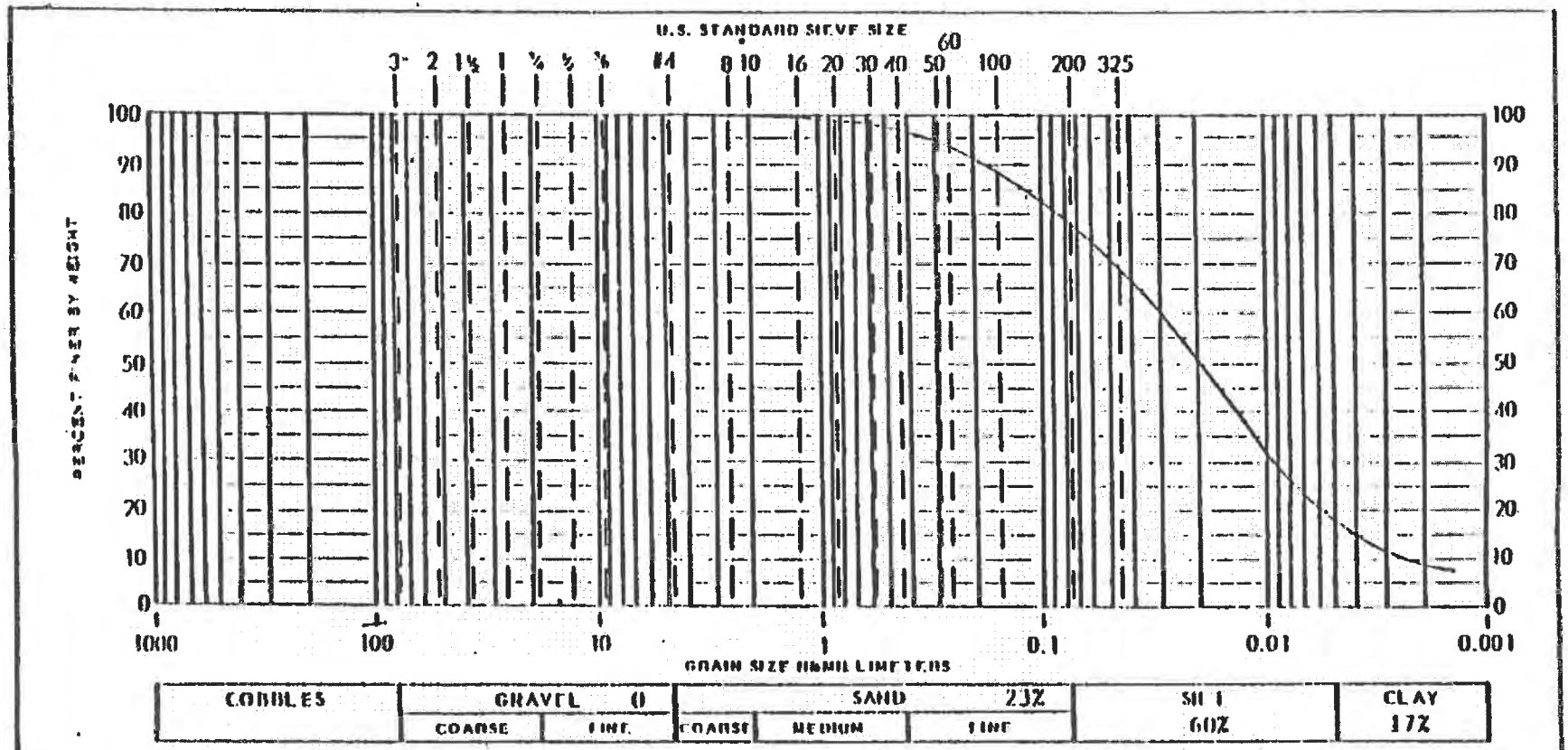


PROJECT	Arthur D. Little Allen Disposal Site
BORING NO.	3-3
SAMPLE NO.	1B
DEPTH	4.0' - 5.5'
CLASSIFICATION	"ML" - Sandy Silt

NATURAL % MOISTURE	51.1
LIQUID LIMIT	Tested
PLASTIC LIMIT	Non
PLASTICITY INDEX	Plastic
COLOR	Gray
REMARKS	"U.S.C.S."

BOWSER-MORNER
TESTING LABORATORIES, INC.

SOIL CLASSIFICATION SHEET

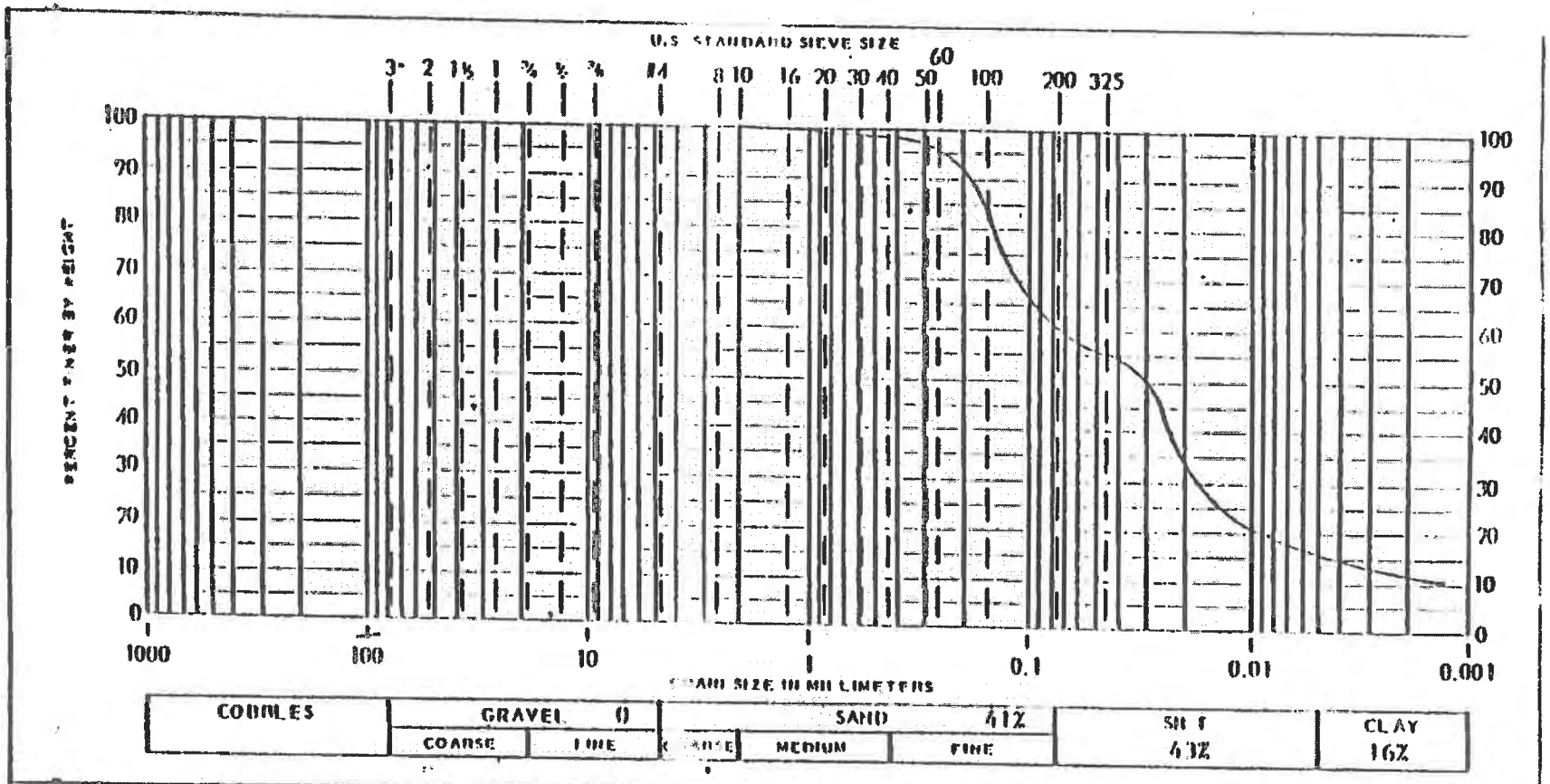


PROJECT	Arthur D. Little Allen Disposal Site	NATURAL % MOISTURE	35.29
BORING NO.	1-3	LIQUID LIMIT	Tested
SAMPLE NO.	2A	PLASTIC LIMIT	Non
DEPTH	12.0' - 14.0'	PLASTICITY INDEX	Plastic
CLASSIFICATION	"III," Sandy, Silt	COLOR	Gray
		REMARKS	"U.S.C.S."

BOWSER-MORNER
TESTING LABORATORIES, INC.

E-28

SOIL CLASSIFICATION SHEET



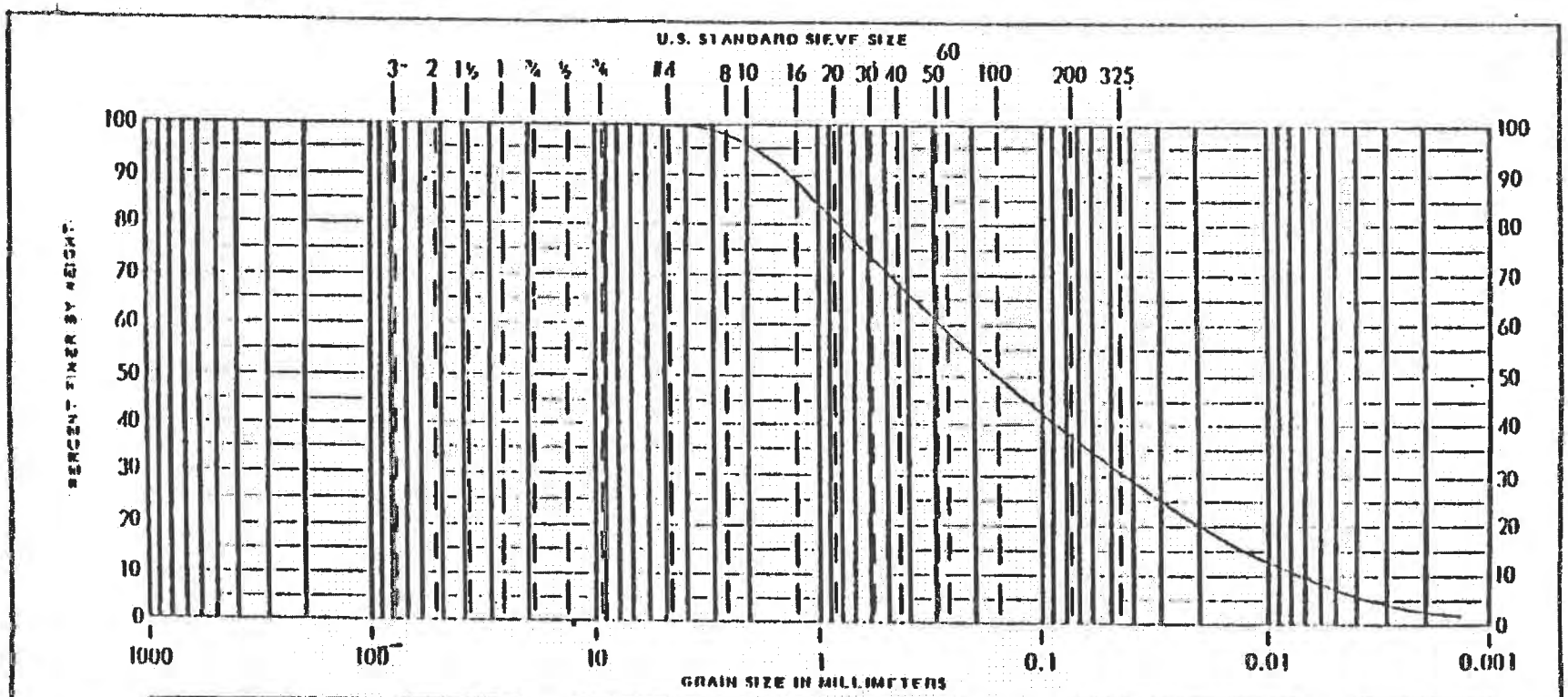
PROJECT	Arthur D. Little Allen Disposal Site	NATURAL % MOISTURE	49.43
BORING NO.	3-3	LIQUID LIMIT	Tested
SAMPLE NO.	6A	PLASTIC LIMIT	Non
DEPTH	28.0' - 30.0'	PLASTICITY INDEX	Plastic
CLASSIFICATION	"ML" Sandy, Silt	COLOR	Reddish Brown
		REMARKS	"U.S.C.S."

BOWSER-MORNER
TESTING LABORATORIES, INC.

E-29

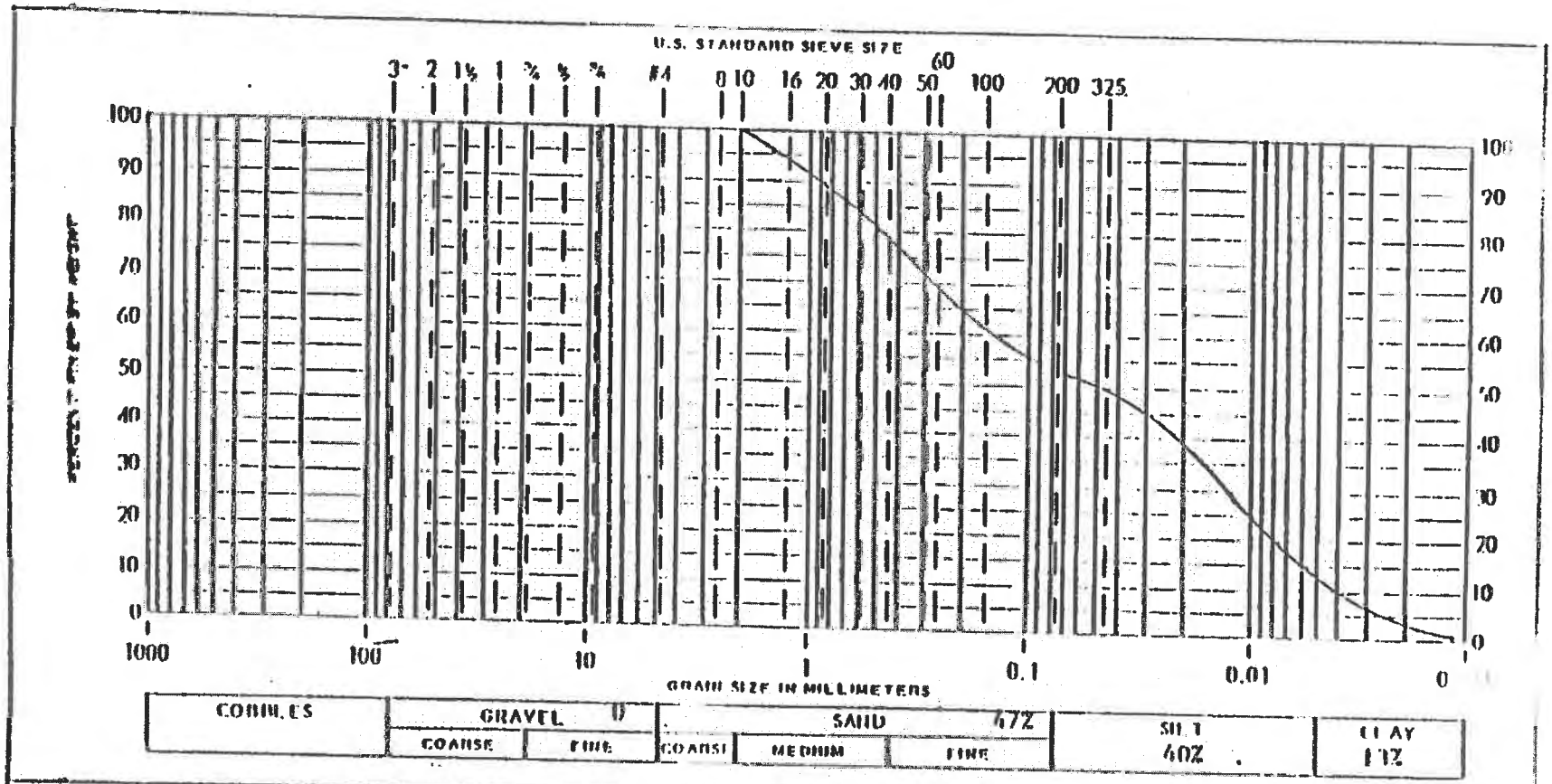
- Doc. Ex. 9129 -

SOIL CLASSIFICATION SHEET



PROJECT	Arthur D. Little, Allen Disposal Site	NATURAL % MOISTURE	30.29	BOWSER-MORNER TESTING LABORATORIES, INC.
BORING NO.	3-3	LIQUID LIMIT	Tested	
SAMPLE NO.	8A	PLASTIC LIMIT	Non	
DEPTH	32.0' - 34.0'	PLASTICITY INDEX	Plastic	
CLASSIFICATION	"SM" Silty Sand	COLOR	Brown	
		REMARKS	"U.S.C.S."	

SOIL CLASSIFICATION SHEET

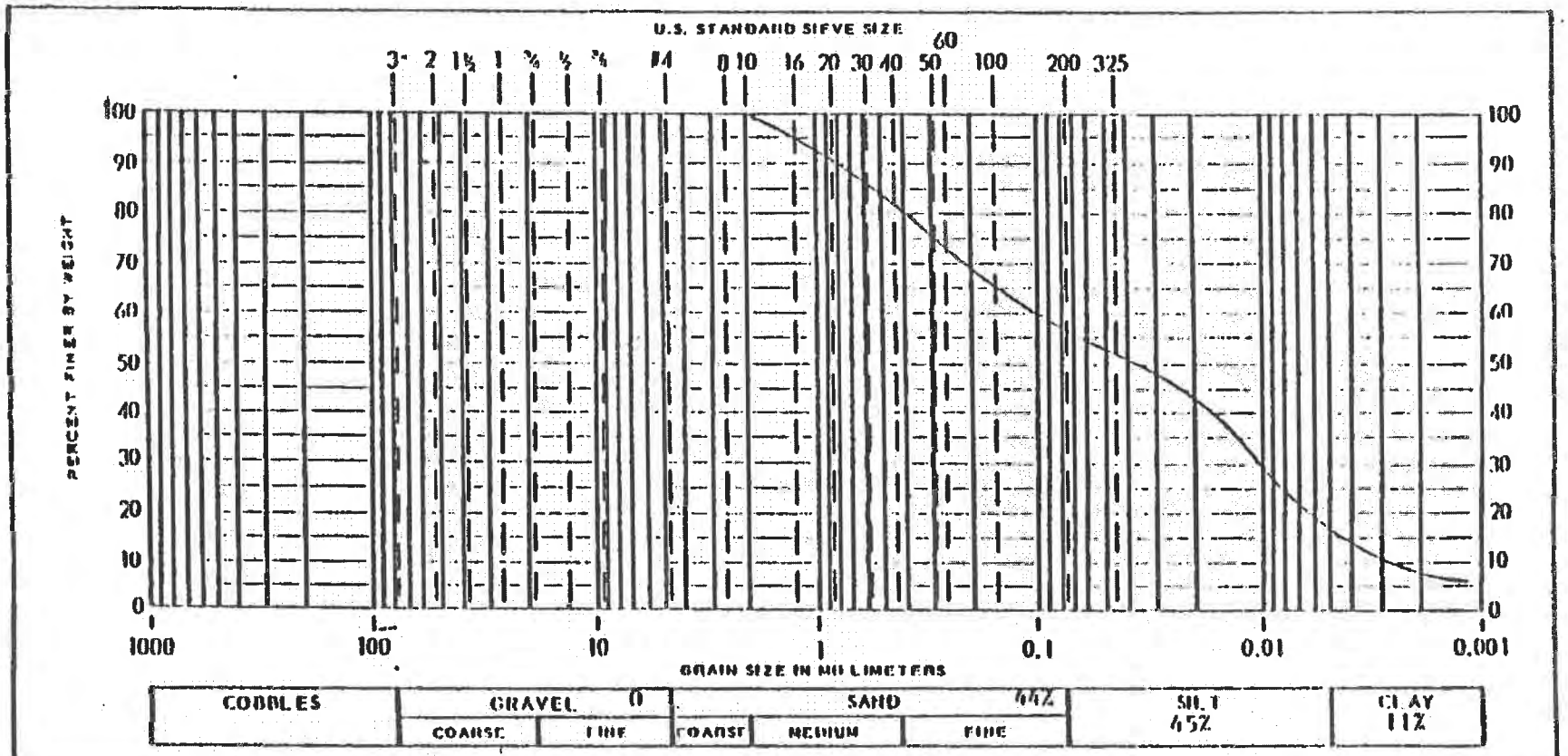


PROJECT	Arthur D. Little Allen Disposal Site	NATURAL % MOISTURE	28.1
BORING NO.	3-5	LIQUID LIMIT	Tested
SAMPLE NO.	5A	PLASTIC LIMIT	Non
DEPTH	19.0' - 21.0'	PLASTICITY INDEX	Plastic
CLASSIFICATION	"ML". Silty, fine sand	COLOR	Brown
		REMARKS	"U.S.C.S."

BOWSER-MORNER
TESTING LABORATORIES, INC.

E-21

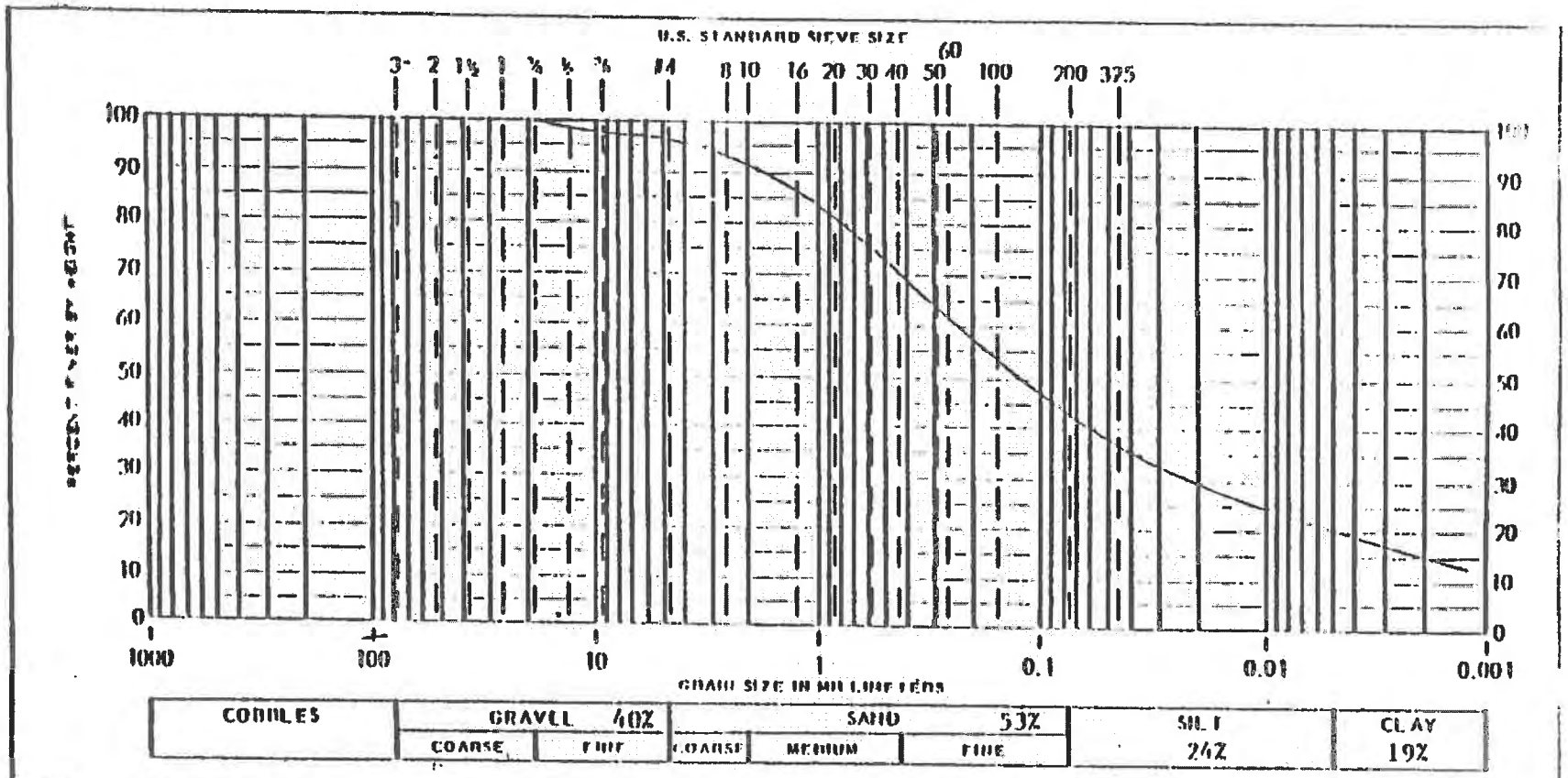
SOIL CLASSIFICATION SHEET



PROJECT	Arthur D. Little Allen Disposal Site	NATURAL % MOISTURE	30.68
BORING NO.	3-6	LIQUID LIMIT	Treated
SAMPLE NO.	7A	PLASTIC LIMIT	Non
DEPTH	12.0' - 14.0'	PLASTICITY INDEX	Plastic
CLASSIFICATION	"ML" Sandy Silt	COLOR	Brown
		REMARKS	"U.S.C.S."

BOWSER-MORNER
TESTING LABORATORIES, INC.

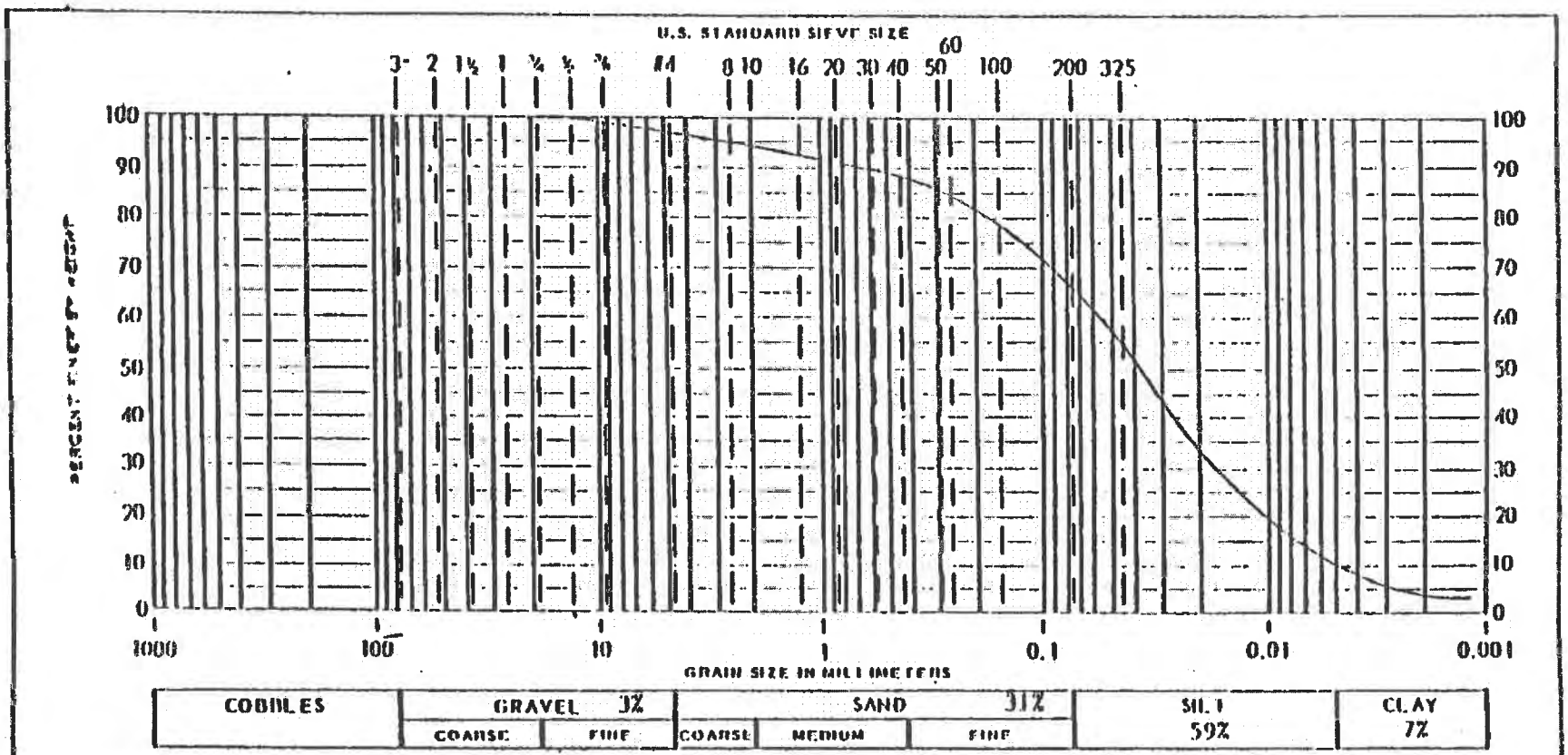
SOIL CLASSIFICATION SHEET



PROJECT	Arthur D. Little Allen Disposal Site	NATURAL % MOISTURE	21.4
BORING NO.	B-6	LIQUID LIMIT	34
SAMPLE NO.	16A	PLASTIC LIMIT	26
DEPTH	32.5' - 34.5'	PLASTICITY INDEX	8
CLASSIFICATION	"SM" Silty Sand	COLOR	Brown & Gray
		REMARKS	"U.S.C.S."

BOWSER-MORNER
TESTING LABORATORIES, INC.

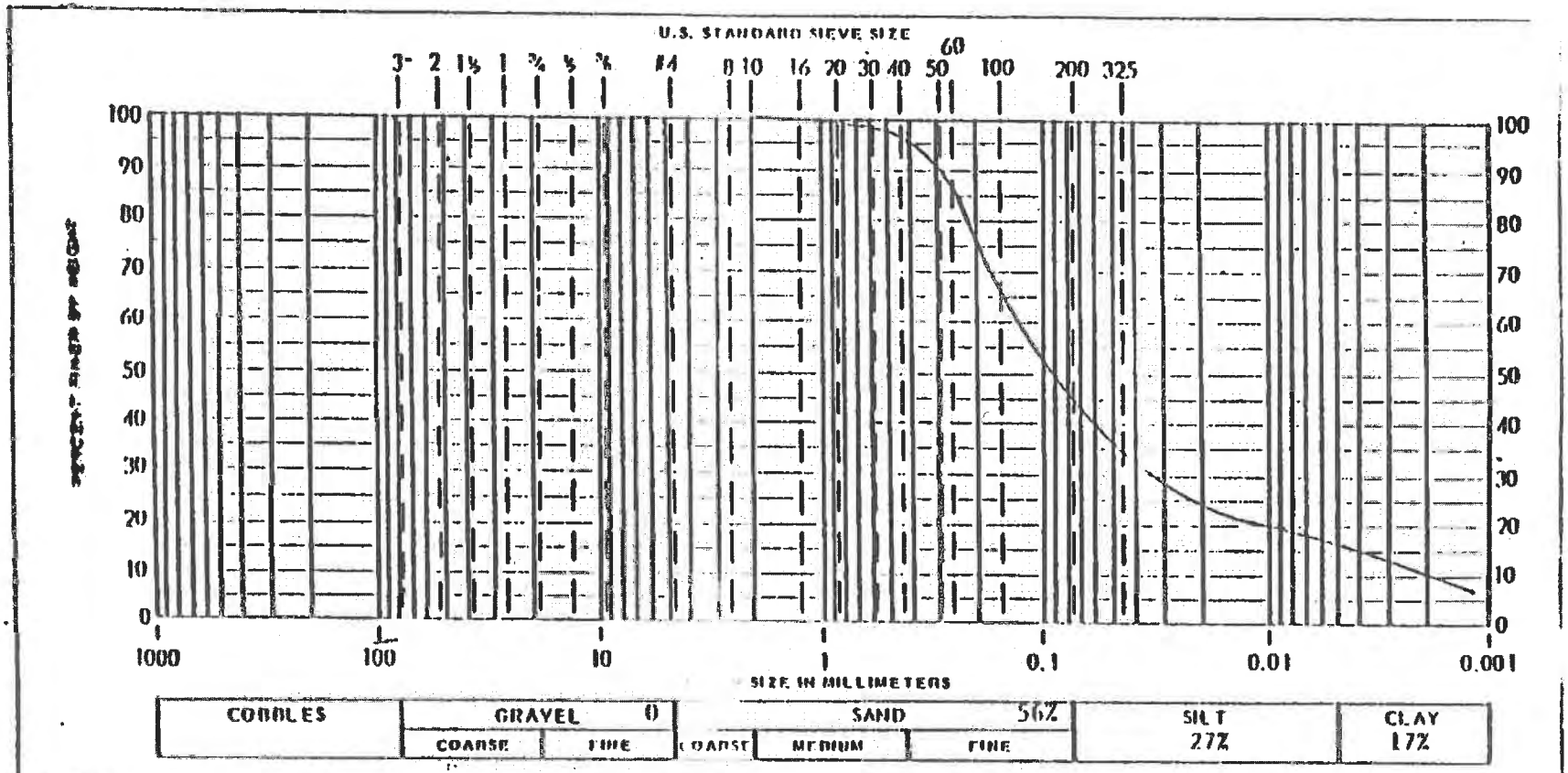
SOIL CLASSIFICATION SHEET



PROJECT	Arthur D. Little Allen Disposal Site	NATURAL % MOISTURE	16.16
BORING NO.	3-6	LIQUID LIMIT	Tested
SAMPLE NO.	21A	PLASTIC LIMIT	Non
DEPTH	54.5' - 56.0'	PLASTICITY INDEX	Plastic
CLASSIFICATION	"ML" Sandy, Silt	COLOR	Gray
		REMARKS	"U.S.C.S."

BOWSER-MORNER
TESTING LABORATORIES, INC.

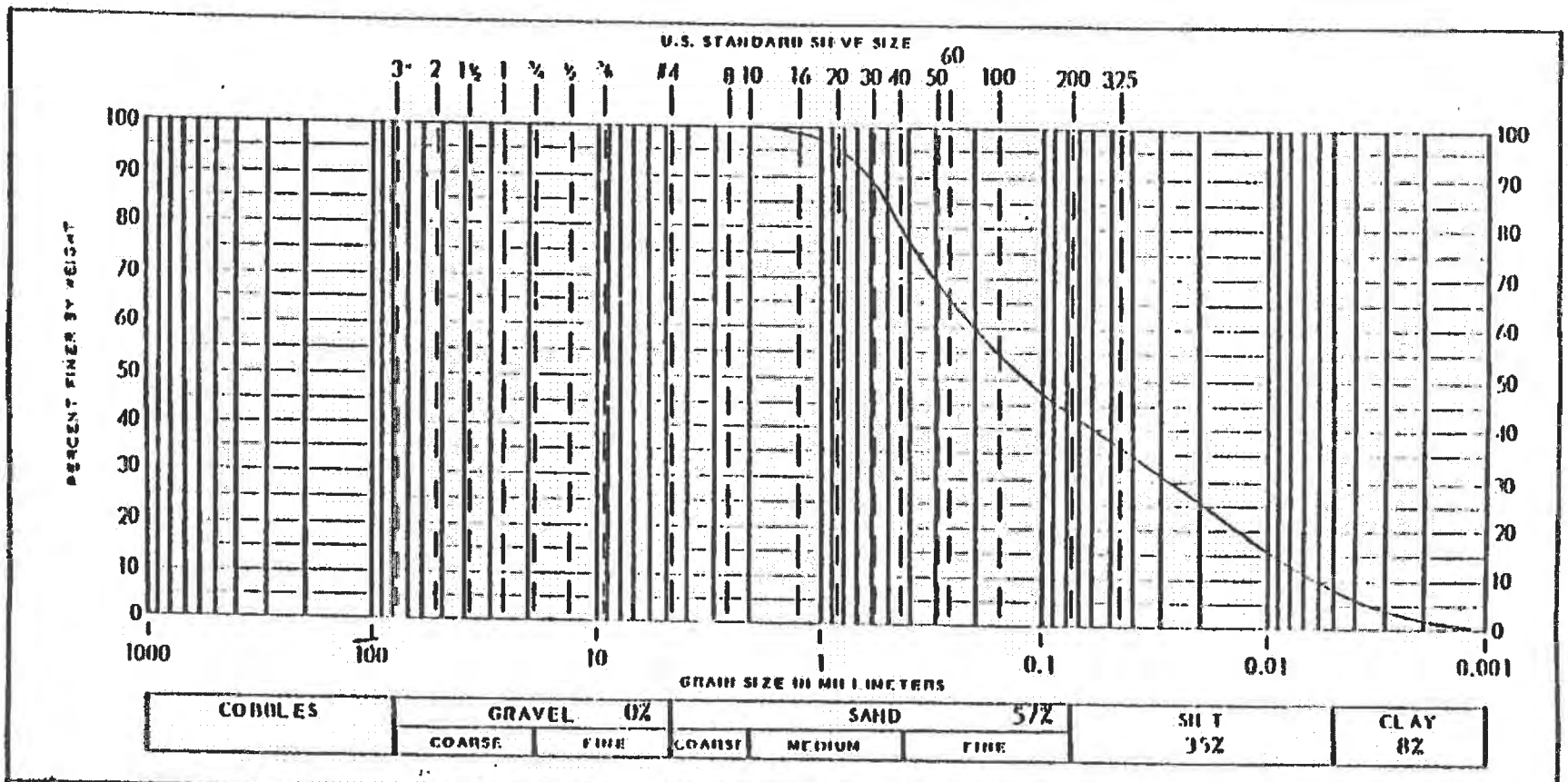
SOIL CLASSIFICATION SHEET



PROJECT	Arthur D. Little Allen Disposal Site	NATURAL % MOISTURE	28.5
BORING NO.	7-7	LIQUID LIMIT	Tested
SAMPLE NO.	6A	PLASTIC LIMIT	Non
DEPTH	14.0' - 16.0'	PLASTICITY INDEX	Plastic
CLASSIFICATION	"SM" Silty, Sand	COLOR	Brown
		REMARKS	"U.S.C.S."

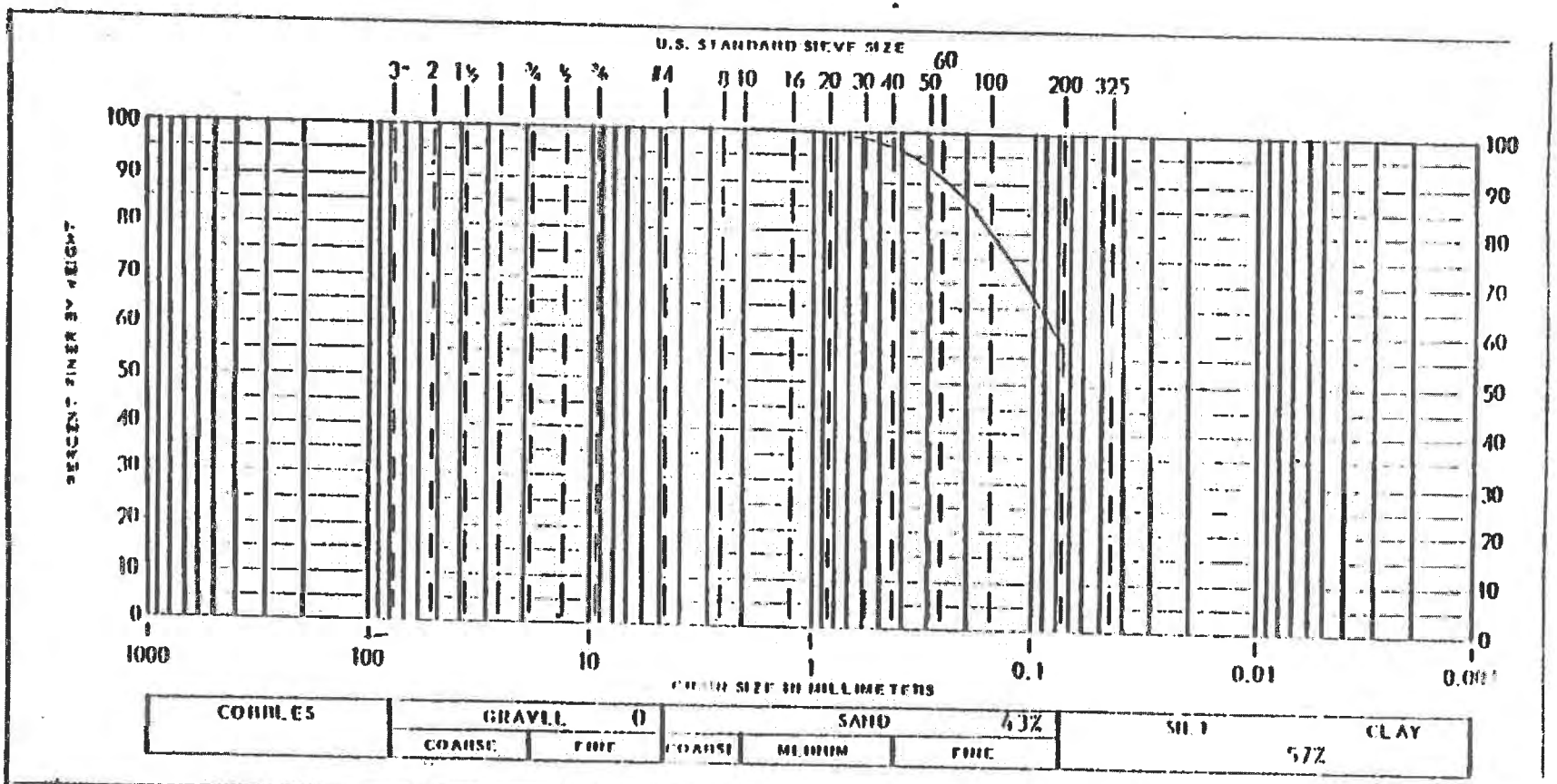
BOWSER-MORNER
TESTING LABORATORIES, INC.

SOIL CLASSIFICATION SHEET



PROJECT	Arthur D. Little Allen Disposal Site	NATURAL % MOISTURE	34.7	BOWSER-MORNER TESTING LABORATORIES, INC.
BORING NO.	B-8	LIQUID LIMIT	Tested	
SAMPLE NO.	6A	PLASTIC LIMIT	Non	
DEPTH	24.0' - 26.0'	PLASTICITY INDEX	Plastic	
CLASSIFICATION	"SM" Silty Sand	COLOR	Brown	
		REMARKS	"U.S.C.S."	

SOIL CLASSIFICATION SHEET



PROJECT	Arthur D. Little Allen Disposal Site	LIQUID LIMIT	Visually
SAMPLE NO.	Bag Sample	PLASTIC LIMIT	Non
CLASSIFICATION	"ML" Sandy silt	PLASTICITY INDEX	Plastic
		COLOR	Brown
		REMARKS	"U.S.C.S."

BOWSER-MORNER
TESTING LABORATORIES, INC.

- Doc. Ex. 9137 -

LABORATORY SUMMARY SHEET

Arthur D. Little, Allen Disposal Site

Boring No.	Sample No.	Depth (Feet)	Material	Liquid Limits	Plastic Limits	Plasticity Index	Moisture Content (%)	Dry Unit Weight (pcf)	Unconfined Compressive Strength (psf)	U.S.C.S. Soil Classification
1-1	1A						39.3			
	2A						37.7			
	3A						Saturated			
	4A						Saturated			
	5A						Saturated			
	6A						Saturated			
	7A						Saturated			
	8A						Saturated			
	9A						Saturated			
	10A						37.6			
	10AA						26.3			
3-2	2A-1						32.9			
	3A-1						Saturated			
	4A-1						45.4			
	5A-1						50.2			
	7A-1						46.8			
	8A-1						51.8			
	9A-1						43.3			
	11A-1						23.3			
3-3	1A-1						40.6			
	2A-1						Saturated			
	3A-1						Saturated			
	4A-1						47.5			
	5A-1						42.3			
	5C-1A						Saturated			
	5C-1						17.5			
	7A-1						25.9			
	8A-1						29.3			

BOWSER-MORNER
Testing Laboratories, Inc.

LABORATORY SUMMARY SHEET

Arthur D. Little, Allen Disposal Site

Boring No.	Sample No.	Depth (Feet)	Material	Liquid Limits	Plastic Limits	Plasticity Index	Moisture Content (%)	Dry Unit Weight (pcf)	Unconfined Compressive Strength (psf)	U.S.C.S. Soil Classification
3-4	1A						38.1			
	2A						24.1			
	3A						31.5			
	4A						31.0			
	5A						25.5			
	6A						23.4			
	7A						24.1			
	8A						15.0			
	1C						19.5			
	9A-1						20.5			
	2C						26.9			
3-4A	1C						20.7			
3-5	1A						24.3			
	2A						21.3			
	3A						23.6			
	4A						26.9			
	5A						29.0			
	6A						29.7			
	7A						30.6			
	8A						27.3			
	9A						25.4			
	1C						28.2			
	10A						30.4			
	10AA						23.7			
	11A						36.7			

- Doc. Ex. 9139 -

LABORATORY SUMMARY SHEET

Arthur D. Little, Allen Disposal Site

Boring No.	Sample No.	Depth (Feet)	Material	Liquid Limits	Plastic Limits	Plasticity Index	Moisture Content (%)	Dry Unit Weight (pcf)	Unconfined Compressive Strength (psf)	U.S.C.S. Soil Classification
3-6	1A						21.3			
	2A						25.2			
	3A						22.4			
	4A						25.1			
	5A						24.8			
	6A						27.0			
	7A						30.9			
	8A						27.5			
	9A						26.9			
	1C						33.6			
	10A						25.9			
	11A						29.6			
	12A						38.8			
	13A						33.6			
	14A						35.0			
	15A-1						30.9			
	15A-2						25.1			
	16A						20.7			
	17A						22.0			
	3C						22.4			
	18A						16.5			
	19A						19.9			
	21A						23.3			
3-6A	1C						45.0			
	2C						34.8			
3-6C	1A-1						10.9			
	1C						34.9			

BOWSER-MORNER
Testing Laboratories, Inc.

LABORATORY SUMMARY SHEET

Arthur D. Little, Allen Disposal Site

Boring No.	Sample No.	Depth (Feet)	Material	Liquid Limits	Plastic Limits	Plasticity Index	Moisture Content (%)	Dry Unit Weight (pcf)	Unconfined Compressive Strength (psf)	U.S.C.S. Soil Classification
B-7	1A						17.9			
	2A						25.3			
	3A						24.0			
	4A						29.5			
	5A-A						24.7			
	5A-B						29.1			
	1C						13.5			
	6A						14.2			
B-7A	1B						23.1			
	2B						28.5			
B-8	1A						20.3			
	2A						23.2			
	3A						14.9			
	4A						45.2			
	5A						42.6			
	6A						36.4			
	7A						37.1			
B-8A	1A						28.9			
	2A						32.4			
	3A						26.9			
	4A						31.4			
B-9	1A						25.8			
	2A						27.3			
	3A						23.6			
	4A						32.0			
	5A						33.9			
	6A						54.8			

- Doc. Ex. 9141 -

LABORATORY SUMMARY SHEET

Arthur D. Little, Allen Disposal Site

Boring No.	Sample No.	Depth (Feet)	Material	Liquid Limits	Plastic Limits	Plasticity Index	Moisture Content (%)	Dry Unit Weight (pcf)	Unconfined Compressive Strength (psf)	U.S.C.S. Soil Classification
3-9A	1C						42.1			
	2A						40.9			
	2C						33.3			
3-4B	1A						18.8			
	2A						14.1			
	3A						24.4			
	4A						24.6			
	1C						16.6			
	5A						14.8			

DEP Docket No. E-7, Sub 1214
Joint Exhibit 10

EPA-600/7-85-028a
June 1985

FULL-SCALE FIELD EVALUATION OF WASTE DISPOSAL FROM COAL-FIRED ELECTRIC GENERATING PLANTS

Volume V. Appendix F

by

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Itamar Bodek, and Charles B. Cooper

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Prepared for:

U.S. Environmental Protection Agency
Office of Research and Development
Washington, DC 20460

APPENDIX F

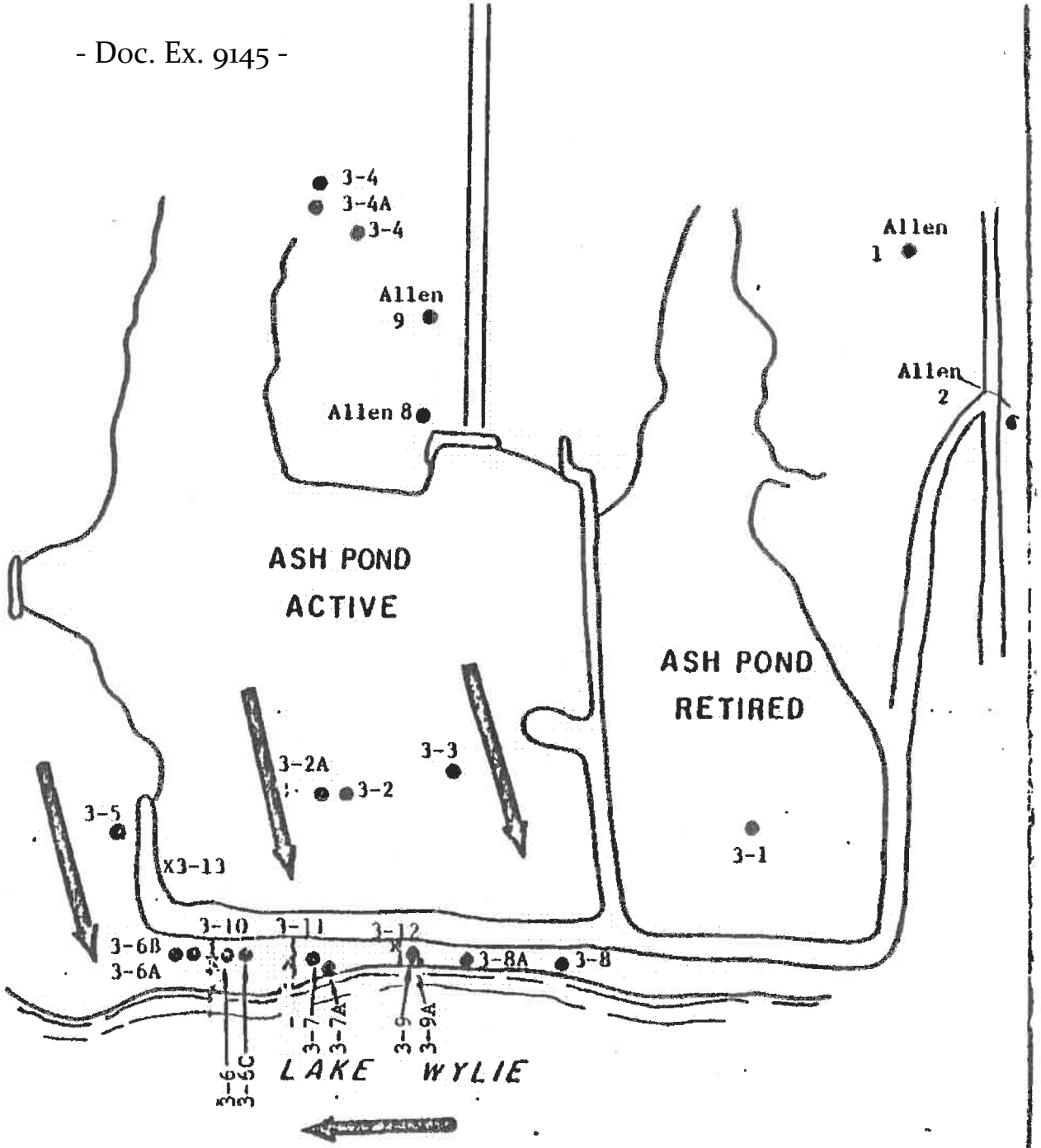
Chemical Sampling and Analysis Data

This appendix provides the chemical sampling and analysis data reported in the format described in the main body of the report. This appendix contains the following sections:

		Page
Site (3): Allen	[PART 1]	3
• site map		
• liquid samples data		
• boiler cleaning wastes data		
• solid samples data		
Site (1): Elrama	[PART 1]	77
• site map		
• liquid samples data		
• solid samples data		
Site (5): Sherco	[PART 2]	271
• site map		
• liquid samples data		
• solid samples data		
Site (6): Powerton	[PART 3]	373
• site map		
• liquid samples data		
• solid samples data		
Site (9): Smith	[PART 3]	441
• site map		
• liquid samples data		
• solid samples data		
Site (7): Dave Johnston	[PART 4]	196
• site map		
• liquid samples data		
• solid samples data		
Soil Attenuation Results	[PART 4]	545

Allen

ALLEN SITE



X Surface Water Sample Locations

● Location of Geotechnical Borings and Monitoring Wells.

Arrows Point in Direction of Ground Water Movement.

PLANT THREE

Sample Numbers

SAMPLING POINT DESIGNATION	TRIPS			
	12881	22381	32381	71482
BACKGROUND WELLS				
3-4 (ALL.)	65	120	193	1265
3-4A (FILL)		116	195	
3-4B (RES./ROCK)	71	95	196	1266
DP-1				1284
DP-2				1285
DP-8				1286
DP-9				1289
RETIRED ASH POND				
3-1 (ASH,ALL.,RES.)		92	189	1261
ACTIVE ASH POND WELLS				
3-2 (ALL.)		93	190	1262
3-2 (ALL.) DIS. SOL.				1298
3-2A (ASH)		91	191	1263
3-3 (RES.)	64	94	192	1264
ASH POND LIQUORS				
3-2 (16-18 FT)	1			
3-2 (20-22 FT)	2			
3-2 (24-26 FT)	3			
3-2 (38-40 FT)	5			
3-2A (24.5-26.4 FT)	7			
3-3 (10-12 FT)	9			
3-3 (22-24 FT)	11			
3-3 (24-26 FT)	12			
DOWNGRADIENT WELLS (RES.)				
3-5	<102	90	197	1269
3-6	67	99	201	1270
3-6C	<106	102		
3-7A	<108	104	208	1277
3-8	69	106	209	1278
3-9	<111	115	211	1281
3-9A	80	117	213	1282
DOWNGRADIENT (ALL.)				
3-6A	<104	89	205	1271
DOWNGRADIENT (FILL)				
3-6B	<105	100	206	1274
3-8A	<110	110	210	1279
DOWNGRADIENT (DIKE)				
3-7	<107	103	207	1275
TOE DRAINS				
3-10		108	214	1290
3-11		119		1291
3-12		SP		1292
ASH POND DISCHARGE				
3-13		121		1293

(< values are negative)

PLANT THELL
CONCENTRATION OF 1 FLUORIDE PPM

SAMPLING POINT DESIGNATION	TRIPS			
	12881	22381	32381	71482
BACKGROUND WELLS				
3-4 (ALL.)	0.1	0.3	<0.2	0.4
3-4A (FILL)		0.2	<0.2	
3-4B (RES./ROCK)	0.1	0.2	<0.2	0.3
DP-1				0.4
DP-2				<0.1
DP-8				<0.1
DP-9				0.2
RETIRED ASH POND				
3-1 (ASH,ALL.,RES.)		0.45	0.3	0.4
ACTIVE ASH POND WELLS				
3-2 (ALL.)		0.3	<0.2	0.3
3-2 (ALL.) DIS. SOL.				
3-2A (ASH)		0.85	0.7	0.5
3-3 (RES.)	0.3	0.4	<0.2	0.2
ASH POND LIQUORS				
3-2 (16-18 FT)	0.7			
3-2 (20-22 FT)	0.1			
3-2 (24-26 FT)	0.2			
3-2 (38-40 FT)				
3-2A (24.5-26.4 FT)	0.25			
3-3 (10-12 FT)	2.5			
3-3 (22-24 FT)	0.9			
3-3 (24-26 FT)	0.9			
DOWNGRADIENT WELLS (RES.)				
3-5		0.1	<0.2	<0.1
3-6	0.1	0.25	<0.2	0.3
3-6C		0.25		
3-7A		0.2	<0.2	0.3
3-8	0.1	0.1	<0.2	<0.1
3-9		<0.2	<0.2	0.3
3-9A	0.1	0.25	<0.2	0.3
DOWNGRADIENT (ALL.)				
3-6A		0.3	<0.2	0.3
DOWNGRADIENT (FILL)				
3-6B		0.1	<0.2	0.2
3-8A		0.2	<0.2	0.2
DOWNGRADIENT (DIKE)				
3-7		<0.2	<0.2	<0.1
TOE DRAINS				
3-10		0.25	<0.2	0.2
3-11		0.25		0.2
3-12				0.2
ASH POND DISCHARGE				
3-13		0.4		0.3

PLANT THREE
CONCENTRATION OF 2 CHLORIDE PPM

SAMPLING POINT DESIGNATION	TRIPS			
	12881	22381	32381	71482
BACKGROUND WELLS				
3-4 (ALL.)	7	17.2	5.5	10.6
3-4A (FILL)		14.5	18.1	
3-4B (RES./ROCK)	4	0.6	3.9	4.5
DP-1				2.4
DP-2				1.2
DP-8				1.3
DP-9				2.2
RETIRED ASH POND				
3-1 (ASH,ALL.,RES.)		6.3	5.2	7.1
ACTIVE ASH POND WELLS				
3-2 (ALL.)		6.8	7.8	9.6
3-2 (ALL.) DIS. SOL.				
3-2A (ASH)		6.8	6.3	6.6
3-3 (RES.)	16	<0.5	1.5	3.9
ASH POND LIQUORS				
3-2 (16-18 FT)	10			
3-2 (20-22 FT)	10.5			
3-2 (24-26 FT)	8.3			
3-2 (38-40 FT)	11			
3-2A (24.5-26.4 FT)	10			
3-3 (10-12 FT)	8.3			
3-3 (22-24 FT)	7			
3-3 (24-26 FT)	6.5			
DOWNGRADIENT WELLS (RES.)				
3-5		<0.5	0.9	1.1
3-6	6	0.7	5.3	6.1
3-6C		0.7		
3-7A		0.6	4.4	6
3-8	3	4.7	4.6	5.5
3-9		5.4	4.8	6.3
3-9A	4	0.6	4.5	5.9
DOWNGRADIENT (ALL.)				
3-6A		<0.5	2.2	3.3
DOWNGRADIENT (FILL)				
3-6B		<0.5	2.5	3.3
3-8A		11.5	9.9	9.9
DOWNGRADIENT (DIKE)				
3-7		<0.5	2.2	3.7
TOE DRAINS				
3-10		0.6	4.3	5.4
3-11		4.7		6
3-12		SP		7.9
ASH POND DISCHARGE				
3-13		0.6		6

PLANT THREE
CONCENTRATION OF 3 NITRATE PPM

SAMPLING POINT DESIGNATION	TRIPS			
	12881	22381	32381	71482
BACKGROUND WELLS				
3-4 (ALL.)	0.5	0.8	<2	0.8
3-4A (FILL)		1.3	<2	
3-4B (RES./ROCK)	0.7	0.8	<2	1.1
DP-1				1.1
DP-2				1
DP-8				1.9
DP-9				1.2
RETIRED ASH POND				
3-1 (ASH,ALL.,RES.)		0.6	<2	<0.6
ACTIVE ASH POND WELLS				
3-2 (ALL.)		0.8	<2	<0.6
3-2 (ALL.) DIS. SOL.				
3-2A (ASH)		1	3	<0.6
3-3 (RES.)	<0.5	0.8	<2	1
ASH POND LIQUORS				
3-2 (16-18 FT)	0.5			
3-2 (20-22 FT)	0.3			
3-2 (24-26 FT)	4			
3-2 (38-40 FT)	2			
3-2A (24.5-26.4 FT)	2.1			
3-3 (10-12 FT)	0.3			
3-3 (22-24 FT)	0.3			
3-3 (24-26 FT)	1.3			
DOWNGRADIENT WELLS (RES.)				
3-5		0.6	<2	0.8
3-6	0.7	0.8	<2	1.2
3-6C		1.5		
3-7A		0.8	<2	<0.6
3-8	1	<0.5	<2	<0.6
3-9		<0.5	<2	<0.6
3-9A	0.2	0.6	<2	<0.6
DOWNGRADIENT (ALL.)				
3-6A		1.3	<2	1
DOWNGRADIENT (FILL)				
3-6B		<0.5	<2	<0.6
3-8A		<0.5	<2	<0.6
DOWNGRADIENT (DIKE)				
3-7		4.5	4	2.2
TOE DRAINS				
3-10		<0.5	<2	<0.6
3-11		<0.5		<0.6
3-12		SP		<0.6
ASH POND DISCHARGE				
3-13		<0.5		<0.6

PLANT THREE
CONCENTRATION OF 4 SULFATE PPM

SAMPLING POINT DESIGNATION	TRIPS			
	12881	22381	32381	71482
BACKGROUND WELLS				
3-4 (ALL.)	2	10	<4	16.6
3-4A (FILL)		10	12	
3-4B (RES./ROCK)		<4	<4	2.1
DP-1				0.7
DP-2				1.4
DP-8				3.7
DP-9				0.5
RETIRED ASH POND				
3-1 (ASH,ALL.,RES.)		100	92	89.9
ACTIVE ASH POND WELLS				
3-2 (ALL.)		<4	<4	1.4
3-2 (ALL.) DIS. SOL.				
3-2A (ASH)		320	320	169.4
3-3 (RES.)	44	7	<4	24.3
ASH POND LIQUORS				
3-2 (16-18 FT)	62			
3-2 (20-22 FT)	190			
3-2 (24-26 FT)	197			
3-2 (38-40 FT)	240			
3-2A (24.5-26.4 FT)	205			
3-3 (10-12 FT)	82			
3-3 (22-24 FT)	12			
3-3 (24-26 FT)	108			
DOWNGRADIENT WELLS (RES.)				
3-5		<4	<4	1.7
3-6	5	<4	<4	5.4
3-6C		<4		
3-7A		13	22	28.5
3-8	48	72	67	76.2
3-9		<4	<4	4
3-9A	2	<4	<4	3
DOWNGRADIENT (ALL.)				
3-6A		<4	<4	1.4
DOWNGRADIENT (FILL)				
3-6B		<4	<4	7.7
3-8A		8	6	6.5
DOWNGRADIENT (DIKE)				
3-7		<4	<4	1.4
TOE DRAINS				
3-10		20	18	17.2
3-11		16		7.2
3-12		SP		7.4
ASH POND DISCHARGE				
3-13		62		56

PLANT THREE
CONCENTRATION OF 5 PHOSPHATE PPM

SAMPLING POINT DESIGNATION	TRIPS			
	12881	22381	32381	71482
BACKGROUND WELLS				
3-4 (ALL.)		<4	<4	<0.3
3-4A (FILL)		<4	<4	
3-4B (RES./ROCK)		<4	<4	<0.3
DP-1				5.2
DP-2				<0.3
DP-8				<0.3
DP-9				<0.3
RETIRED ASH POND				
3-1 (ASH,ALL.,RES.)		<4	<4	<0.3
ACTIVE ASH POND WELLS				
3-2 (ALL.)		<4	<4	<0.3
3-2 (ALL.) DIS. SOL.				
3-2A (ASH)		<4	<4	3.9
3-3 (RES.)		<4	<4	<0.3
ASH POND LIQUORS				
3-2 (16-18 FT)	<4			
3-2 (20-22 FT)	<4			
3-2 (24-26 FT)				
3-2 (38-40 FT)	<4			
3-2A (24.5-26.4 FT)	<4			
3-3 (10-12 FT)	<4			
3-3 (22-24 FT)	<4			
3-3 (24-26 FT)	<4			
DOWNGRADIENT WELLS (RES.)				
3-5		<4		<0.3
3-6		<4		<0.3
3-6C		<4		
3-7A		<4	<4	<0.3
3-8		<4	<4	<0.3
3-9		<4	<4	<0.3
3-9A		<4	<4	<0.3
DOWNGRADIENT (ALL.)				
3-6A		<4	<4	3.6
DOWNGRADIENT (FILL)				
3-6B		<4	<4	<0.3
3-8A		<4	<4	<0.3
DOWNGRADIENT (DIKE)				
3-7		<4	<4	<0.3
TOE DRAINS				
3-10		<4	<4	<0.3
3-11		<4		<0.3
3-12		SP		<0.3
ASH POND DISCHARGE				
3-13		<4		<0.3

PLANT THREE
CONCENTRATION OF 6 BROMIDE PPM

SAMPLING POINT DESIGNATION	TRIPS			
	12881	22381	32381	71482
BACKGROUND WELLS				
3-4 (ALL.)		<5	<5	<0.3
3-4A (FILL)		<5	<5	
3-4B (RES./ROCK)		<5	<5	<0.3
DP-1				<0.3
DP-2				<0.3
DP-8				<0.3
DP-9				<0.3
RETIRED ASH POND				
3-1 (ASH,ALL.,RES.)		<5	<5	<0.3
ACTIVE ASH POND WELLS				
3-2 (ALL.)		<5	<5	0.7
3-2 (ALL.) DIS. SOL.				
3-2A (ASH)		<5	<5	<0.3
3-3 (RES.)		<5	<5	<0.3
ASH POND LIQUORS				
3-2 (16-18 FT)	<5			
3-2 (20-22 FT)	<5			
3-2 (24-26 FT)				
3-2 (38-40 FT)	<5			
3-2A (24.5-26.4 FT)	<5			
3-3 (10-12 FT)	<5			
3-3 (22-24 FT)	<5			
3-3 (24-26 FT)	<5			
DOWNGRADIENT WELLS (RES.)				
3-5		<5		<0.3
3-6		<5		<0.3
3-6C		<5		
3-7A		<5	<5	<0.3
3-8		<5	<5	<0.3
3-9		<5	<5	<0.3
3-9A		<5	<5	<0.3
DOWNGRADIENT (ALL.)				
3-6A		<5	<5	<0.3
DOWNGRADIENT (FILL)				
3-6B		<5	<5	<0.3
3-8A		<5	<5	<0.3
DOWNGRADIENT (DIKE)				
3-7		<5	<5	<0.3
TOE DRAINS				
3-10		<5	<5	<0.3
3-11		<5		<0.3
3-12		SP		<0.3
ASH POND DISCHARGE				
3-13		<5		<0.3

PLANT THREE
CONCENTRATION OF / SILVER PPM

SAMPLING POINT DESIGNATION	TRIPS 12881	22381	32381	71482
BACKGROUND WELLS				
3-4 (ALL.)		<0.005	<0.005	<0.005
3-4A (FILL)		<0.005	<0.005	
3-4B (RES./ROCK)		<0.005	<0.005	<0.005
DP-1				<0.005
DP-2				<0.005
DP-8				<0.005
DP-9				<0.005
RETIRED ASH POND				
3-1 (ASH,ALL.,RES.)		<0.005	<0.005	<0.005
ACTIVE ASH POND WELLS				
3-2 (ALL.)		<0.005	<0.005	<0.005
3-2 (ALL.) DIS. SOL.				<0.005
3-2A (ASH)		<0.005	<0.005	<0.005
3-3 (RES.)		<0.005	<0.005	<0.005
ASH POND LIQUORS				
3-2 (16-18 FT)	<0.005			
3-2 (20-22 FT)	<0.005			
3-2 (24-26 FT)				
3-2 (38-40 FT)	<0.005			
3-2A (24.5-26.4 FT)	<0.005			
3-3 (10-12 FT)	<0.005			
3-3 (22-24 FT)	<0.005			
3-3 (24-26 FT)	<0.005			
DOWNGRADIENT WELLS (RES.)				
3-5		<0.005	<0.005	<0.005
3-6		<0.005	<0.005	<0.005
3-6C		<0.005		
3-7A		<0.005	<0.005	<0.005
3-8		<0.005	<0.005	<0.005
3-9		<0.005	<0.005	<0.005
3-9A		<0.005	<0.005	<0.005
DOWNGRADIENT (ALL.)				
3-6A		<0.005	0.008	<0.005
DOWNGRADIENT (FILL)				
3-6B		<0.005	<0.005	<0.005
3-8A		<0.005	<0.005	<0.005
DOWNGRADIENT (DIKE)				
3-7		<0.005	0.01	<0.005
TOE DRAINS				
3-10		<0.005	<0.005	<0.005
3-11		<0.005		<0.005
3-12				<0.005
ASH POND DISCHARGE				
3-13		<0.005		<0.005

PLANT THREE
CONCENTRATION OF 8 ALUMINUM PPM

SAMPLING POINT DESIGNATION	TRIPS			
	12881	22381	32381	71482
BACKGROUND WELLS				
3-4 (ALL.)		<0.3	<0.3	<0.3
3-4A (FILL)		<0.3	<0.3	
3-4B (RES./ROCK)		<0.3	<0.3	<0.3
DP-1				<0.3
DP-2				<0.3
DP-8				<0.3
DP-9				<0.3
RETIRED ASH POND				
3-1 (ASH,ALL.,RES.)		8.11	9.28	11.9
ACTIVE ASH POND WELLS				
3-2 (ALL.)		<0.3	<0.3	<0.3
3-2 (ALL.) DIS. SOL.				<0.3
3-2A (ASH)		0.25	0.2	<0.3
3-3 (RES.)		<0.3	<0.3	<0.3
ASH POND LIQUORS				
3-2 (16-18 FT)	<0.3			
3-2 (20-22 FT)	0.97			
3-2 (24-26 FT)				
3-2 (38-40 FT)	<0.3			
3-2A (24.5-26.4 FT)	0.38			
3-3 (10-12 FT)	<0.3			
3-3 (22-24 FT)	<0.3			
3-3 (24-26 FT)	<0.3			
DOWNGRADIENT WELLS (RES.)				
3-5		<0.3	<0.3	<0.3
3-6		<0.3	<0.3	<0.3
3-6C		<0.3		
3-7A		<0.3	<0.3	<0.3
3-8		<0.3	<0.3	<0.3
3-9		<0.3	<0.3	<0.3
3-9A		<0.3	<0.3	<0.3
DOWNGRADIENT (ALL.)				
3-6A		<0.3	<0.3	<0.3
DOWNGRADIENT (FILL)				
3-6B		<0.3	<0.3	<0.3
3-8A		<0.3	<0.3	<0.3
DOWNGRADIENT (DIKE)				
3-7		<0.3	<0.3	<0.3
TOE DRAINS				
3-10		<0.3	<0.3	<0.3
3-11		<0.3		<0.3
3-12				<0.3
ASH POND DISCHARGE				
3-13		<0.3		<0.3

PLANT HIRAM
CONCENTRATION OF 9 BORON PPM

SAMPLING POINT DESIGNATION	TRIPS 12881	22381	32381	71482
BACKGROUND WELLS				
3-4 (ALL.)		0.015	0.018	0.06
3-4A (FILL)		0.03	0.068	
3-4B (RES./ROCK)		<0.005	<0.005	0.016
DP-1				0.004
DP-2				<0.004
DP-8				<0.004
DP-9				0.005
RETIRED ASH POND				
3-1 (ASH,ALL.,RES.)		1.82	1.71	1.87
ACTIVE ASH POND WELLS				
3-2 (ALL.)		0.057	0.058	0.076
3-2 (ALL.) DIS. SOL.				0.055
3-2A (ASH)		3.68	3.64	1.99
3-3 (RES.)		0.058	<0.005	0.119
ASH POND LIQUORS				
3-2 (16-18 FT)	1.08			
3-2 (20-22 FT)	2.11			
3-2 (24-26 FT)				
3-2 (38-40 FT)	3.4			
3-2A (24.5-26.4 FT)	2.15			
3-3 (10-12 FT)	2.54			
3-3 (22-24 FT)	1.39			
3-3 (24-26 FT)	1.86			
DOWNGRADIENT WELLS (RES.)				
3-5		<0.005	<0.005	<0.004
3-6		0.007	<0.005	0.005
3-6C		0.009		
3-7A		0.05	0.05	0.148
3-8		0.924	0.955	0.999
3-9		0.06	0.019	0.116
3-9A		0.056	<0.005	0.196
DOWNGRADIENT (ALL.)				
3-6A		<0.005	<0.005	<0.004
DOWNGRADIENT (FILL)				
3-6B		0.005	<0.005	<0.004
3-8A		0.294	0.217	0.158
DOWNGRADIENT (DIKE)				
3-7		<0.005	<0.005	0.005
TOE DRAINS				
3-10		0.02	<0.005	0.068
3-11		0.03		0.059
3-12				0.535
ASH POND DISCHARGE				
3-13		0.238		0.205

PLANT THREE
CONCENTRATION OF 10 BARIUM PPM

SAMPLING POINT DESIGNATION	TRIPS			
	12881	22381	32381	71482
BACKGROUND WELLS				
3-4 (ALL.)		0.11	0.085	0.101
3-4A (FILL)		0.07	0.109	
3-4B (RES./ROCK)		0.02	0.013	0.044
DP-1				0.02
DP-2				0.012
DP-8				0.016
DP-9				0.043
RETIRED ASH POND				
3-1 (ASH,ALL.,RES.)		0.06	0.061	0.155
ACTIVE ASH POND WELLS				
3-2 (ALL.)		0.92	1.34	1.07
3-2 (ALL.) DIS. SOL.				1.01
3-2A (ASH)		0.37	0.423	0.298
3-3 (RES.)		<0.01	<0.005	0.063
ASH POND LIQUORS				
3-2 (16-18 FT)	0.22			
3-2 (20-22 FT)	0.15			
3-2 (24-26 FT)				
3-2 (38-40 FT)	0.39			
3-2A (24.5-26.4 FT)	0.15			
3-3 (10-12 FT)	0.25			
3-3 (22-24 FT)	0.23			
3-3 (24-26 FT)	0.25			
DOWNGRADIENT WELLS (RES.)				
3-5		0.02	0.013	0.026
3-6		0.05	0.037	0.058
3-6C		0.06		
3-7A		0.05	0.061	0.068
3-8		0.05	0.061	0.054
3-9		<0.01	<0.005	0.005
3-9A		0.02	0.013	0.024
DOWNGRADIENT (ALL.)				
3-6A		0.02	0.025	0.022
DOWNGRADIENT (FILL)				
3-6B		0.02	0.013	0.009
3-8A		0.01	0.012	0.031
DOWNGRADIENT (DIKE)				
3-7		0.02	0.013	0.016
TOE DRAINS				
3-10		0.02	0.037	0.031
3-11		0.03		0.028
3-12				0.01
ASH POND DISCHARGE				
3-13		0.1		0.111

PLANT ISRLI
CONCENTRATION OF 11 BERYLLIUM PPM

SAMPLING POINT DESIGNATION	TRIPS 12881	22381	32381	71482
BACKGROUND WELLS				
3-4 (ALL.)		<0.0005	<0.0005	<0.0005
3-4A (FILL)		<0.0005	<0.0005	
3-4B (RES./ROCK)		<0.0005	<0.0005	<0.0005
DP-1				<0.0005
DP-2				<0.0005
DP-8				<0.0005
DP-9				<0.0005
RETIRED ASH POND				
3-1 (ASH,ALL.,RES.)		<0.0005	<0.0005	<0.0005
ACTIVE ASH POND WELLS				
3-2 (ALL.)		<0.0005	<0.0005	<0.0005
3-2 (ALL.) DIS. SOL.				<0.0005
3-2A (ASH)		<0.0005	<0.0005	<0.0005
3-3 (RES.)		<0.0005	<0.0005	<0.0005
ASH POND LIQUORS				
3-2 (16-18 FT)	<0.0005			
3-2 (20-22 FT)	<0.0005			
3-2 (24-26 FT)				
3-2 (38-40 FT)	<0.0005			
3-2A (24.5-26.4 FT)	<0.0005			
3-3 (10-12 FT)	<0.0005			
3-3 (22-24 FT)	<0.0005			
3-3 (24-26 FT)	<0.0005			
DOWNGRADIENT WELLS (RES.)				
3-5		<0.0005	<0.0005	<0.0005
3-6		<0.0005	<0.0005	<0.0005
3-6C		<0.0005		
3-7A		<0.0005	0.0009	<0.0005
3-8		<0.0005	<0.0005	<0.0005
3-9		<0.0005	<0.0005	<0.0005
3-9A		<0.0005	<0.0005	<0.0005
DOWNGRADIENT (ALL.)				
3-6A		<0.0005	<0.0005	<0.0005
DOWNGRADIENT (FILL)				
3-6B		<0.0005	0.0009	<0.0005
3-8A		<0.0005	<0.0005	<0.0005
DOWNGRADIENT (DIKE)				
3-7		<0.0005	<0.0005	<0.0005
TOE DRAINS				
3-10		<0.0005	<0.0005	<0.0005
3-11		<0.0005		<0.0005
3-12				<0.0005
ASH POND DISCHARGE				
3-13		<0.0005		<0.0005

PLANT THREE
CONCENTRATION OF 12 CALCIUM PPM

SAMPLING POINT DESIGNATION	TRIPS			
	12881	22381	32381	71482
BACKGROUND WELLS				
3-4 (ALL.)		8.93	6.54	11.5
3-4A (FILL)		9.13	12.3	
3-4B (RES./ROCK)		9.95	9.99	10.9
DP-1				5.43
DP-2				0.74
DP-8				6.83
DP-9				7.1
RETIRED ASH POND				
3-1 (ASH,ALL.,RES.)		59.4	60.7	64.1
ACTIVE ASH POND WELLS				
3-2 (ALL.)		17	15.8	16.2
3-2 (ALL.) DIS. SOL.				14.6
3-2A (ASH)		126	129	63.7
3-3 (RES.)		3.77	2.55	3.83
ASH POND LIQUORS				
3-2 (16-18 FT)	49.2			
3-2 (20-22 FT)	72.6			
3-2 (24-26 FT)				
3-2 (38-40 FT)	89.6			
3-2A (24.5-26.4 FT)	66.2			
3-3 (10-12 FT)	55.7			
3-3 (22-24 FT)	52.6			
3-3 (24-26 FT)	59.3			
DOWNGRADIENT WELLS (RES.)				
3-5		0.79	0.88	0.57
3-6		16.5	16.4	18
3-6C		18.4		
3-7A		29.5	29.9	37.9
3-8		18.1	18.7	20.4
3-9		12.5	12.4	11.2
3-9A		4.83	4.55	5.19
DOWNGRADIENT (ALL.)				
3-6A		4.85	5.08	5.57
DOWNGRADIENT (FILL)				
3-6B		2.76	2.84	0.97
3-8A		30	32.5	27.8
DOWNGRADIENT (DIKE)				
3-7		0.44	0.32	0.34
TOE DRAINS				
3-10		57.4	57.6	56
3-11		66.9		70.8
3-12				51.2
ASH POND DISCHARGE				
3-13		21.4		19.6

PLANT THREE
CONCENTRATION OF 13 CADMIUM PPM

SAMPLING POINT DESIGNATION	TRIPS			
	12681	22381	32381	71482
BACKGROUND WELLS				
3-4 (ALL.)		<0.007	<0.1	<0.01
3-4A (FILL)		<0.007	<0.1	
3-4B (RES./ROCK)		<0.007	<0.1	<0.01
DP-1				<0.01
DP-2				<0.01
DP-8				<0.01
DP-9				<0.01
RETIRED ASH POND				
3-1 (ASH,ALL.,RES.)		<0.007	<0.1	<0.01
ACTIVE ASH POND WELLS				
3-2 (ALL.)		<0.007	<0.1	<0.01
3-2 (ALL.) DIS. SOL.				<0.01
3-2A (ASH)		<0.007	<0.1	<0.01
3-3 (RES.)		<0.007	<0.1	<0.01
ASH POND LIQUORS				
3-2 (16-18 FT)	<0.007			
3-2 (20-22 FT)	<0.007			
3-2 (24-26 FT)				
3-2 (38-40 FT)	<0.007			
3-2A (24.5-26.4 FT)	0.053			
3-3 (10-12 FT)	<0.007			
3-3 (22-24 FT)	<0.007			
3-3 (24-26 FT)	<0.007			
DOWNGRADIENT WELLS (RES.)				
3-5		<0.007	<0.1	<0.01
3-6		<0.007	<0.1	<0.01
3-6C		<0.007		
3-7A		<0.007	<0.1	<0.01
3-8		<0.007	<0.1	<0.01
3-9		<0.007	<0.1	<0.01
3-9A		<0.007	<0.1	<0.01
DOWNGRADIENT (ALL.)				
3-6A		<0.007	<0.1	<0.01
DOWNGRADIENT (FILL)				
3-6B		<0.007	<0.1	<0.01
3-8A		<0.007	<0.1	<0.01
DOWNGRADIENT (DIKE)				
3-7		<0.007	<0.1	<0.01
TOE DRAINS				
3-10		<0.007	<0.1	<0.01
3-11		<0.007		<0.01
3-12				<0.01
ASH POND DISCHARGE				
3-13		<0.007		<0.01

PLANT THREE
CONCENTRATION OF 14 COBALT PPM

SAMPLING POINT DESIGNATION	TRIPS			
	12881	22381	32381	71482
BACKGROUND WELLS				
3-4 (ALL.)		<0.05	<0.05	<0.05
3-4A (FILL)		<0.05	<0.05	
3-4B (RES./ROCK)		<0.05	<0.05	<0.05
DP-1				<0.05
DP-2				<0.05
DP-8				<0.05
DP-9				<0.05
RETIRED ASH POND				
3-1 (ASH,ALL.,RES.)		<0.05	<0.05	<0.05
ACTIVE ASH POND WELLS				
3-2 (ALL.)		<0.05	<0.05	<0.05
3-2 (ALL.) DIS. SOL.				<0.05
3-2A (ASH)		<0.05	<0.05	<0.05
3-3 (RES.)		<0.05	<0.05	<0.05
ASH POND LIQUORS				
3-2 (16-18 FT)	<0.05			
3-2 (20-22 FT)	<0.05			
3-2 (24-26 FT)				
3-2 (38-40 FT)	<0.05			
3-2A (24.5-26.4 FT)	<0.05			
3-3 (10-12 FT)	<0.05			
3-3 (22-24 FT)	0.07			
3-3 (24-26 FT)	0.07			
DOWNGRADIENT WELLS (RES.)				
3-5		<0.05	<0.05	<0.05
3-6		<0.05	<0.05	<0.05
3-6C		<0.05		
3-7A		<0.05	<0.05	<0.05
3-8		<0.05	<0.05	<0.05
3-9		<0.05	<0.05	<0.05
3-9A		<0.05	<0.05	<0.05
DOWNGRADIENT (ALL.)				
3-6A		<0.05	<0.05	<0.05
DOWNGRADIENT (FILL)				
3-6B		<0.05	<0.05	<0.05
3-8A		<0.05	<0.05	<0.05
DOWNGRADIENT (DIKE)				
3-7		<0.05	<0.05	<0.05
TOE DRAINS				
3-10		<0.05	<0.05	<0.05
3-11		<0.05		<0.05
3-12				<0.05
ASH POND DISCHARGE				
3-13		0.06		<0.05

PLANT HIRLL
CONCENTRATION OF 15 CHROMIUM PPM

SAMPLING POINT DESIGNATION	TRIPS			
	12881	22381	32381	71482
BACKGROUND WELLS				
3-4 (ALL.)		<0.008	<0.01	<0.01
3-4A (FILL)		<0.008	0.01	
3-4B (RES./ROCK)		<0.008	<0.01	<0.01
DP-1				<0.01
DP-2				<0.01
DP-8				<0.01
DP-9				<0.01
RETIRED ASH POND				
3-1 (ASH,ALL.,RES.)		<0.008	<0.01	<0.01
ACTIVE ASH POND WELLS				
3-2 (ALL.)		<0.008	0.02	<0.01
3-2 (ALL.) DIS. SOL.				<0.01
3-2A (ASH)		0.01	<0.01	<0.01
3-3 (RES.)		<0.008	<0.01	<0.01
ASH POND LIQUORS				
3-2 (16-18 FT)	<0.008			
3-2 (20-22 FT)	<0.008			
3-2 (24-26 FT)				
3-2 (38-40 FT)	0.015			
3-2A (24.5-26.4 FT)	<0.008			
3-3 (10-12 FT)	0.017			
3-3 (22-24 FT)	0.013			
3-3 (24-26 FT)	0.011			
DOWNGRADIENT WELLS (RES.)				
3-5		<0.008	<0.01	<0.01
3-6		<0.008	<0.01	<0.01
3-6C		<0.008		
3-7A		<0.008	<0.01	<0.01
3-8		<0.008	0.02	<0.01
3-9		<0.008	<0.01	<0.01
3-9A		<0.008	<0.01	<0.01
DOWNGRADIENT (ALL.)				
3-6A		<0.008	<0.01	<0.01
DOWNGRADIENT (FILL)				
3-6B		<0.008	<0.01	<0.01
3-8A		<0.008	0.02	<0.01
DOWNGRADIENT (DIKE)				
3-7		<0.008	<0.01	<0.01
TOE DRAINS				
3-10		<0.008	<0.01	<0.01
3-11		<0.008		<0.01
3-12				<0.01
ASH POND DISCHARGE				
3-13		0.01		<0.01

PLANT THREE
CONCENTRATION OF 16 COPPER PPM

SAMPLING POINT DESIGNATION	TRIPS 12881	22381	32381	71482
BACKGROUND WELLS				
3-4 (ALL.)		<0.008	<0.005	<0.008
3-4A (FILL)		<0.008	<0.005	
3-4B (RES./ROCK)		<0.008	<0.005	<0.008
DP-1				<0.008
DP-2				<0.008
DP-8				<0.008
DP-9				<0.008
RETIRED ASH POND				
3-1 (ASH,ALL.,RES.)		<0.008	<0.005	<0.008
ACTIVE ASH POND WELLS				
3-2 (ALL.)		<0.008	<0.005	<0.008
3-2 (ALL.) DIS. SOL.				<0.008
3-2A (ASH)		<0.008	<0.005	<0.008
3-3 (RES.)		<0.008	<0.005	<0.008
ASH POND LIQUORS				
3-2 (16-18 FT)	0.016			
3-2 (20-22 FT)	<0.008			
3-2 (24-26 FT)				
3-2 (38-40 FT)	0.015			
3-2A (24.5-26.4 FT)	0.049			
3-3 (10-12 FT)	<0.008			
3-3 (22-24 FT)	<0.008			
3-3 (24-26 FT)	0.023			
DOWNGRADIENT WELLS (RES.)				
3-5		<0.008	<0.005	<0.008
3-6		<0.008	<0.005	<0.008
3-6C		<0.008		
3-7A		0.013	<0.005	<0.008
3-8		<0.008	<0.005	<0.008
3-9		<0.008	<0.005	<0.008
3-9A		<0.008	<0.005	<0.008
DOWNGRADIENT (ALL.)				
3-6A		<0.008	<0.005	<0.008
DOWNGRADIENT (FILL)				
3-6B		<0.008	0.028	<0.008
3-8A		<0.008	<0.005	<0.008
DOWNGRADIENT (DIKE)				
3-7		<0.008	<0.005	<0.008
TOE DRAINS				
3-10		<0.008	<0.005	<0.008
3-11		<0.008		<0.008
3-12				<0.008
ASH POND DISCHARGE				
3-13		<0.008		<0.008

PLANT THREE
CONCENTRATION OF T/ IRON PPM

SAMPLING POINT DESIGNATION	TRIPS			
	12881	22381	32381	71482
BACKGROUND WELLS				
3-4 (ALL.)		4.46	1.93	7.1
3-4A (FILL)		9.22	16.5	
3-4B (RES./ROCK)		<0.01	<0.01	<0.01
DP-1				<0.01
DP-2				<0.01
DP-8				<0.01
DP-9				<0.01
RETIRED ASH POND				
3-1 (ASH,ALL.,RES.)		0.01	<0.01	<0.01
ACTIVE ASH POND WELLS				
3-2 (ALL.)		3.03	26.9	10.3
3-2 (ALL.) DIS. SOL.				25.9
3-2A (ASH)		0.02	<0.01	0.02
3-3 (RES.)		0.93	1.39	0.08
ASH POND LIQUORS				
3-2 (16-18 FT)	0.01			
3-2 (20-22 FT)	0.02			
3-2 (24-26 FT)				
3-2 (38-40 FT)	0.01			
3-2A (24.5-26.4 FT)	0.03			
3-3 (10-12 FT)	0.02			
3-3 (22-24 FT)	0.02			
3-3 (24-26 FT)	0.03			
DOWNGRADIENT WELLS (RES.)				
3-5		0.02	<0.01	<0.01
3-6		<0.01	<0.01	0.01
3-6C		0.02		
3-7A		<0.01	<0.01	0.02
3-8		<0.01	<0.01	<0.01
3-9		5.68	9.12	14.4
3-9A		0.05	<0.01	0.02
DOWNGRADIENT (ALL.)				
3-6A		<0.01	<0.01	<0.01
DOWNGRADIENT (FILL)				
3-6B		0.15	0.24	0.76
3-8A		23.7	24.5	16.2
DOWNGRADIENT (DIKE)				
3-7		<0.01	<0.01	<0.01
TOE DRAINS				
3-10		<0.01	<0.01	0.13
3-11		0.03		0.05
3-12				<0.01
ASH POND DISCHARGE				
3-13		0.02		<0.01

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PLANT THREE
CONCENTRATION OF 18 POTASSIUM PPM

SAMPLING POINT DESIGNATION	TRIPS			
	12881	22381	32381	71482
BACKGROUND WELLS				
3-4 (ALL.)		1	<1	2
3-4A (FILL)		3	1	
3-4B (RES./ROCK)		<1	<1	2
DP-1				<1
DP-2				<1
DP-8				<1
DP-9				2
RETIRED ASH POND				
3-1 (ASH,ALL.,RES.)		24	25	30
ACTIVE ASH POND WELLS				
3-2 (ALL.)		7	6	8
3-2 (ALL.) DIS. SOL.				7
3-2A (ASH)		11	10	9
3-3 (RES.)		1	<1	4
ASH POND LIQUORS				
3-2 (16-18 FT)	14			
3-2 (20-22 FT)	15			
3-2 (24-26 FT)				
3-2 (38-40 FT)	10			
3-2A (24.5-26.4 FT)	17			
3-3 (10-12 FT)	11			
3-3 (22-24 FT)	16			
3-3 (24-26 FT)	14			
DOWNGRADIENT WELLS (RES.)				
3-5		<1	<1	<1
3-6		3	1	2
3-6C		2		
3-7A		3	3	3
3-8		3	3	3
3-9		<1	<1	<1
3-9A		<1	<1	<1
DOWNGRADIENT (ALL.)				
3-6A		<1	<1	<1
DOWNGRADIENT (FILL)				
3-6B		<1	<1	<1
3-8A		<1	<1	1
DOWNGRADIENT (DIKE)				
3-7		<1	<1	1
TOE DRAINS				
3-10		2	<1	3
3-11		1		1
3-12				3
ASH POND DISCHARGE				
3-13		8		7

PLANT THREE
CONCENTRATION OF 19 MAGNESIUM PPM

SAMPLING POINT DESIGNATION	TRIPS			
	12881	22381	32381	71482
BACKGROUND WELLS				
3-4 (ALL.)		6.98	4.96	5.83
3-4A (FILL)		7.12	11.6	
3-4B (RES./ROCK)		3.66	4.31	2.44
DP-1				2.98
DP-2				0.25
DP-8				1.2
DP-9				1.72
RETIRED ASH POND				
3-1 (ASH,ALL.,RES.)		0.11	0.03	0.04
ACTIVE ASH POND WELLS				
3-2 (ALL.)		9.66	11.4	11.7
3-2 (ALL.) DIS. SOL.				10.8
3-2A (ASH)		10.5	11.7	6
3-3 (RES.)		1.16	0.99	0.87
ASH POND LIQUORS				
3-2 (16-18 FT)	2.53			
3-2 (20-22 FT)	2.84			
3-2 (24-26 FT)				
3-2 (38-40 FT)	19.5			
3-2A (24.5-26.4 FT)	3.3			
3-3 (10-12 FT)	22.1			
3-3 (22-24 FT)	7.63			
3-3 (24-26 FT)	8.33			
DOWNGRADIENT WELLS (RES.)				
3-5		1.23	1,59	0.93
3-6		6.31	7,23	5.99
3-6C		6.4		
3-7A		7.92	9.28	9.27
3-8		4.45	5.35	4.61
3-9		7.94	8.72	7.13
3-9A		3.29	3.45	2.98
DOWNGRADIENT (ALL.)				
3-6A		1.69	2	1.55
DOWNGRADIENT (FILL)				
3-6B		1.01	1.21	0.33
3-8A		8.56	10.7	9.27
DOWNGRADIENT (DIKE)				
3-7		0.75	0.85	0.69
TOE DRAINS				
3-10		7.91	8.15	5.86
3-11		9.3		8.53
3-12				4.38
ASH POND DISCHARGE				
3-13		2.69		2.3

PLANT THREE
CONCENTRATION OF 20 MANGANESE PPM

SAMPLING POINT DESIGNATION	TRIPS			
	12881	22381	32381	71482
BACKGROUND WELLS				
3-4 (ALL.)		11.1	3.52	7.11
3-4A (FILL)		3.56	7.36	
3-4B (RES./ROCK)		0.014	0.07	<0.01
DP-1				0.02
DP-2				<0.01
DP-8				<0.01
DP-9				<0.01
RETIRED ASH POND				
3-1 (ASH,ALL.,RES.)		<0.008	<0.01	<0.01
ACTIVE ASH POND WELLS				
3-2 (ALL.)		14	13.6	6.44
3-2 (ALL.) DIS. SOL.				6.2
3-2A (ASH)		0.058	0.07	0.16
3-3 (RES.)		2.18	1.87	0.54
ASH POND LIQUORS				
3-2 (16-18 FT)	0.019			
3-2 (20-22 FT)	0.01			
3-2 (24-26 FT)				
3-2 (38-40 FT)	0.17			
3-2A (24.5-26.4 FT)	0.081			
3-3 (10-12 FT)	0.257			
3-3 (22-24 FT)	0.098			
3-3 (24-26 FT)	0.164			
DOWNGRADIENT WELLS (RES.)				
3-5		0.034	0.05	0.02
3-6		0.029	0.03	<0.01
3-6C		0.252		
3-7A		0.024	0.03	<0.01
3-8		0.05	0.07	0.02
3-9		2.55	2.71	2.72
3-9A		0.103	0.1	0.05
DOWNGRADIENT (ALL.)				
3-6A		<0.008	0.03	<0.01
DOWNGRADIENT (FILL)				
3-6B		0.075	0.12	0.07
3-8A		4.79	5.09	4.23
DOWNGRADIENT (DIKE)				
3-7		0.057	0.05	0.05
TOE DRAINS				
3-10		<0.008	0.03	0.72
3-11		0.045		0.37
3-12				<0.01
ASH POND DISCHARGE				
3-13		0.088		<0.01

PLANT THREE
CONCENTRATION OF 21 MOLYBDENUM PPM

SAMPLING POINT DESIGNATION	TRIPS 12881	22381	32381	71482
BACKGROUND WELLS				
3-4 (ALL.)		<0.3	<0.2	<0.3
3-4A (FILL)		<0.3	<0.2	
3-4B (RES./ROCK)		<0.3	<0.2	<0.3
DP-1				<0.3
DP-2				<0.3
DP-8				<0.3
DP-9				<0.3
RETIRED ASH POND				
3-1 (ASH,ALL.,RES.)		0.6	<0.2	0.7
ACTIVE ASH POND WELLS				
3-2 (ALL.)		<0.3	<0.2	<0.3
3-2 (ALL.) DIS. SOL.				<0.3
3-2A (ASH)		0.9	0.7	0.5
3-3 (RES.)		<0.3	<0.2	<0.3
ASH POND LIQUORS				
3-2 (16-18 FT)	0.3			
3-2 (20-22 FT)	0.4			
3-2 (24-26 FT)				
3-2 (38-40 FT)	1			
3-2A (24.5-26.4 FT)	0.6			
3-3 (10-12 FT)	0.9			
3-3 (22-24 FT)	0.4			
3-3 (24-26 FT)	0.6			
DOWNGRADIENT WELLS (RES.)				
3-5		<0.3	<0.2	<0.3
3-6		<0.3	<0.2	<0.3
3-6C		<0.3		
3-7A		<0.3	<0.2	<0.3
3-8		<0.3	<0.2	<0.3
3-9		<0.3	<0.2	<0.3
3-9A		<0.3	<0.2	<0.3
DOWNGRADIENT (ALL.)				
3-6A		<0.3	<0.2	<0.3
DOWNGRADIENT (FILL)				
3-6B		<0.3	<0.2	<0.3
3-8A		<0.3	<0.2	<0.3
DOWNGRADIENT (DIKE)				
3-7		<0.3*	<0.2	<0.3
TOE DRAINS				
3-10		<0.3	<0.2	<0.3
3-11		<0.3		<0.3
3-12				<0.3
ASH POND DISCHARGE				
3-13		<0.3		<0.3

PLANT THRLE
CONCENTRATION OF 22 SODIUM PPM

SAMPLING POINT DESIGNATION	TRIPS			
	12881	22381	32381	71482
BACKGROUND WELLS				
3-4 (ALL.)		14	11	19
3-4A (FILL)		6	3	
3-4B (RES./ROCK)		12	10	12
DP-1				6
DP-2				1
DP-8				5
DP-9				8
RETIRED ASH POND				
3-1 (ASH,ALL.,RES.)		11	9	13
ACTIVE ASH POND WELLS				
3-2 (ALL.)		9	5	8
3-2 (ALL.) DIS. SOL.				7
3-2A (ASH)		5	2	10
3-3 (RES.)		8	7	14
ASH POND LIQUORS				
3-2 (16-18 FT)	19			
3-2 (20-22 FT)	13			
3-2 (24-26 FT)				
3-2 (38-40 FT)	8			
3-2A (24.5-26.4 FT)	15			
3-3 (10-12 FT)	7			
3-3 (22-24 FT)	13			
3-3 (24-26 FT)	12			
DOWNGRADIENT WELLS (RES.)				
3-5		2	<2	2
3-6		10	8	10
3-6C		9		
3-7A		10	9	11
3-8		15	14	12
3-9		3	<2	3
3-9A		4	2	4
DOWNGRADIENT (ALL.)				
3-6A		6	6	7
DOWNGRADIENT (FILL)				
3-6B		6	5	6
3-8A		8	6	10
DOWNGRADIENT (DIKE)				
3-7		3	<2	3
TOE DRAINS				
3-10		5	4	8
3-11		8		8
3-12				6
ASH POND DISCHARGE				
3-13		16		14

PLANT THREE
CONCENTRATION OF 23 NICKEL PPM

SAMPLING POINT DESIGNATION	TRIPS 12881	22381	32381	71482
BACKGROUND WELLS				
3-4 (ALL.)		<0.01	<0.05	<0.05
3-4A (FILL)		<0.01	<0.05	
3-4B (RLS./ROCK)		<0.01	<0.05	<0.05
DP-1				<0.05
DP-2				<0.05
DP-8				<0.05
DP-9				<0.05
RETIRED ASH POND				
3-1 (ASH,ALL.,RES.)		<0.01	<0.05	<0.05
ACTIVE ASH POND WELLS				
3-2 (ALL.)		<0.01	<0.05	<0.05
3-2 (ALL.) DIS. SOL.				<0.05
3-2A (ASH)		0.02	<0.05	<0.05
3-3 (RES.)		<0.01	<0.05	<0.05
ASH POND LIQUORS				
3-2 (16-18 FT)	0.03			
3-2 (20-22 FT)	0.04			
3-2 (24-26 FT)				
3-2 (38-40 FT)	0.04			
3-2A (24.5-26.4 FT)	0.34			
3-3 (10-12 FT)	0.05			
3-3 (22-24 FT)	0.03			
3-3 (24-26 FT)	0.07			
DOWNGRADIENT WELLS (RES.)				
3-5		<0.01	<0.05	<0.05
3-6		<0.01	<0.05	<0.05
3-6C		0.02		
3-7A		<0.01	<0.05	<0.05
3-8		<0.01	<0.05	<0.05
3-9		<0.01	<0.05	<0.05
3-9A		<0.01	<0.05	<0.05
DOWNGRADIENT (ALL.)				
3-6A		<0.01	<0.05	<0.05
DOWNGRADIENT (FILL)				
3-6B		<0.01	<0.05	<0.05
3-8A		<0.01	<0.05	<0.05
DOWNGRADIENT (DIKE)				
3-7		<0.01	<0.05	<0.05
TOE DRAINS				
3-10		<0.01	<0.05	<0.05
3-11		<0.01		<0.05
3-12				<0.05
ASH POND DISCHARGE				
3-13		<0.01		<0.05

PLANT THREE
CONCENTRATION OF 24 PHOSPHORUS PPM

SAMPLING POINT DESIGNATION	TRIPS			
	12881	22381	32381	71482
BACKGROUND WELLS				
3-4 (ALL.)		<0.6	<0.5	<0.6
3-4A (FILL)		<0.6	<0.5	
3-4B (RES./ROCK)		<0.6	<0.5	<0.6
DP-1				<0.6
DP-2				<0.6
DP-8				<0.6
DP-9				<0.6
RETIRED ASH POND				
3-1 (ASH,ALL.,RES.)		<0.6	<0.5	<0.6
ACTIVE ASH POND WELLS				
3-2 (ALL.)		<0.6	<0.5	<0.6
3-2 (ALL.) DIS. SOL.				<0.6
3-2A (ASH)		0.6	0.8	0.7
3-3 (RES.)		<0.6	<0.5	<0.6
ASH POND LIQUORS				
3-2 (16-18 FT)	<0.6			
3-2 (20-22 FT)	<0.6			
3-2 (24-26 FT)				
3-2 (38-40 FT)	<0.6			
3-2A (24.5-26.4 FT)	<0.6			
3-3 (10-12 FT)	<0.6			
3-3 (22-24 FT)	<0.6			
3-3 (24-26 FT)	<0.6			
DOWNGRADIENT WELLS (RES.)				
3-5		<0.6	<0.5	<0.6
3-6		<0.6	<0.5	<0.6
3-6C		<0.6		
3-7A		<0.6	<0.5	<0.6
3-8		<0.6	<0.5	<0.6
3-9		<0.6	<0.5	<0.6
3-9A		<0.6	<0.5	<0.6
DOWNGRADIENT (ALL.)				
3-6A		<0.6	0.5	<0.6
DOWNGRADIENT (FILL)				
3-6B		<0.6	<0.5	<0.6
3-8A		<0.6	<0.5	<0.6
DOWNGRADIENT (DIKE)				
3-7		<0.6	<0.5	<0.6
TOE DRAINS				
3-10		<0.6	<0.5	<0.6
3-11		<0.6		<0.6
3-12				<0.6
ASH POND DISCHARGE				
3-13		<0.6		<0.6

PLANT THREE
CONCENTRATION OF 25 LEAD PPM

SAMPLING POINT DESIGNATION	TRIPS			
	12881	22381	32381	71482
BACKGROUND WELLS				
3-4 (ALL.)		<0.05	<0.05	<0.05
3-4A (FILL)		<0.05	<0.05	
3-4B (RES./ROCK)		<0.05	<0.05	<0.05
DP-1				<0.05
DP-2				<0.05
DP-8				<0.05
DP-9				<0.05
RETIRED ASH POND				
3-1 (ASH,ALL.,RES.)		<0.05	<0.05	<0.05
ACTIVE ASH POND WELLS				
3-2 (ALL.)		<0.05	<0.05	<0.05
3-2 (ALL.) DIS. SOL.				<0.05
3-2A (ASH)		<0.05	<0.05	<0.05
3-3 (RES.)		<0.05	<0.05	<0.05
ASH POND LIQUORS				
3-2 (16-18 FT)	<0.05			
3-2 (20-22 FT)	<0.05			
3-2 (24-26 FT)				
3-2 (38-40 FT)	<0.05			
3-2A (24.5-26.4 FT)	<0.05			
3-3 (10-12 FT)	<0.05			
3-3 (22-24 FT)	<0.05			
3-3 (24-26 FT)	<0.05			
DOWNGRADIENT WELLS (RES.)				
3-5		<0.05	<0.05	<0.05
3-6		<0.05	<0.05	<0.05
3-6C		<0.05		
3-7A		<0.05	<0.05	<0.05
3-8		<0.05	<0.05	<0.05
3-9		<0.05	<0.05	<0.05
3-9A		<0.05	<0.05	<0.05
DOWNGRADIENT (ALL.)				
3-6A		<0.05	<0.05	<0.05
DOWNGRADIENT (FILL)				
3-6B		<0.05	<0.05	<0.05
3-8A		<0.05	<0.05	<0.05
DOWNGRADIENT (DIKE)				
3-7		<0.05	<0.05	<0.05
TOE DRAINS				
3-10		<0.05	<0.05	<0.05
3-11		<0.05		<0.05
3-12				<0.05
ASH POND DISCHARGE				
3-13		<0.05		<0.05

PLANT THREE
CONCENTRATION OF 26 SILICON PPM

SAMPLING POINT DESIGNATION	TRIPS			
	12881	22381	32381	71482
BACKGROUND WELLS				
3-4 (ALL.)		16.6	20.5	12.3
3-4A (FILL)		3.38	4.2	
3-4B (RES./ROCK)		29.5	32.1	25.8
DP-1				18.3
DP-2				5.82
DP-8				18.9
DP-9				16.9
RETIRED ASH POND				
3-1 (ASH,ALL.,RES.)		1.24	1.8	2.05
ACTIVE ASH POND WELLS				
3-2 (ALL.)		4.76	6.28	5.82
3-2 (ALL.) DIS. SOL.				5.45
3-2A (ASH)		1.65	2.04	3.61
3-3 (RES.)		2.69	3.21	4.4
ASH POND LIQUORS				
3-2 (16-18 FT)	1.7			
3-2 (20-22 FT)	0.92			
3-2 (24-26 FT)				
3-2 (38-40 FT)	2.08			
3-2A (24.5-26.4 FT)	0.92			
3-3 (10-12 FT)	2.99			
3-3 (22-24 FT)	2.11			
3-3 (24-26 FT)	2			
DOWNGRADIENT WELLS (RES.)				
3-5		6.96	7.7	6.06
3-6		23.4	26.7	23.9
3-6C		22.6		
3-7A		14	16.2	14.2
3-8		9.17	11	9.65
3-9		2.06	2.37	2.43
3-9A		7.51	8.7	7.65
DOWNGRADIENT (ALL.)				
3-6A		20.5	23.2	20.3
DOWNGRADIENT (FILL)				
3-6B		15.4	17.7	17.1
3-8A		1.8	2.12	2.25
DOWNGRADIENT (DIKE)				
3-7		3.85	4.62	4.03
TOE DRAINS				
3-10		6.75	10.2	14.5
3-11		11.2		12.3
3-12				3.43
ASH POND DISCHARGE				
3-13		4		3.71

PLANT THREE
CONCENTRATION OF 27 STRONTIUM PPM

SAMPLING POINT DESIGNATION	TRIPS 12881	22381	32381	71482
BACKGROUND WELLS				
3-4 (ALL.)		0.114	0.099	0.145
3-4A (FILL)		0.048	0.078	
3-4B (RES./ROCK)		0.141	0.166	0.162
DP-1				0.077
DP-2				0.008
DP-8				0.06
DP-9				0.075
RETIRED ASH POND				
3-1 (ASH,ALL.,RES.)		3.6	4.71	4.63
ACTIVE ASH POND WELLS				
3-2 (ALL.)		0.25	0.274	0.241
3-2 (ALL.) DIS. SOL.				0.218
3-2A (ASH)		3.71	4.13	1.35
3-3 (RES.)		0.007	0.008	0.053
ASH POND LIQUORS				
3-2 (16-18 FT)	1.44			
3-2 (20-22 FT)	2.05			
3-2 (24-26 FT)				
3-2 (38-40 FT)	2.27			
3-2A (24.5-26.4 FT)	2.02			
3-3 (10-12 FT)	2.14			
3-3 (22-24 FT)	1.19			
3-3 (24-26 FT)	1.39			
DOWNGRADIENT WELLS (RES.)				
3-5		0.007	0.011	0.012
3-6		0.139	0.164	0.146
3-6C		0.142		
3-7A		0.35	0.409	0.411
3-8		0.231	0.278	0.241
3-9		0.099	0.107	0.078
3-9A		0.113	0.125	0.113
DOWNGRADIENT (ALL.)				
3-6A		0.075	0.094	0.088
DOWNGRADIENT (FILL)				
3-6B		0.033	0.039	0.016
3-8A		0.069	0.106	0.075
DOWNGRADIENT (DIKE)				
3-7		0.005	0.01	0.008
TOE DRAINS				
3-10		0.072	0.114	0.086
3-11		0.143		0.137
3-12				0.036
ASH POND DISCHARGE				
3-13		0.342		0.297

PLANT THREE
CONCENTRATION OF 28 THORIUM PPM

SAMPLING POINT DESIGNATION	TRIPS 12081	22381	32381	71482
BACKGROUND WELLS				
3-4 (ALL.)		<0.01	<0.01	<0.01
3-4A (FILL)		<0.01	<0.01	
3-4B (RES./ROCK)		<0.01	<0.01	0.01
DP-1				<0.01
DP-2				<0.01
DP-8				<0.01
DP-9				0.03
RETIRED ASH POND				
3-1 (ASH,ALL.,RES.)		<0.01	<0.01	0.01
ACTIVE ASH POND WELLS				
3-2 (ALL.)		<0.01	<0.01	<0.01
3-2 (ALL.) DIS. SOL.				<0.01
3-2A (ASH)		0.01	<0.01	<0.01
3-3 (RES.)		<0.01	<0.01	<0.01
ASH POND LIQUORS				
3-2 (16-18 FT)	0.02			
3-2 (20-22 FT)	0.03			
3-2 (24-26 FT)				
3-2 (38-40 FT)	0.02			
3-2A (24.5-26.4 FT)	0.02			
3-3 (10-12 FT)	0.02			
3-3 (22-24 FT)	0.05			
3-3 (24-26 FT)	0.04			
DOWNGRADIENT WELLS (RES.)				
3-5		<0.01	<0.01	<0.01
3-6		<0.01	<0.01	<0.01
3-6C		<0.01		
3-7A		<0.01	<0.01	0.01
3-8		<0.01	<0.01	0.02
3-9		0.01	<0.01	<0.01
3-9A		<0.01	<0.01	<0.01
DOWNGRADIENT (ALL.)				
3-6A		<0.01	<0.01	<0.01
DOWNGRADIENT (FILL)				
3-6B		<0.01	<0.01	<0.01
3-8A		<0.01	<0.01	0.01
DOWNGRADIENT (DIKE)				
3-7		<0.01	<0.01	0.02
TOE DRAINS				
3-10		<0.01	<0.01	0.03
3-11		<0.01		0.04
3-12				0.02
ASH POND DISCHARGE				
3-13		0.02		0.03

NOTE: Values above detection limit may not be real since blanks showed levels of 0.01 to 0.03.

PLANT HIRI
CONCENTRATION OF 29 TITANIUM PPM

SAMPLING POINT DESIGNATION	TRIPS			
	12881	22381	32381	71482
BACKGROUND WELLS				
3-4 (ALL.)		<0.005	<0.005	<0.005
3-4A (FILL)		<0.005	<0.005	
3-4B (RES./ROCK)		<0.005	<0.005	<0.005
DP-1				<0.005
DP-2				<0.005
DP-8				<0.005
DP-9				<0.005
RETIRED ASH POND				
3-1 (ASH,ALL.,RES.)		<0.005	<0.005	<0.005
ACTIVE ASH POND WELLS				
3-2 (ALL.)		<0.005	<0.005	<0.005
3-2 (ALL.) DIS. SOL.				<0.005
3-2A (ASH)		<0.005	<0.005	<0.005
3-3 (RES.)		<0.005	<0.005	<0.005
ASH POND LIQUORS				
3-2 (16-18 FT)	<0.005			
3-2 (20-22 FT)	<0.005			
3-2 (24-26 FT)				
3-2 (38-40 FT)	1			
3-2A (24.5-26.4 FT)	<0.005			
3-3 (10-12 FT)	<0.005			
3-3 (22-24 FT)	<0.005			
3-3 (24-26 FT)	<0.005			
DOWNGRADIENT WELLS (RES.)				
3-5		<0.005	<0.005	<0.005
3-6		<0.005	<0.005	<0.005
3-6C		<0.005		
3-7A		<0.005	<0.005	<0.005
3-8		<0.005	<0.005	<0.005
3-9		<0.005	<0.005	<0.005
3-9A		<0.005	<0.005	<0.005
DOWNGRADIENT (ALL.)				
3-6A		<0.005	<0.005	<0.005
DOWNGRADIENT (FILL)				
3-6B		<0.005	<0.005	<0.005
3-8A		<0.005	<0.005	<0.005
DOWNGRADIENT (DIKE)				
3-7		<0.005	<0.005	<0.005
TOE DRAINS				
3-10		<0.005	<0.005	<0.005
3-11		<0.005		<0.005
3-12				<0.005
ASH POND DISCHARGE				
3-13		<0.005		<0 005

PLANT THREE
CONCENTRATION OF 30 VANADIUM PPM

SAMPLING POINT DESIGNATION	TRIPS			
	12881	22381	32381	71482
BACKGROUND WELLS				
3-4 (ALL.)		<0.005	<0.005	<0.005
3-4A (FILL)		<0.005	<0.005	
3-4B (RES./ROCK)		<0.005	<0.005	0.016
DP-1				0.008
DP-2				<0.005
DP-8				<0.005
DP-9				0.009
RETIRED ASH POND				
3-1 (ASH,ALL.,RES.)		0.029	0.018	0.034
ACTIVE ASH POND WELLS				
3-2 (ALL.)		<0.005	<0.005	<0.005
3-2 (ALL.) DIS. SOL.				<0.005
3-2A (ASH)		0.035	0.037	0.043
3-3 (RES.)		<0.005	<0.005	<0.005
ASH POND LIQUORS				
3-2 (16-18 FT)	0.029			
3-2 (20-22 FT)	0.009			
3-2 (24-26 FT)				
3-2 (38-40 FT)	0.014			
3-2A (24.5-26.4 FT)	0.042			
3-3 (10-12 FT)	<0.005			
3-3 (22-24 FT)	0.313			
3-3 (24-26 FT)	0.132			
DOWNGRADIENT WELLS (RES.)				
3-5		<0.005	<0.005	0.007
3-6		<0.005	<0.005	0.014
3-6C		<0.005		
3-7A		<0.005	<0.005	0.006
3-8		<0.005	<0.005	<0.005
3-9		<0.005	<0.005	<0.005
3-9A		<0.005	<0.005	<0.005
DOWNGRADIENT (ALL.)				
3-6A		<0.005	<0.005	0.007
DOWNGRADIENT (FILL)				
3-6B		<0.005	<0.005	<0.005
3-8A		<0.005	<0.005	<0.005
DOWNGRADIENT (DIKE)				
3-7		<0.005	<0.005	<0.005
TOE DRAINS				
3-10		<0.005	<0.005	0.008
3-11		<0.005		0.007
3-12				<0.005
ASH POND DISCHARGE				
3-13		0.03		0.047

PLANT THREE
CONCENTRATION OF 31 ZINC PPM

SAMPLING POINT DESIGNATION	TRIPS 12881	22381	32381	71482
BACKGROUND WELLS				
3-4 (ALL.)		<0.02	<0.05	0.25
3-4A (FILL)		0.03	<0.05	
3-4B (RES./ROCK)		<0.02	<0.05	<0.05
DP-1				<0.05
DP-2				<0.05
DP-8				<0.05
DP-9				<0.05
RETIRED ASH POND				
3-1 (ASH,ALL.,RES.)		<0.02	<0.05	<0.05
ACTIVE ASH POND WELLS				
3-2 (ALL.)		<0.02	<0.05	<0.05
3-2 (ALL.) DIS. SOL.				<0.05
3-2A (ASH)		<0.02	<0.05	<0.05
3-3 (RES.)		<0.02	<0.05	<0.05
ASH POND LIQUORS				
3-2 (16-18 FT)	<0.02			
3-2 (20-22 FT)	<0.02			
3-2 (24-26 FT)				
3-2 (38-40 FT)	<0.02			
3-2A (24.5-26.4 FT)	0.03			
3-3 (10-12 FT)	<0.02			
3-3 (22-24 FT)	<0.02			
3-3 (24-26 FT)	<0.02			
DOWNGRADIENT WELLS (RES.)				
3-5		<0.02	<0.05	<0.05
3-6		<0.02	<0.05	<0.05
3-6C		<0.02		
3-7A		<0.02	<0.05	<0.05
3-8		<0.02	<0.05	<0.05
3-9		<0.02	<0.05	<0.05
3-9A		<0.02	<0.05	<0.05
DOWNGRADIENT (ALL.)				
3-6A		<0.02	<0.05	<0.05
DOWNGRADIENT (FILL)				
3-6B		<0.02	<0.05	<0.05
3-8A		<0.02	<0.05	<0.05
DOWNGRADIENT (DIKE)				
3-7		<0.02	<0.05	<0.05
TOE DRAINS				
3-10		<0.02	<0.05	<0.05
3-11		<0.02		<0.05
3-12				<0.05
ASH POND DISCHARGE				
3-13		<0.02		<0.05

PLANT THREE
CONCENTRATION OF 32 ZIRCONIUM PPM

SAMPLING POINT DESIGNATION	TRIPS			
	12881	22381	32381	71482
BACKGROUND WELLS				
3-4 (ALL.)		<0.05	<0.02	<0.05
3-4A (FILL)		<0.05	<0.02	
3-4B (RES./ROCK)		<0.05	<0.02	<0.05
DP-1				<0.05
DP-2				<0.05
DP-8				<0.05
DP-9				<0.05
RETIRED ASH POND				
3-1 (ASH,ALL.,RES.)		<0.05	<0.02	<0.05
ACTIVE ASH POND WELLS				
3-2 (ALL.)		<0.05	<0.02	<0.05
3-2 (ALL.) DIS. SOL.				<0.05
3-2A (ASH)		<0.05	<0.02	<0.05
3-3 (RES.)		<0.05	<0.02	<0.05
ASH POND LIQUORS				
3-2 (16-18 FT)	<0.05			
3-2 (20-22 FT)	<0.05			
3-2 (24-26 FT)				
3-2 (38-40 FT)	<0.05			
3-2A (24.5-26.4 FT)	<0.05			
3-3 (10-12 FT)	<0.05			
3-3 (22-24 FT)	<0.05			
3-3 (24-26 FT)	<0.05			
DOWNGRADIENT WELLS (RES.)				
3-5		<0.05	<0.02	<0.05
3-6		<0.05	<0.02	<0.05
3-6C		<0.05		
3-7A		<0.05	<0.02	<0.05
3-8		<0.05	<0.02	<0.05
3-9		<0.05	<0.02	<0.05
3-9A		<0.05	<0.02	<0.05
DOWNGRADIENT (ALL.)				
3-6A		<0.05	<0.02	<0.05
DOWNGRADIENT (FILL)				
3-6B		<0.05	<0.02	<0.05
3-8A		<0.05	<0.02	<0.05
DOWNGRADIENT (DIKE)				
3-7		<0.05	<0.02	<0.05
TOE DRAINS				
3-10		<0.05	<0.02	<0.05
3-11		<0.05		<0.05
3-12				<0.05
ASH POND DISCHARGE				
3-13		<0.05		<0.05

PLANT THREE
CONCENTRATION OF 33 ARSENIC (LIQUID) PPB

SAMPLING POINT DESIGNATION	TRIPS			
	12881	22381	32381	71482
BACKGROUND WELLS				
3-4 (ALL.)			<0.2	
3-4A (FILL)			<0.2	
3-4B (RES./ROCK)			<0.2	7
DP-1				
DP-2				
DP-8				0.2
DP-9				
RETIRED ASH POND				
3-1 (ASH,ALL.,RES.)		57.2	56.3	
ACTIVE ASH POND WELLS				
3-2 (ALL.)		<0.15	1.6	
3-2 (ALL.) DIS. SOL.				
3-2A (ASH)		1550	2425	318
3-3 (RES.)		1	1	
ASH POND LIQUORS				
3-2 (16-18 FT)	101			
3-2 (20-22 FT)	89			
3-2 (24-26 FT)	56			
3-2 (38-40 FT)	1525			
3-2A (24.5-26.4 FT)				
3-3 (10-12 FT)	975			
3-3 (22-24 FT)				
3-3 (24-26 FT)				
DOWNGRADIENT WELLS (RES.)				
3-5				
3-6				
3-6C				
3-7A		<0.15	0.78	<0.1
3-8		1	0.7	0.1
3-9			<0.2	
3-9A			<0.2	<0.1
DOWNGRADIENT (ALL.)				
3-6A			<0.2	
DOWNGRADIENT (FILL)				
3-6B			<0.2	
3-8A			<0.2	
DOWNGRADIENT (DIKE)				
3-7				
TOL DRAINS				
3-10			<0.2	
3-11		<0.2		
3-12		SP		
ASH POND DISCHARGE				
3-13		58		

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PLANT THREE
CONCENTRATION OF 34 SELENIUM (LIQUID) PPB

SAMPLING POINT DESIGNATION	TRIPS 12881	22381	32381	71482
BACKGROUND WELLS				
3-4 (ALL.)			<0.26	
3-4A (FILL)			<0.26	
3-4B (RES./ROCK)			<0.26	0.7
DP-1				
DP-2				<0.1
DP-8				
DP-9				
RETIRED ASH POND				
3-1 (ASH,ALL.,RES.)		<0.26		
ACTIVE ASH POND WELLS				
3-2 (ALL.)		<0.26		
3-2 (ALL.) DIS. SOL.				
3-2A (ASH)		3	<2	6.6
3-3 (RES.)		<0.26		
ASH POND LIQUORS				
3-2 (16-18 FT)	<2			
3-2 (20-22 FT)	3			
3-2 (24-26 FT)	8			
3-2 (38-40 FT)	3			
3-2A (24.5-26.4 FT)				
3-3 (10-12 FT)	<2			
3-3 (22-24 FT)				
3-3 (24-26 FT)				
DOWNGRADIENT WELLS (RES.)				
3-5				
3-6				
3-6C				
3-7A		<0.26		<0.1
3-8			<0.26	<0.1
3-9				
3-9A				<0.1
DOWNGRADIENT (ALL.)				
3-6A				
DOWNGRADIENT (FILL)				
3-6B				
3-8A				
DOWNGRADIENT (DIKE)				
3-7				
TOE DRAINS				
3-10				
3-11				
3-12		SP		
ASH POND DISCHARGE				
3-13		8		

PLANT THREE
CONCENTRATION OF 37 PH LAB

SAMPLING POINT DESIGNATION	TRIPS 12881	22381	32381	71482
BACKGROUND WELLS				
3-4 (ALL.)			5.8	
3-4A (FILL)			5.9	
3-4B (RES./ROCK)			5.9	
DP-1				
DP-2				
DP-8				
DP-9				
RETIRED ASH POND				
3-1 (ASH,ALL.,RES.)			10.2	
ACTIVE ASH POND WELLS				
3-2 (ALL.)			6.4	
3-2 (ALL.) DIS. SOL.				
3-2A (ASH)			8.3	
3-3 (RES.)			6.3	
ASH POND LIQUORS				
3-2 (16-18 FT)				
3-2 (20-22 FT)				
3-2 (24-26 FT)				
3-2 (38-40 FT)				
3-2A (24.5-26.4 FT)				
3-3 (10-12 FT)				
3-3 (22-24 FT)				
3-3 (24-26 FT)				
DOWNGRADIENT WELLS (RES.)				
3-5			4.9	
3-6			6.5	
3-6C				
3-7A			6.5	
3-8			6.1	
3-9			6.3	
3-9A			5.8	
DOWNGRADIENT (ALL.)				
3-6A			6	
DOWNGRADIENT (FILL)				
3-6B			5.5	
3-8A			6.1	
DOWNGRADIENT (DIKE)				
3-7			4.7	
TOE DRAINS				
3-10			7.5	
3-11				
3-12				
ASH POND DISCHARGE				
3-13				

PLANT THREE
CONCENTRATION OF 38 PH FIELD

SAMPLING POINT DESIGNATION	TRIPS			
	12881	22381	32381	71482
BACKGROUND WELLS				
3-4 (ALL.)		6.1	*	
3-4A (FILL)		5.6	5.7	
3-4B (RES./ROCK)		6.2	6.3	6.7
DP-1				7.4
DP-2				7.2
DP-8				7.6
DP-9				7.6
RETIRED ASH POND				
3-1 (ASH,ALL.,RES.)		10.5	11.4	10.6
ACTIVE ASH POND WELLS				
3-2 (ALL.)		6.5	6.9	7.5
3-2 (ALL.) DIS. SOL.				
3-2A (ASH)		8.5	8.3	9.2
3-3 (RES.)		6.4	6.8	7.1
ASH POND LIQUORS				
3-2 (16-18 FT)				
3-2 (20-22 FT)				
3-2 (24-26 FT)				
3-2 (38-40 FT)				
3-2A (24.5-26.4 FT)				
3-3 (10-12 FT)				
3-3 (22-24 FT)				
3-3 (24-26 FT)				
DOWNGRADIENT WELLS (RES.)				
3-5		5.1		5.4
3-6		6.3		7.1
3-6C		7.3		
3-7A		6.9	6.3	6.9
3-8		6.6	6.3	5.9
3-9		7	*	6.6
3-9A		5.9	5.8	6.3
DOWNGRADIENT (ALL.)				
3-6A		6.3	5.8	6
DOWNGRADIENT (FILL)				
3-6B		5.9	6	5.5
3-8A		6.5	6.4	6.4
DOWNGRADIENT (DIKE)				
3-7		4.4	4.9	5.4
TOE DRAINS				
3-10		7	7.8	7.2
3-11		7.6		7.7
3-12				7.7
ASH POND DISCHARGE				
3-13		8		8.9

PLANT HIREE
CONCENTRATION OF 40 CONDUCTIVITY FIELD UMHOS/CM

SAMPLING POINT DESIGNATION	TRIPS			
	12881	22381	32381	71482
BACKGROUND WELLS				
3-4 (ALL.)	220	205		
3-4A (FILL)		250	190	
3-4B (RES./ROCK)	129	130	117	130
DP-1				80
DP-2				17
DP-8				68
DP-9				85
RETIRED ASH POND				
3-1 (ASH,ALL.,RES.)		525	560	580
ACTIVE ASH POND WELLS				
3-2 (ALL.)		350	395	430
3-2 (ALL.) DIS. SOL.				
3-2A (ASH)		770	675	440
3-3 (RES.)		82	68	115
ASH POND LIQUORS				
3-2 (16-18 FT)				
3-2 (20-22 FT)				
3-2 (24-26 FT)				
3-2 (38-40 FT)				
3-2A (24.5-26.4 FT)				
3-3 (10-12 FT)				
3-3 (22-24 FT)				
3-3 (24-26 FT)				
DOWNGRADIENT WELLS (RES.)				
3-5	73	29		22
3-6	137	117		180
3-6C	173	183		
3-7A	105	265	230	270
3-8	202	240	205	220
3-9	113	210		171
3-9A	111	72	68	74
DOWNGRADIENT (ALL.)				
3-6A	131	68	65	70
DOWNGRADIENT (FILL)				
3-6B	94	57	57	38
3-8A	192	370	325	290
DOWNGRADIENT (DIKE)				
3-7	29	30	29	34
TOE DRAINS				
3-10		310	310	340
3-11		445		410
3-12				320
ASH POND DISCHARGE				
3-13		225		220

PLANT THRLE
CONCENTRATION OF 41 GROUNDWATER LEVEL FT (Mean Sea Level)

SAMPLING POINT DESIGNATION	TRIPS	12881	22381	32381	71482
BACKGROUND WELLS					
3-4 (ALL.)			627.3	627.5	
3-4A (FILL)			623.7	627.7	
3-4B (RES./ROCK)			627.1	626.9	
DP-1					
DP-2					
DP-8					
DP-9					
RETIRED ASH POND					
3-1 (ASH,ALL.,RES.)			604.9	604.4	609.5
ACTIVE ASH POND WELLS					
3-2 (ALL.)			623.4	623.3	625.6
3-2 (ALL.) DIS. SOL.					629.4
3-2A (ASH)			624.5	624.7	629
3-3 (RES.)			623	623.9	625.4
ASH POND LIQUORS					
3-2 (16-18 FT)					
3-2 (20-22 FT)					
3-2 (24-26 FT)					
3-2 (38-40 FT)					
3-2A (24.5-26.4 FT)					
3-3 (10-12 FT)					
3-3 (22-24 FT)					
3-3 (24-26 FT)					
DOWNGRADIENT WELLS (RES.)					
3-5			612.7	613.1	615.7
3-6			574.1	573.6	573.8
3-6C					
3-7A			578.3	582.2	577.2
3-8			578.3	580.4	578.1
3-9			569.8	568.9	569.4
3-9A			569.4	568.5	568.5
DOWNGRADIENT (ALL.)					
3-6A			571.6	571.3	571.7
DOWNGRADIENT (FILL)					
3-6B			571.6	570.6	571.6
3-8A			571.5	563.5	570.4
DOWNGRADIENT (DIKE)					
3-7			578.1	577.2	577.5
TOE DRAINS					
3-10					
3-11					
3-12					
ASH POND DISCHARGE					
3-13					

SUMMARY OF GROUNDWATER LEVELS - ALLEN

(in feet from top of casing)*

ADL Wells	TOC	Date 1/28/81	2/23/81	3/23/81	7/14/82
3-1	622.5	18.0(604.5)	17.6(604.9)	18.1(604.4)	13.0(609.5)
3-2	627.4	35.2(592.2)	3.6(623.8)	4.1(623.3)	1.8(625.6)
3-2A	625.5	5.4(620.1)	1.0(624.5)	0.8(624.7)	1.7(629.0)
3-3	627.7	40.2(587.5)	3.7(624.0)	3.9(623.8)	2.3(625.4)
3-4	628.8	1.9(628.9)	1.5(627.3)	1.3(627.5)	-
3-4A	628.6	7.7(620.9)	4.9(623.7)	5.8(627.7)	-
3-4B	628.6	2.5(626.1)	1.5(627.1)	3.2(626.9)	-
3-5	635.2	23.1(612.1)	22.5(612.7)	22.1(613.1)	19.5(615.7)
3-6	578.5	5.0(573.5)	4.4(574.1)	4.9(573.6)	4.7(573.8)
3-6A	579.9	9.2(570.7)	8.2(571.7)	8.6(571.3)	8.2(571.7)
3-6B	580.2	9.8(570.4)	8.6(571.6)	9.6(570.6)	8.6(571.6)
3-7	597.0	19.8(577.2)	18.9(578.1)	19.8(577.2)	19.5(577.5)
3-7A	596.9	19.2(577.7)	18.6(578.3)	14.7(582.2)	19.7(577.2)
3-8	592.5	15.4(577.1)	14.2(578.3)	12.1(580.4)	14.4(578.1)
3-8A	582.5	12.2(570.3)	11.0(571.5)	19.0(563.5)	12.1(570.4)
3-9	581.3	12.6(568.7)	11.5(569.8)	12.4(568.9)	11.9(569.4)
3-9A	581.0	12.5(568.4)	11.6(569.4)	12.5(568.5)	12.5(568.5)
POND LEVEL		(624.2)			

*Values in parenthesis are feet relative to mean sea level.

TOC = Top of casing elevation in feet relative to mean sea level.

PLANT THREE
CONCENTRATION OF 42 DISSOLVED OXYGEN PPM

SAMPLING POINT DESIGNATION	TRIPS			
	12881	22381	32381	71482
BACKGROUND WELLS				
3-4 (ALL.)			1.5	
3-4A (FILL)			1.4	
3-4B (RES./ROCK)			1.5	2.1
DP-1				3
DP-2				2.9
DP-8				2.8
DP-9				3.2
RETIRED ASH POND				
3-1 (ASH,ALL.,RES.)			1	2
ACTIVE ASH POND WELLS				
3-2 (ALL.)			0.2	0.3
3-2 (ALL.) DIS. SOL.				
3-2A (ASH)			0.7	0.25
3-3 (RES.)			1.5	2.25
ASH POND LIQUORS				
3-2 (16-18 FT)				
3-2 (20-22 FT)				
3-2 (24-26 FT)				
3-2 (38-40 FT)				
3-2A (24.5-26.4 FT)				
3-3 (10-12 FT)				
3-3 (22-24 FT)				
3-3 (24-26 FT)				
DOWNGRADIENT WELLS (RES.)				
3-5			1.9	1.5
3-6			1.6	2
3-6C				
3-7A			1.3	1.5
3-8			0.7	0.3
3-9				3.7
3-9A			0.6	0.8
DOWNGRADIENT (ALL.)				
3-6A			2.9	2.2
DOWNGRADIENT (FILL)				
3-6B			0.8	0.8
3-8A			0.6	2.9
DOWNGRADIENT (DIKE)				
3-7			0.4	0.7
TOE DRAINS				
3-10			8.2	2.45
3-11				2.1
3-12				5.7
ASH POND DISCHARGE				
3-13				6.1

F 544	11 18 81	UNIT 4 BOILER	BROMATE CLEANING SOL/DEEPBLUE
F 545	11 18 81	UNIT 4 BOILER	BROM 1ST RNSE(CLR)(ICAP-COMP 545-6)
F 546	11 18 81	UNIT 4 BOILER	BROMATE SECOND RINSE/CLEAR

			544	545	546
7	SILVER	PPM	0.252	0.015	CM
8	ALUMINUM	PPM	<0.01	<0.01	CM
9	BORON	PPM	0.045	0.028	CM
10	BARIUM	PPM	0.008	0.009	CM
11	BERYLLIUM	PPM	0.0008	<0.0005	CM
12	CALCIUM	PPM	1.14	3.77	CM
13	CADMIUM	PPM	0.05	<0.01	CM
14	COBALT	PPM	0.23	0.14	CM
15	CHROMIUM	PPM	0.02	0.01	CM
16	COPPER	PPM	1330	0.748	CM
17	IRON	PPM	<0.01	0.01	CM
18	POTASSIUM	PPM	5	4	CM
19	MAGNESIUM	PPM	1.27	1.16	CM
20	MANGANESE	PPM	<0.01	<0.01	CM
21	MOLYBDENUM	PPM	0.4	<0.3	CM
22	SODIUM	PPM	256	29	CM
23	NICKEL	PPM	0.54	<0.05	CM
24	PHOSPHORUS	PPM	811	<0.6	CM
25	LEAD	PPM	<0.05	<0.05	CM
26	SILICON	PPM	<0.05	0.81	CM
27	STRONTIUM	PPM	<0.001	0.019	CM
28	THORIUM	PPM	0.13	0.08	CM
29	TITANIUM	PPM	0.005	<0.005	CM
30	VANADIUM	PPM	0.048	0.022	CM
31	ZINC	PPM	46	<0.05	CM
32	ZIRCONIUM	PPM	<0.05	<0.05	CM
37	PH LAB	-	10.8	10.4	10.1
57	BROMATE	PMM	900	26	<6

# 548	11 18 81	UNIT 4 BOILER	HCL CLEAN SOL/LT.GREEN W/PURP.SOL
# 549	11 18 81	UNIT 4 BOILER	HCL 1ST RINSE/CLEAR W/GRAY SOL
# 550	11 18 81	UNIT 4 BOILER	HCL 2ND RINSE/YEL/GREEN W/GRAY SOL

			548	549	550
7	SILVER	PPM	<0.005	<0.005	<0.005
8	ALUMINUM	PPM	12.5	0.72	<0.01
9	BORON	PPM	<0.004	<0.004	<0.004
10	BARIUM	PPM	0.121	0.017	0.008
11	BERYLLIUM	PPM	0.0009	<0.0005	<0.0005
12	CALCIUM	PPM	12.5	6.1	5.61
13	CADMIUM	PPM	0.75	0.09	0.04
14	COBALT	PPM	9.89	0.46	<0.05
15	CHROMIUM	PPM	0.42	0.03	<0.01
16	COPPER	PPM	425	10.5	0.505
17	IRON	PPM	5440	967	404
18	POTASSIUM	PPM	<1	4	2
19	MAGNESIUM	PPM	5	1.69	1.47
20	MANGANESE	PPM	46.5	5.38	2.1
21	MOLYBDENUM	PPM	<0.3	<0.3	<0.3
22	SODIUM	PPM	15	28	23
23	NICKEL	PPM	379	57.9	6.25
24	PHOSPHORUS	PPM	<0.6	6.9	0.9
25	LEAD	PPM	2.6	<0.05	<0.05
26	SILICON	PPM	70	2.28	1.03
27	STRONTIUM	PPM	0.074	0.033	0.044
28	THORIUM	PPM	<0.01	0.04	<0.01
29	TITANIUM	PPM	0.744	0.073	<0.005
30	VANADIUM	PPM	0.321	0.067	<0.005
31	ZINC	PPM	417	32.6	2.48
32	ZIRCONIUM	PPM	0.08	<0.05	<0.05
37	PH LAB	-	1.3	1.8	3.7
57	BROMATE	PMM			

552	11 18 81	UNIT 4 BOILER	NEUT.SOL/CLEAR W/GRAY SOL
553	11 18 81	UNIT 4 BOILER	NEUT. RNSE 1ST (ICAP-COMP 553-5)
554	11 18 81	UNIT 4 BOILER	NEUT.2ND RINSE/CLEAR W/GRAY SOL
555	11 18 81	UNIT BOILER	NEUT.3RD RINSE/CLEAR W/GRAY SOL

			552	553	554	555
7	SILVER	PPM	<0.005	<0.005	CM	CM
8	ALUMINUM	PPM	0.03	<0.01	CM	CM
9	BORON	PPM	0.027	0.044	CM	CM
10	BARIUM	PPM	<0.005	<0.005	CM	CM
11	BERYLLIUM	PPM	<0.0005	<0.0005	CM	CM
12	CALCIUM	PPM	0.13	3.19	CM	CM
13	CADMIUM	PPM	<0.01	<0.01	CM	CM
14	COBALT	PPM	<0.05	<0.05	CM	CM
15	CHROMIUM	PPM	<0.01	<0.01	CM	CM
16	COPPER	PPM	2.67	0.01	CM	CM
17	IRON	PPM	<0.01	<0.01	CM	CM
18	POTASSIUM	PPM	<1	3	CM	CM
19	MAGNESIUM	PPM	0.02	0.95	CM	CM
20	MANGANESE	PPM	<0.01	<0.01	CM	CM
21	MOLYBDENUM	PPM	0.6	<0.3	CM	CM
22	SODIUM	PPM	4020	69	CM	CM
23	NICKEL	PPM	<0.05	<0.05	CM	CM
24	PHOSPHORUS	PPM	<0.6	<0.6	CM	CM
25	LEAD	PPM	<0.05	<0.05	CM	CM
26	SILICON	PPM	<0.05	0.9	CM	CM
27	STRONTIUM	PPM	0.002	0.019	CM	CM
28	THORIUM	PPM	<0.01	<0.01	CM	CM
29	TITANIUM	PPM	<0.005	<0.005	CM	CM
30	VANADIUM	PPM	<0.005	0.005	CM	CM
31	ZINC	PPM	0.05	<0.05	CM	CM
32	ZIRCONIUM	PPM	<0.05	<0.05	CM	CM
37	PH LAB	-	10.9	10.4	9.9	9.7
57	BROMATE	PMM				

F558 11 18 81 UNIT 4 BOILER SLUICE WATER

558

7	SILVER	PPM	<0.005
8	ALUMINUM	PPM	<0.01
9	BORON	PPM	0.157
10	BARIUM	PPM	0.139
11	BERYLLIUM	PPM	<0.0005
12	CALCIUM	PPM	19.5
13	CADMIUM	PPM	<0.01
14	COBALT	PPM	<0.05
15	CHROMIUM	PPM	<0.01
16	COPPER	PPM	<0.008
17	IRON	PPM	<0.01
18	POTASSIUM	PPM	7
19	MAGNESIUM	PPM	2.81
20	MANGANESE	PPM	0.05
21	MOLYBDENUM	PPM	<0.3
22	SODIUM	PPM	18
23	NICKEL	PPM	0.05
24	PHOSPHORUS	PPM	<0.6
25	LEAD	PPM	<0.05
26	SILICON	PPM	2.68
27	STRONTIUM	PPM	0.306
28	THORIUM	PPM	<0.01
29	TITANIUM	PPM	<0.005
30	VANADIUM	PPM	0.014
31	ZINC	PPM	0.07
32	ZIRCONIUM	PPM	<0.05
37	PH LAB	-	7.3
57	BROMATE	PPM	

PLANT THREE

Sample Numbers

SAMPLING POINT DESIGNATION	TRIPS
	12881
ASH SAMPLES	
3-2 (16.-18. FT)	9001
3-2 (20.-20.2 FT)	9002
3-2 (38.-40. FT)	9005
3-2 (47.-47.5 FT)	9036
3-3 (10.-12. FT)	9009
3-3 (24.-26. FT)	9012
SOILS UNDER ASH	
3-2 (47.5-48.5 FT,ALLUV,SS)	9037
3-2 (48.5-50. FT,ALLUV,SS)	9038
3-2 (50.-51. FT,ALLUV,SS)	9039
3-2 (51.-52. FT,ALLUV,SS)	9040
3-2 (52.-54. FT,ALLUV,SS)	9041
3-3 (28.-30. FT,POSSIBLE FILL,SS)	9049
3-3 (30.-32. FT,RESIDUAL,SS)	9047
3-3 (32.-34. FT,RESIDUAL,SS)	9048
3-3 (34.-34.5 FT,RESIDUAL,SH)	9022
3-3 (37.5-39.5 FT,RESIDUAL,SH)	9024
3-3 (39.5-41.5 FT,RESIDUAL,SH)	9025
BACKGROUND SOILS	
3-4 (16.-18.5 FT,ALLUV)	9013
3-4 (18.5-20.5 FT,ALLUV)	9051
3-4 (20.5-22.5 FT, WEATH. BEDROC)	9014
3-4A (8.-10.5 FT,FILL)	9015
3-4B (16.0-18.0 FT,RESIDUAL)	9026
3-4B (18.5-20.5 FT,WEATH. BEDROC)	9053

PLANT THREE
SOLID CONCENTRATION OF 7 SILVER PPM

SAMPLING POINT DESIGNATION	TRIPS
	12881
ASH SAMPLES	
3-2 (16.-18. FT)	<0.05
3-2 (20.-20.2 FT)	<0.05
3-2 (38.-40. FT)	<0.05
3-2 (47.-47.5 FT)	<0.05
3-3 (10.-12. FT)	<0.05
3-3 (24.-26. FT)	<0.05
SOILS UNDER ASH	
3-2 (47.5-48.5 FT,ALLUV,SS)	<0.05
3-2 (48.5-50. FT,ALLUV,SS)	<0.05
3-2 (50.-51. FT,ALLUV,SS)	<0.05
3-2 (51.-52. FT,ALLUV,SS)	<0.05
3-2 (52.-54. FT,ALLUV,SS)	<0.05
3-3 (28.-30. FT,POSSIBLE FILL,SS)	<0.05
3-3 (30.-32. FT,RESIDUAL,SS)	<0.05
3-3 (32.-34. FT,RESIDUAL,SS)	<0.05
3-3 (34.-34.5 FT,RESIDUAL,SH)	<0.05
3-3 (37.5-39.5 FT,RESIDUAL,SH)	<0.05
3-3 (39.5-41.5 FT,RESIDUAL,SH)	<0.05
BACKGROUND SOILS	
3-4 (16.-18.5 FT,ALLUV)	<0.05
3-4 (18.5-20.5 FT,ALLUV)	<0.05
3-4 (20.5-22.5 FT, WEATH. BEDROC)	<0.05
3-4A (8.-10.5 FT,FILL)	<0.05
3-4B (16.0-18.0 FT,RESIDUAL)	<0.05
3-4B (18.5-20.5 FT,WEATH. BEDROC)	<0.05

PLANT THREE
SOLID CONCENTRATION OF 8 ALUMINUM PPM

SAMPLING POINT DESIGNATION	TRIPS
	12881
ASH SAMPLES	
3-2 (16.-18. FT)	16395
3-2 (20.-20.2 FT)	15913
3-2 (38.-40. FT)	9980
3-2 (47.-47.5 FT)	21485
3-3 (10.-12. FT)	21024
3-3 (24.-26. FT)	8436
SOILS UNDER ASH	
3-2 (47.5-48.5 FT,ALLUV,SS)	22064
3-2 (48.5-50. FT,ALLUV,SS)	21077
3-2 (50.-51. FT,ALLUV,SS)	5373
3-2 (51.-52. FT,ALLUV,SS)	12793
3-2 (52.-54. FT,ALLUV,SS)	23536
3-3 (28.-30. FT,POSSIBLE FILL,SS)	27100
3-3 (30.-32. FT,RESIDUAL,SS)	3301
3-3 (32.-34. FT,RESIDUAL,SS)	24389
3-3 (34.-34.5 FT,RESIDUAL,SH)	31893
3-3 (37.5-39.5 FT,RESIDUAL,SH)	30762
3-3 (39.5-41.5 FT,RESIDUAL,SH)	34490
BACKGROUND SOILS	
3-4 (16.-18.5 FT,ALLUV)	3205
3-4 (18.5-20.5 FT,ALLUV)	21432
3-4 (20.5-22.5 FT, WEATH. BEDROC)	16259
3-4A (8.-10.5 FT,FILL)	25343
3-4B (16.0-18.0 FT,RESIDUAL)	18935
3-4B (18.5-20.5 FT,WEATH. BEDROC)	18492

PLANT THREE
SOLID CONCENTRATION OF 10 BARIUM PPM

SAMPLING POINT DESIGNATION	TRIPS
	12881
ASH SAMPLES	
3-2 (16.-18. FT)	322
3-2 (20.-20.2 FT)	221
3-2 (38.-40. FT)	260
3-2 (47.-47.5 FT)	300
3-3 (10.-12. FT)	358
3-3 (24.-26. FT)	229
SOILS UNDER ASH	
3-2 (47.5-48.5 FT,ALLUV,SS)	131
3-2 (48.5-50. FT,ALLUV,SS)	116
3-2 (50.-51. FT,ALLUV,SS)	37
3-2 (51.-52. FT,ALLUV,SS)	321
3-2 (52.-54. FT,ALLUV,SS)	229
3-3 (28.-30. FT,POSSIBLE FILL,SS)	128
3-3 (30.-32. FT,RESIDUAL,SS)	153
3-3 (32.-34. FT,RESIDUAL,SS)	169
3-3 (34.-34.5 FT,RESIDUAL,SH)	133
3-3 (37.5-39.5 FT,RESIDUAL,SH)	160
3-3 (39.5-41.5 FT,RESIDUAL,SH)	171
BACKGROUND SOILS	
3-4 (16.-18.5 FT,ALLUV)	134
3-4 (18.5-20.5 FT,ALLUV)	92
3-4 (20.5-22.5 FT, WEATH. BEDROC)	82
3-4A (8.-10.5 FT,FILL)	62
3-4B (16.0-18.0 FT,RESIDUAL)	107
3-4B (18.5-20.5 FT,WEATH. BEDROC)	1083

PLANT THREE
SOLID CONCENTRATION OF 11 BERYLLIUM PPM

SAMPLING POINT DESIGNATION	IRIPS 12881
ASH SAMPLES	
3-2 (16.-18. FT)	1.39
3-2 (20.-20.2 FT)	1.95
3-2 (38.-40. FT)	1.49
3-2 (47.-47.5 FT)	1.71
3-3 (10.-12. FT)	2.37
3-3 (24.-26. FT)	1.07
SOILS UNDER ASH	
3-2 (47.5-48.5 FT,ALLUV,SS)	0.71
3-2 (48.5-50. FT,ALLUV,SS)	0.68
3-2 (50.-51. FT,ALLUV,SS)	0.24
3-2 (51.-52. FT,ALLUV,SS)	0.81
3-2 (52.-54. FT,ALLUV,SS)	1.1
3-3 (28.-30. FT,POSSIBLE FILL,SS)	0.72
3-3 (30.-32. FT,RESIDUAL,SS)	0.66
3-3 (32.-34. FT,RESIDUAL,SS)	0.51
3-3 (34.-34.5 FT,RESIDUAL,SH)	0.72
3-3 (37.5-39.5 FT,RESIDUAL,SH)	0.42
3-3 (39.5-41.5 FT,RESIDUAL,SH)	0.64
BACKGROUND SOILS	
3-4 (16.-18.5 FT,ALLUV)	0.64
3-4 (18.5-20.5 FT,ALLUV)	0.51
3-4 (20.5-22.5 FT, WEATH. BEDROC)	0.37
3-4A (8.-10.5 FT,FILL)	0.69
3-4B (16.0-18.0 FT,RESIDUAL)	0.35
3-4B (18.5-20.5 FT,WEATH. BEDROC)	0.79

PLANT THREE
SOLID CONCENTRATION OF 12 CALCIUM PPM

SAMPLING POINT DESIGNATION	TRIPS
	12881
ASH SAMPLES	
3-2 (16.-18. FT)	4578
3-2 (20.-20.2 FT)	4183
3-2 (38.-40. FT)	2340
3-2 (47.-47.5 FT)	2289
3-3 (10.-12. FT)	2612
3-3 (24.-26. FT)	2251.
SOILS UNDER ASH	
3-2 (47.5-48.5 FT,ALLUV,SS)	483
3-2 (48.5-50. FT,ALLUV,SS)	329
3-2 (50.-51. FT,ALLUV,SS)	193
3-2 (51.-52. FT,ALLUV,SS)	278
3-2 (52.-54. FT,ALLUV,SS)	681
3-3 (28.-30. FT,POSSIBLE FILL,SS)	459
3-3 (30.-32. FT,RESIDUAL,SS)	227
3-3 (32.-34. FT,RESIDUAL,SS)	98
3-3 (34.-34.5 FT,RESIDUAL,SH)	178
3-3 (37.5-39.5 FT,RESIDUAL,SH)	139
3-3 (39.5-41.5 FT,RESIDUAL,SH)	306
BACKGROUND SOILS	
3-4 (16.-18.5 FT,ALLUV)	1025
3-4 (18.5-20.5 FT,ALLUV)	1226
3-4 (20.5-22.5 FT, WEATH. BEDROC)	2634
3-4A (8.-10.5 FT,FILL)	471
3-4B (16.0-18.0 FT,RESIDUAL)	4056
3-4B (18.5-20.5 FT,WEATH. BEDROC)	4056

PLANT THREE
SOLID CONCENTRATION OF 13 CADMIUM PPM

SAMPLING POINT DESIGNATION	TRIPS 12881
ASH SAMPLES	
3-2 (16.-18. FT)	<0.08
3-2 (20.-20.2 FT)	<0.08
3-2 (38.-40. FT)	<0.08
3-2 (47.-47.5 FT)	<0.08
3-3 (10.-12. FT)	<0.08
3-3 (24.-26. FT)	<0.08
SOILS UNDER ASH	
3-2 (47.5-48.5 FT,ALLUV,SS)	<0.08
3-2 (48.5-50. FT,ALLUV,SS)	<0.08
3-2 (50.-51. FT,ALLUV,SS)	<0.08
3-2 (51.-52. FT,ALLUV,SS)	<0.08
3-2 (52.-54. FT,ALLUV,SS)	<0.07
3-3 (28.-30. FT,POSSIBLE FILL,SS)	<0.08
3-3 (30.-32. FT,RESIDUAL,SS)	<0.08
3-3 (32.-34. FT,RESIDUAL,SS)	<0.08
3-3 (34.-34.5 FT,RESIDUAL,SH)	<0.08
3-3 (37.5-39.5 FT,RESIDUAL,SH)	<0.08
3-3 (39.5-41.5 FT,RESIDUAL,SH)	<0.08
BACKGROUND SOILS	
3-4 (16.-18.5 FT,ALLUV)	<0.08
3-4 (18.5-20.5 FT,ALLUV)	<0.08
3-4 (20.5-22.5 FT, WEATH. BEDROC)	<0.08
3-4A (8.-10.5 FT,FILL)	<0.08
3-4B (16.0-18.0 FT,RESIDUAL)	<0.08
3-4B (18.5-20.5 FT,WEATH. BEDROC)	<0.08

PLANT THREE
SOLID CONCENTRATION OF 14 COBALT PPM

SAMPLING POINT DESIGNATION	TRIPS 12881
ASH SAMPLES	
3-2 (16.-18. FT)	<0.5
3-2 (20.-20.2 FT)	<0.5
3-2 (38.-40. FT)	<0.5
3-2 (47.-47.5 FT)	<0.5
3-3 (10.-12. FT)	<0.5
3-3 (24.-26. FT)	<0.5
SOILS UNDER ASH	
3-2 (47.5-48.5 FT,ALLUV,SS)	<0.5
3-2 (48.5-50. FT,ALLUV,SS)	<0.5
3-2 (50.-51. FT,ALLUV,SS)	<0.5
3-2 (51.-52. FT,ALLUV,SS)	<0.5
3-2 (52.-54. FT,ALLUV,SS)	<0.5
3-3 (28.-30. FT,POSSIBLE FILL,SS)	<0.5
3-3 (30.-32. FT,RESIDUAL,SS)	<0.5
3-3 (32.-34. FT,RESIDUAL,SS)	<0.5
3-3 (34.-34.5 FT,RESIDUAL,SH)	<0.5
3-3 (37.5-39.5 FT,RESIDUAL,SH)	<0.5
3-3 (39.5-41.5 FT,RESIDUAL,SH)	<0.5
BACKGROUND SOILS	
3-4 (16.-18.5 FT,ALLUV)	<0.5
3-4 (18.5-20.5 FT,ALLUV)	<0.5
3-4 (20.5-22.5 FT, WEATH. BEDROC)	<0.5
3-4A (8.-10.5 FT,FILL)	<0.5
3-4B (16.0-18.0 FT,RESIDUAL)	<0.5
3-4B (18.5-20.5 FT,WEATH. BEDROC)	<0.5

PLANT THREE
SOLID CONCENTRATION OF 15 CHROMIUM PPM

SAMPLING POINT DESIGNATION	TRIPS 12881 1
ASH SAMPLES	
3-2 (16.-18. FT)	<0.08
3-2 (20.-20.2 FT)	16
3-2 (38.-40. FT)	8.74
3-2 (47.-47.5 FT)	0.64
3-3 (10.-12. FT)	17.35
3-3 (24.-26. FT)	<0.08
SOILS UNDER ASH	
3-2 (47.5-48.5 FT,ALLUV,SS)	<0.08
3-2 (48.5-50. FT,ALLUV,SS)	<0.08
3-2 (50.-51. FT,ALLUV,SS)	1.14
3-2 (51.-52. FT,ALLUV,SS)	<0.08
3-2 (52.-54. FT,ALLUV,SS)	<0.08
3-3 (28.-30. FT,POSSIBLE FILL,SS)	<0.08
3-3 (30.-32. FT,RESIDUAL,SS)	<0.08
3-3 (32.-34. FT,RESIDUAL,SS)	<0.08
3-3 (34.-34.5 FT,RESIDUAL,SH)	<0.08
3-3 (37.5-39.5 FT,RESIDUAL,SH)	<0.08
3-3 (39.5-41.5 FT,RESIDUAL,SH)	<0.08
BACKGROUND SOILS	
3-4 (16.-18.5 FT,ALLUV)	4.01
3-4 (18.5-20.5 FT,ALLUV)	<0.08
3-4 (20.5-22.5 FT, WEATH. BEDROC)	<0.08
3-4A (8.-10.5 FT,FILL)	<0.08
3-4B (16.0-18.0 FT,RESIDUAL)	<0.08
3-4B (18.5-20.5 FT,WEATH. BEDROC)	<0.08

PLANT THREE
SOLID CONCENTRATION OF 16 COPPER PPM

SAMPLING POINT DESIGNATION	TRIPS 12881
ASH SAMPLES	
3-2 (16.-18. FT)	40.9
3-2 (20.-20.2 FT)	39.6
3-2 (38.-40. FT)	28.3
3-2 (47.-47.5 FT)	27.5
3-3 (10.-12. FT)	45.1
3-3 (24.-26. FT)	20.8
SOILS UNDER ASH	
3-2 (47.5-48.5 FT,ALLUV,SS)	13.4
3-2 (48.5-50. FT,ALLUV,SS)	12.2
3-2 (50.-51. FT,ALLUV,SS)	4.75
3-2 (51.-52. FT,ALLUV,SS)	12.2
3-2 (52.-54. FT,ALLUV,SS)	14.1
3-3 (28.-30. FT,POSSIBLE FILL,SS)	14.4
3-3 (30.-32. FT,RESIDUAL,SS)	18.3
3-3 (32.-34. FT,RESIDUAL,SS)	29.5
3-3 (34.-34.5 FT,RESIDUAL,SH)	29.9
3-3 (37.5-39.5 FT,RESIDUAL,SH)	11.5
3-3 (39.5-41.5 FT,RESIDUAL,SH)	10.4
BACKGROUND SOILS	
3-4 (16.-18.5 FT,ALLUV)	17
3-4 (18.5-20.5 FT,ALLUV)	12.2
3-4 (20.5-22.5 FT, WEATH. BEDROC)	17.6
3-4A (8.-10.5 FT,FILL)	16.9
3-4B (16.0-18.0 FT,RESIDUAL)	15.3
3-4B (18.5-20.5 FT,WEATH. BEDROC)	9.52

PLANT THRIF
SOLID CONCENTRATION OF 1/ IRON PPM

SAMPLING POINT DESIGNATION	TRIPS
	12881
ASH SAMPLES	
3-2 (16.-18. FT)	29491
3-2 (20.-20.2 FT)	15012
3-2 (38.-40. FT)	11700
3-2 (47.-47.5 FT)	23092
3-3 (10.-12. FT)	18370
3-3 (24.-26. FT)	17131
SOILS UNDER ASH	
3-2 (47.5-48.5 FT,ALLUV,SS)	23398
3-2 (48.5-50. FT,ALLUV,SS)	18544
3-2 (50.-51. FT,ALLUV,SS)	11563
3-2 (51.-52. FT,ALLUV,SS)	19489
3-2 (52.-54. FT,ALLUV,SS)	35402
3-3 (28.-30. FT,POSSIBLE FILL,SS)	20500
3-3 (30.-32. FT,RESIDUAL,SS)	25659
3-3 (32.-34. FT,RESIDUAL,SS)	23789
3-3 (34.-34.5 FT,RESIDUAL,SH)	22524
3-3 (37.5-39.5 FT,RESIDUAL,SH)	23071
3-3 (39.5-41.5 FT,RESIDUAL,SH)	24422
BACKGROUND SOILS	
3-4 (16.-18.5 FT,ALLUV)	12344
3-4 (18.5-20.5 FT,ALLUV)	11164
3-4 (20.5-22.5 FT, WEATH. BEDROC)	16558
3-4A (8.-10.5 FT,FILL)	24441
3-4B (16.0-18.0 FT,RESIDUAL)	19533
3-4B (18.5-20.5 FT,WEATH. BEDROC)	21673

PLANT THREE
SOLID CONCENTRATION OF 18 POTASSIUM PPM

SAMPLING POINT DESIGNATION	TRIPS
	12881
ASH SAMPLES	
3-2 (16.-18. FT)	AP
3-2 (20.-20.2 FT)	AP
3-2 (38.-40. FT)	AP
3-2 (47.-47.5 FT)	AP
3-3 (10.-12. FT)	AP
3-3 (24.-26. FT)	AP
SOILS UNDER ASH	
3-2 (47.5-48.5 FT,ALLUV,SS)	AP
3-2 (48.5-50. FT,ALLUV,SS)	AP
3-2 (50.-51. FT,ALLUV,SS)	AP
3-2 (51.-52. FT,ALLUV,SS)	AP
3-2 (52.-54. FT,ALLUV,SS)	AP
3-3 (28.-30. FT,POSSIBLE FILL,SS)	AP
3-3 (30.-32. FT,RESIDUAL,SS)	AP
3-3 (32.-34. FT,RESIDUAL,SS)	AP
3-3 (34.-34.5 FT,RESIDUAL,SH)	AP
3-3 (37.5-39.5 FT,RESIDUAL,SH)	AP
3-3 (39.5-41.5 FT,RESIDUAL,SH)	AP
BACKGROUND SOILS	
3-4 (16.-18.5 FT,ALLUV)	AP
3-4 (18.5-20.5 FT,ALLUV)	AP
3-4 (20.5-22.5 FT, WEATH. BEDROC)	AP
3-4A (8.-10.5 FT,FILL)	AP
3-4B (16.0-18.0 FT,RESIDUAL)	AP
3-4B (18.5-20.5 FT,WEATH. BEDROC)	AP

PLANT THREE
SOLID CONCENTRATION OF 19 MAGNESIUM PPM

SAMPLING POINT DESIGNATION	TRIPS
	12881
ASH SAMPLES	
3-2 (16.-18. FT)	1579
3-2 (20.-20.2 FT)	1441
3-2 (38.-40. FT)	882
3-2 (47.-47.5 FT)	1365
3-3 (10.-12. FT)	1500
3-3 (24.-26. FT)	768
SOILS UNDER ASH	
3-2 (47.5-48.5 FT,ALLUV,SS)	660
3-2 (48.5-50. FT,ALLUV,SS)	674
3-2 (50.-51. FT,ALLUV,SS)	181
3-2 (51.-52. FT,ALLUV,SS)	575
3-2 (52.-54. FT,ALLUV,SS)	1500
3-3 (28.-30. FT,POSSIBLE FILL,SS)	3250
3-3 (30.-32. FT,RESIDUAL,SS)	5092
3-3 (32.-34. FT,RESIDUAL,SS)	5507
3-3 (34.-34.5 FT,RESIDUAL,SH)	4624
3-3 (37.5-39.5 FT,RESIDUAL,SH)	5253
3-3 (39.5-41.5 FT,RESIDUAL,SH)	5930
BACKGROUND SOILS	
3-4 (16.-18.5 FT,ALLUV)	2737
3-4 (18.5-20.5 FT,ALLUV)	2392
3-4 (20.5-22.5 FT, WEATH. BEDROC)	3162
3-4A (8.-10.5 FT,FILL)	856
3-4B (16.0-18.0 FT,RESIDUAL)	5481
3-4B (18.5-20.5 FT,WEATH. BEDROC)	5587

PLANT THREE
SOLID CONCENTRATION OF 20 MANGANESE PPM

SAMPLING POINT DESIGNATION	TRIPS
	12881
ASH SAMPLES	
3-2 (16.-18. FT)	171
3-2 (20.-20.2 FT)	84.3
3-2 (38.-40. FT)	69.2
3-2 (47.-47.5 FT)	144
3-3 (10.-12. FT)	83.1
3-3 (24.-26. FT)	84.
SOILS UNDER ASH	
3-2 (47.5-48.5 FT,ALLUV,SS)	1364
3-2 (48.5-50. FT,ALLUV,SS)	557
3-2 (50.-51. FT,ALLUV,SS)	189
3-2 (51.-52. FT,ALLUV,SS)	6086
3-2 (52.-54. FT,ALLUV,SS)	1726
3-3 (28.-30. FT,POSSIBLE FILL,SS)	512
3-3 (30.-32. FT,RESIDUAL,SS)	621
3-3 (32.-34. FT,RESIDUAL,SS)	551
3-3 (34.-34.5 FT,RESIDUAL,SH)	451
3-3 (37.5-39.5 FT,RESIDUAL,SH)	727
3-3 (39.5-41.5 FT,RESIDUAL,SH)	698
BACKGROUND SOILS	
3-4 (16.-18.5 FT,ALLUV)	155
3-4 (18.5-20.5 FT,ALLUV)	303
3-4 (20.5-22.5 FT, WEATH. BEDROC)	181
3-4A (8.-10.5 FT,FILL)	791
3-4B (16.0-18.0 FT,RESIDUAL)	497
3-4B (18.5-20.5 FT,WEATH. BEDROC)	482

PLANT THREE
SOLID CONCENTRATION OF 21 MOLYBDENUM PPM

SAMPLING POINT DESIGNATION	TRIPS
	12881
ASH SAMPLES	
3-2 (16.-18. FT)	<3
3-2 (20.-20.2 FT)	<3
3-2 (38.-40. FT)	<3
3-2 (47.-47.5 FT)	<3
3-3 (10.-12. FT)	<3
3-3 (24.-26. FT)	<3
SOILS UNDER ASH	
3-2 (47.5-48.5 FT,ALLUV,SS)	<3
3-2 (48.5-50. FT,ALLUV,SS)	<3
3-2 (50.-51. FT,ALLUV,SS)	<3
3-2 (51.-52. FT,ALLUV,SS)	<3
3-2 (52.-54. FT,ALLUV,SS)	<3
3-3 (28.-30. FT,POSSIBLE FILL,SS)	<3
3-3 (30.-32. FT,RESIDUAL,SS)	<3
3-3 (32.-34. FT,RESIDUAL,SS)	<3
3-3 (34.-34.5 FT,RESIDUAL,SH)	<3
3-3 (37.5-39.5 FT,RESIDUAL,SH)	<3
3-3 (39.5-41.5 FT,RESIDUAL,SH)	<3
BACKGROUND SOILS	
3-4 (16.-18.5 FT,ALLUV)	<3
3-4 (18.5-20.5 FT,ALLUV)	<3
3-4 (20.5-22.5 FT, WEATH. BEDROC)	<3
3-4A (8.-10.5 FT,FILL)	<3
3-4B (16.0-18.0 FT,RESIDUAL)	<3
3-4B (18.5-20.5 FT,WEATH. BEDROC)	<3

PLANT THREE
SOLID CONCENTRATION OF 22 SODIUM PPM

SAMPLING POINT DESIGNATION	TRIPS
	12881
ASH SAMPLES	
3-2 (16.-18. FT)	379
3-2 (20.-20.2 FT)	430
3-2 (38.-40. FT)	230
3-2 (47.-47.5 FT)	341
3-3 (10.-12. FT)	479
3-3 (24.-26. FT)	209.
SOILS UNDER ASH	
3-2 (47.5-48.5 FT,ALLUV,SS)	30.8
3-2 (48.5-50. FT,ALLUV,SS)	30.4
3-2 (50.-51. FT,ALLUV,SS)	19.9
3-2 (51.-52. FT,ALLUV,SS)	20
3-2 (52.-54. FT,ALLUV,SS)	29.4
3-3 (28.-30. FT,POSSIBLE FILL,SS)	40
3-3 (30.-32. FT,RESIDUAL,SS)	29.8
3-3 (32.-34. FT,RESIDUAL,SS)	20
3-3 (34.-34.5 FT,RESIDUAL,SH)	29.9
3-3 (37.5-39.5 FT,RESIDUAL,SH)	20
3-3 (39.5-41.5 FT,RESIDUAL,SH)	29.9
BACKGROUND SOILS	
3-4 (16.-18.5 FT,ALLUV)	89
3-4 (18.5-20.5 FT,ALLUV)	69.8
3-4 (20.5-22.5 FT, WEATH. BEDROC)	89.8
3-4A (8.-10.5 FT,FILL)	20
3-4B (16.0-18.0 FT,RESIDUAL)	89.7
3-4B (18.5-20.5 FT,WEATH. BEDROC)	99.4

PLANT THREE
SOLID CONCENTRATION OF 23 NICKEL PPM

SAMPLING POINT DESIGNATION	TRIPS 12881
ASH SAMPLES	
3-2 (16.-18. FT)	26
3-2 (20.-20.2 FT)	17.7
3-2 (38.-40. FT)	15.3
3-2 (47.-47.5 FT)	20.1
3-3 (10.-12. FT)	23.6
3-3 (24.-26. FT)	16.8
SOILS UNDER ASH	
3-2 (47.5-48.5 FT,ALLUV,SS)	6.36
3-2 (48.5-50. FT,ALLUV,SS)	6.99
3-2 (50.-51. FT,ALLUV,SS)	2.69
3-2 (51.-52. FT,ALLUV,SS)	8.29
3-2 (52.-54. FT,ALLUV,SS)	7.75
3-3 (28.-30. FT,POSSIBLE FILL,SS)	6.6
3-3 (30.-32. FT,RESIDUAL,SS)	7.86
3-3 (32.-34. FT,RESIDUAL,SS)	3.1
3-3 (34.-34.5 FT,RESIDUAL,SH)	4.68
3-3 (37.5-39.5 FT,RESIDUAL,SH)	3.6
3-3 (39.5-41.5 FT,RESIDUAL,SH)	3.89
BACKGROUND SOILS	
3-4 (16.-18.5 FT,ALLUV)	10.8
3-4 (18.5-20.5 FT,ALLUV)	6.08
3-4 (20.5-22.5 FT, WEATH. BEDROC)	10
3-4A (8.-10.5 FT,FILL)	8.01
3-4B (16.0-18.0 FT,RESIDUAL)	4.48
3-4B (18.5-20.5 FT,WEATH. BEDROC)	7.16

PLANT THREE
SOLID CONCENTRATION OF 24 PHOSPHORUS PPM

SAMPLING POINT DESIGNATION	TRIPS
	12881
ASH SAMPLES	
3-2 (16.-18. FT)	179
3-2 (20.-20.2 FT)	156
3-2 (38.-40. FT)	120
3-2 (47.-47.5 FT)	94.8
3-3 (10.-12. FT)	156
3-3 (24.-26. FT)	123.
SOILS UNDER ASH	
3-2 (47.5-48.5 FT,ALLUV,SS)	82.1
3-2 (48.5-50. FT,ALLUV,SS)	96.2
3-2 (50.-51. FT,ALLUV,SS)	10.9
3-2 (51.-52. FT,ALLUV,SS)	69.9
3-2 (52.-54. FT,ALLUV,SS)	275
3-3 (28.-30. FT,POSSIBLE FILL,SS)	108
3-3 (30.-32. FT,RESIDUAL,SS)	53.7
3-3 (32.-34. FT,RESIDUAL,SS)	<6
3-3 (34.-34.5 FT,RESIDUAL,SH)	<6
3-3 (37.5-39.5 FT,RESIDUAL,SH)	<6
3-3 (39.5-41.5 FT,RESIDUAL,SH)	<6
BACKGROUND SOILS	
3-4 (16.-18.5 FT,ALLUV)	<6
3-4 (18.5-20.5 FT,ALLUV)	<6
3-4 (20.5-22.5 FT, WEATH. BEDROC)	209
3-4A (8.-10.5 FT,FILL)	23
3-4B (16.0-18.0 FT,RESIDUAL)	382
3-4B (18.5-20.5 FT,WEATH. BEDROC)	401

PLANT DIRLE
SOLID CONCENTRATION OF 25 LEAD PPM

SAMPLING POINT DESIGNATION	TRIPS 12881
ASH SAMPLES	
3-2 (16.-18. FT)	8
3-2 (20.-20.2 FT)	12.01
3-2 (38.-40. FT)	6.19
3-2 (47.-47.5 FT)	4.62
3-3 (10.-12. FT)	10.21
3-3 (24.-26. FT)	3.19
SOILS UNDER ASH	
3-2 (47.5-48.5 FT,ALLUV,SS)	5.54
3-2 (48.5-50. FT,ALLUV,SS)	6.08
3-2 (50.-51. FT,ALLUV,SS)	0.99
3-2 (51.-52. FT,ALLUV,SS)	6
3-2 (52.-54. FT,ALLUV,SS)	4.71
3-3 (28.-30. FT,POSSIBLE FILL,SS)	3.8
3-3 (30.-32. FT,RESIDUAL,SS)	3.78
3-3 (32.-34. FT,RESIDUAL,SS)	3.2
3-3 (34.-34.5 FT,RESIDUAL,SH)	2.59
3-3 (37.5-39.5 FT,RESIDUAL,SH)	3.8
3-3 (39.5-41.5 FT,RESIDUAL,SH)	3.99
BACKGROUND SOILS	
3-4 (16.-18.5 FT,ALLUV)	3.38
3-4 (18.5-20.5 FT,ALLUV)	4.59
3-4 (20.5-22.5 FT, WEATH. BEDROC)	0.79
3-4A (8.-10.5 FT,FILL)	6.81
3-4B (16.0-18.0 FT,RESIDUAL)	1.4
3-4B (18.5-20.5 FT,WEATH. BEDROC)	1.19

PLANT THREE
SOLID CONCENTRATION OF 26 SILICON* PPM

SAMPLING POINT DESIGNATION	TRIPS 12881
ASH SAMPLES	
3-2 (16.-18. FT)	22.5
3-2 (20.-20.2 FT)	17.5
3-2 (38.-40. FT)	7.09
3-2 (47.-47.5 FT)	<0.5
3-3 (10.-12. FT)	6.94
3-3 (24.-26. FT)	<0.5
SOILS UNDER ASH	
3-2 (47.5-48.5 FT,ALLUV,SS)	26.5
3-2 (48.5-50. FT,ALLUV,SS)	13.71
3-2 (50.-51. FT,ALLUV,SS)	5.58
3-2 (51.-52. FT,ALLUV,SS)	7.9
3-2 (52.-54. FT,ALLUV,SS)	8.43
3-3 (28.-30. FT,POSSIBLE FILL,SS)	9.7
3-3 (30.-32. FT,RESIDUAL,SS)	2.18
3-3 (32.-34. FT,RESIDUAL,SS)	<0.5
3-3 (34.-34.5 FT,RESIDUAL,SH)	3.59
3-3 (37.5-39.5 FT,RESIDUAL,SH)	<0.5
3-3 (39.5-41.5 FT,RESIDUAL,SH)	<0.5
BACKGROUND SOILS	
3-4 (16.-18.5 FT,ALLUV)	2.89
3-4 (18.5-20.5 FT,ALLUV)	3.29
3-4 (20.5-22.5 FT, WEATH. BEDROC)	<0.5
3-4A (8.-10.5 FT,FILL)	13.62
3-4B (16.0-18.0 FT,RESIDUAL)	<0.5
3-4B (18.5-20.5 FT,WEATH. BEDROC)	<0.5

*(partial digestion)

PLANT THREE
SOLID CONCENTRATION OF 27 STRONTIUM PPM

SAMPLING POINT DESIGNATION	TRIPS
	12881
ASH SAMPLES	
3-2 (16.-18. FT)	189
3-2 (20.-20.2 FT)	213
3-2 (38.-40. FT)	140
3-2 (47.-47.5 FT)	160
3-3 (10.-12. FT)	239
3-3 (24.-26. FT)	112
SOILS UNDER ASH	
3-2 (47.5-48.5 FT,ALLUV,SS)	13
3-2 (48.5-50. FT,ALLUV,SS)	8.71
3-2 (50.-51. FT,ALLUV,SS)	11.2
3-2 (51.-52. FT,ALLUV,SS)	11.2
3-2 (52.-54. FT,ALLUV,SS)	12.6
3-3 (28.-30. FT,POSSIBLE FILL,SS)	18.5
3-3 (30.-32. FT,RESIDUAL,SS)	9.89
3-3 (32.-34. FT,RESIDUAL,SS)	7.01
3-3 (34.-34.5 FT,RESIDUAL,SH)	9.35
3-3 (37.5-39.5 FT,RESIDUAL,SH)	5.36
3-3 (39.5-41.5 FT,RESIDUAL,SH)	8.89
BACKGROUND SOILS	
3-4 (16.-18.5 FT,ALLUV)	19.1
3-4 (18.5-20.5 FT,ALLUV)	16.1
3-4 (20.5-22.5 FT, WEATH. BEDROC)	29.3
3-4A (8.-10.5 FT,FILL)	8.85
3-4B (16.0-18.0 FT,RESIDUAL)	31.9
3-4B (18.5-20.5 FT,WEATH. BEDROC)	33.1

PLANT THREE
SOLID CONCENTRATION OF 28 THORIUM PPM

SAMPLING POINT DESIGNATION	TRIPS 12881
ASH SAMPLES	
3-2 (16.-18. FT)	<0.1
3-2 (20.-20.2 FT)	4.9
3-2 (38.-40. FT)	3.59
3-2 (47.-47.5 FT)	4.42
3-3 (10.-12. FT)	4.89
3-3 (24.-26. FT)	2.39
SOILS UNDER ASH	
3-2 (47.5-48.5 FT,ALLUV,SS)	6.36
3-2 (48.5-50. FT,ALLUV,SS)	8.11
3-2 (50.-51. FT,ALLUV,SS)	1.4
3-2 (51.-52. FT,ALLUV,SS)	11.4
3-2 (52.-54. FT,ALLUV,SS)	7.06
3-3 (28.-30. FT,POSSIBLE FILL,SS)	7.8
3-3 (30.-32. FT,RESIDUAL,SS)	7.06
3-3 (32.-34. FT,RESIDUAL,SS)	5.1
3-3 (34.-34.5 FT,RESIDUAL,SH)	5.28
3-3 (37.5-39.5 FT,RESIDUAL,SH)	7.29
3-3 (39.5-41.5 FT,RESIDUAL,SH)	5.98
BACKGROUND SOILS	
3-4 (16.-18.5 FT,ALLUV)	2.88
3-4 (18.5-20.5 FT,ALLUV)	4.59
3-4 (20.5-22.5 FT, WEATH. BEDROC)	3.89
3-4A (8.-10.5 FT,FILL)	6.11
3-4B (16.0-18.0 FT,RESIDUAL)	2.69
3-4B (18.5-20.5 FT,WEATH. BEDROC)	2.9

PLANT THREE
SOLID CONCENTRATION OF 29 TITANIUM PPM

SAMPLING POINT DESIGNATION	TRIPS
	12881
ASH SAMPLES	
3-2 (16.-18. FT)	566
3-2 (20.-20.2 FT)	555
3-2 (38.-40. FT)	364
3-2 (47.-47.5 FT)	654
3-3 (10.-12. FT)	687
3-3 (24.-26. FT)	364
SOILS UNDER ASH	
3-2 (47.5-48.5 FT,ALLUV,SS)	322
3-2 (48.5-50. FT,ALLUV,SS)	321
3-2 (50.-51. FT,ALLUV,SS)	320
3-2 (51.-52. FT,ALLUV,SS)	354
3-2 (52.-54. FT,ALLUV,SS)	475
3-3 (28.-30. FT,POSSIBLE FILL,SS)	615
3-3 (30.-32. FT,RESIDUAL,SS)	739
3-3 (32.-34. FT,RESIDUAL,SS)	635
3-3 (34.-34.5 FT,RESIDUAL,SH)	699
3-3 (37.5-39.5 FT,RESIDUAL,SH)	638
3-3 (39.5-41.5 FT,RESIDUAL,SH)	687
BACKGROUND SOILS	
3-4 (16.-18.5 FT,ALLUV)	356
3-4 (18.5-20.5 FT,ALLUV)	479
3-4 (20.5-22.5 FT, WEATH. BEDROC)	791
3-4A (8.-10.5 FT,FILL)	446
3-4B (16.0-18.0 FT,RESIDUAL)	1335
3-4B (18.5-20.5 FT,WEATH. BEDROC)	1352

PLANT THREE
SOLID CONCENTRATION OF 30 VANADIUM PPM

SAMPLING POINT DESIGNATION	TRIPS 12881
ASH SAMPLES	
3-2 (16.-18. FT)	34.9
3-2 (20.-20.2 FT)	33.5
3-2 (38.-40. FT)	28.8
3-2 (47.-47.5 FT)	35.2
3-3 (10.-12. FT)	41.5
3-3 (24.-26. FT)	22.2
SOILS UNDER ASH	
3-2 (47.5-48.5 FT,ALLUV,SS)	37.2
3-2 (48.5-50. FT,ALLUV,SS)	34.3
3-2 (50.-51. FT,ALLUV,SS)	24.3
3-2 (51.-52. FT,ALLUV,SS)	38.8
3-2 (52.-54. FT,ALLUV,SS)	48.8
3-3 (28.-30. FT,POSSIBLE FILL,SS)	50.9
3-3 (30.-32. FT,RESIDUAL,SS)	51.3
3-3 (32.-34. FT,RESIDUAL,SS)	38.1
3-3 (34.-34.5 FT,RESIDUAL,SH)	31.6
3-3 (37.5-39.5 FT,RESIDUAL,SH)	28.3
3-3 (39.5-41.5 FT,RESIDUAL,SH)	35.7
BACKGROUND SOILS	
3-4 (16.-18.5 FT,ALLUV)	39.5
3-4 (18.5-20.5 FT,ALLUV)	28.1
3-4 (20.5-22.5 FT, WEATH. BEDROC)	39.8
3-4A (8.-10.5 FT,FILL)	49.1
3-4B (16.0-18.0 FT,RESIDUAL)	36.5
3-4B (18.5-20.5 FT,WEATH. BEDROC)	42.2

PLANT HIRLE
SOLID CONCENTRATION OF 31 ZINC PPM

SAMPLING POINT DESIGNATION	TRIPS
	12881
ASH SAMPLES	
3-2 (16.-18. FT)	45.7
3-2 (20.-20.2 FT)	32.9
3-2 (38.-40. FT)	15.1
3-2 (47.-47.5 FT)	18.5
3-3 (10.-12. FT)	29.2
3-3 (24.-26. FT)	20.8
SOILS UNDER ASH	
3-2 (47.5-48.5 FT,ALLUV,SS)	21.4
3-2 (48.5-50. FT,ALLUV,SS)	23.5
3-2 (50.-51. FT,ALLUV,SS)	7.28
3-2 (51.-52. FT,ALLUV,SS)	25.7
3-2 (52.-54. FT,ALLUV,SS)	27.9
3-3 (28.-30. FT,POSSIBLE FILL,SS)	30.3
3-3 (30.-32. FT,RESIDUAL,SS)	40
3-3 (32.-34. FT,RESIDUAL,SS)	36.1
3-3 (34.-34.5 FT,RESIDUAL,SH)	28.1
3-3 (37.5-39.5 FT,RESIDUAL,SH)	32.6
3-3 (39.5-41.5 FT,RESIDUAL,SH)	41
BACKGROUND SOILS	
3-4 (16.-18.5 FT,ALLUV)	36.2
3-4 (18.5-20.5 FT,ALLUV)	32.1
3-4 (20.5-22.5 FT, WEATH. BEDROC)	22.8
3-4A (8.-10.5 FT,FILL)	24.4
3-4B (16.0-18.0 FT,RESIDUAL)	33.7
3-4B (18.5-20.5 FT,WEATH. BEDROC)	33.2

PLANT THREE
SOLID CONCENTRATION OF 32 ZIRCONIUM PPM

SAMPLING POINT DESIGNATION	TRIPS 12881
ASH SAMPLES	
3-2 (16.-18. FT)	11.3
3-2 (20.-20.2 FT)	11
3-2 (38.-40. FT)	5.14
3-2 (47.-47.5 FT)	4.16
3-3 (10.-12. FT)	7.83
3-3 (24.-26. FT)	8.03
SOILS UNDER ASH	
3-2 (47.5-48.5 FT,ALLUV,SS)	9.16
3-2 (48.5-50. FT,ALLUV,SS)	12
3-2 (50.-51. FT,ALLUV,SS)	2.36
3-2 (51.-52. FT,ALLUV,SS)	11.9
3-2 (52.-54. FT,ALLUV,SS)	8.91
3-3 (28.-30. FT,POSSIBLE FILL,SS)	3.86
3-3 (30.-32. FT,RESIDUAL,SS)	4.14
3-3 (32.-34. FT,RESIDUAL,SS)	3.96
3-3 (34.-34.5 FT,RESIDUAL,SH)	3.77
3-3 (37.5-39.5 FT,RESIDUAL,SH)	4.22
3-3 (39.5-41.5 FT,RESIDUAL,SH)	4.23
BACKGROUND SOILS	
3-4 (16.-18.5 FT,ALLUV)	2.97
3-4 (18.5-20.5 FT,ALLUV)	2.98
3-4 (20.5-22.5 FT, WEATH. BEDROC)	2.55
3-4A (8.-10.5 FT,FILL)	7.14
3-4B (16.0-18.0 FT,RESIDUAL)	2.73
3-4B (18.5-20.5 FT,WEATH. BEDROC)	3.02

PLANT TIRRELL
SOLID CONCENTRATION OF 33 ARSENIC (SOLID) PPM

SAMPLING POINT DESIGNATION	TRIPS
	12881
ASH SAMPLES	
3-2 (16.-18. FT)	32.7
3-2 (20.-20.2 FT)	38
3-2 (38.-40. FT)	36.1
3-2 (47.-47.5 FT)	19.5
3-3 (10.-12. FT)	57.1
3-3 (24.-26. FT)	16.2
SOILS UNDER ASH	
3-2 (47.5-48.5 FT,ALLUV,SS)	2.87
3-2 (48.5-50. FT,ALLUV,SS)	1.3
3-2 (50.-51. FT,ALLUV,SS)	1.71
3-2 (51.-52. FT,ALLUV,SS)	1.07
3-2 (52.-54. FT,ALLUV,SS)	3.33
3-3 (28.-30. FT,POSSIBLE FILL,SS)	3.4
3-3 (30.-32. FT,RESIDUAL,SS)	1.37
3-3 (32.-34. FT,RESIDUAL,SS)	0.25
3-3 (34.-34.5 FT,RESIDUAL,SH)	1.26
3-3 (37.5-39.5 FT,RESIDUAL,SH)	0.25
3-3 (39.5-41.5 FT,RESIDUAL,SH)	0.3
BACKGROUND SOILS	
3-4 (16.-18.5 FT,ALLUV)	0.06
3-4 (18.5-20.5 FT,ALLUV)	0.27
3-4 (20.5-22.5 FT, WEATH. BEDROC)	0.61
3-4A (8.-10.5 FT,FILL)	1.41
3-4B (16.0-18.0 FT,RESIDUAL)	0.41
3-4B (18.5-20.5 FT,WEATH. BEDROC)	0.48

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FULL-SCALE FIELD EVALUATION OF WASTE DISPOSAL FROM COAL-FIRED ELECTRIC GENERATING PLANTS

Volume VI. Appendices G Through I

by

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ABSTRACT

This report summarizes results of a 3-year study of current coal ash and flue gas desulfurization (FGD) waste disposal practices at coal-fired electric generating plants. The study was conducted by Arthur D. Little, Inc., under EPA contract 68-02-3167, and involved characterizing wastes, gathering environmental data, assessing environmental effects, and evaluating the engineering/costs of disposal practices at six selected sites in various locations around the country. Results of the study are providing technical background data and information to EPA, State and local permitting officials, and the utility industry for implementing environmentally sound disposal practices.

Data from the study suggest that no major environmental effects have occurred at any of the six sites. For example, data from wells downgradient of the disposal sites indicate that the contribution of waste leachate to the groundwater has generally resulted in concentrations of chemicals less than the primary drinking water standards established by EPA. Although occasional exceedances of the standards were observed, these were not necessarily attributable to coal ash and FGD waste. A generic environmental evaluation based on a matrix of four waste types, three disposal methods, and five environmental settings (based on climate and hydrogeology) shows that technology exists for environmentally sound disposal of coal ash and FGD wastes for ponding, interim ponding/landfilling, and landfilling. For some combinations of waste types, disposal methods, and environmental settings, measures must be taken to avoid adverse environmental effects. However, site-specific application of good engineering design and practices can mitigate most potentially adverse effects of coal ash and FGD waste disposal. Costs of waste disposal operations are highly system- and site-specific.

APPENDIX G

ENGINEERING/COST DATA

FULL-SCALE FIELD EVALUATION OF WASTE DISPOSAL FROM COAL-FIRED ELECTRIC GENERATING PLANTS

By

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APPENDIX G

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TABLE 1

PLANT ALLEN AREA ACCOUNTS

The following series of equipment numbers were assigned to the solid waste handling/disposal system at Plant Allen and are divided among the area accounts specified below:

1100 Series	=	Plant Allen fly ash handling system
1200 Series	=	Plant Allen bottom ash handling system
1300 Series	=	Plant Allen coal ash transport system
1400 Series	=	Plant Allen coal pile runoff transport system
1500 Series	=	Plant Allen miscellaneous plant wastes transport system
1600 Series	=	Plant Allen coal ash/coal pile runoff/ miscellaneous plant wastes disposal system

Source: Arthur D. Little, Inc.

TABLE 2

PLANT ALLEN EQUIPMENT LIST

AREA 1100 - PLANT ALLEN FLY ASH HANDLING SYSTEM

Item No.	Description	No. Required
	BLOWERS	
B - 1101 - A/C	Units 3 and 4 Fly Ash Blowers	3
	EDUCTORS	
E - 1101	Unit 1 Fly Ash/Water Hydroveyor Exhauster	1
E - 1102	Unit 2 Fly Ash/Water Hydroveyor Exhauster	1
E - 1103 - A/B	Unit 3 Fly Ash/Water Hydroveyor Exhauster	2
E - 1104 - A/B	Unit 4 Fly Ash/Water Hydroveyor Exhauster	2
E - 1105 - A/D	Unit 5 Fly Ash/Water Hydroveyor Exhauster	4
	VESSELS	
V - 1101	Units 1 and 2 Air Separator Tank	1
V - 1102	Unit 3 Air Separator Tank	1
V - 1103	Unit 4 Air Separator Tank	1
V - 1104 - A/B	Unit 5 Air Separator Tank	2

AREA 1200 - PLANT ALLEN BOTTOM ASH HANDLING SYSTEM

	EDUCTORS	
E - 1201	Unit 1 Bottom Ash Jet Pump	1
E - 1202	Unit 2 Bottom Ash Jet Pump	1
E - 1203	Unit 3 Bottom Ash Jet Pump	1
E - 1204	Unit 4 Bottom Ash Jet Pump	1
E - 1205	Unit 5 Bottom Ash Jet Pump	1
	PUMPS	
P - 1201	Unit 1 Bottom Ash Service Water Booster Pump	1
P - 1202	Unit 2 Bottom Ash Service Water Booster Pump	1
P - 1203	Unit 3 Bottom Ash Service Water Booster Pump	1
P - 1204	Unit 4 Bottom Ash Service Water Booster Pump	1
P - 1205 - A/B	Unit 5 Bottom Ash Service Water Booster Pump	2

TABLE 2 (Continued)

PLANT ALLEN EQUIPMENT LIST

AREA 1300 - PLANT ALLEN COAL ASH TRANSPORT SYSTEM

Item No.	Description	No. Required
	EDUCTORS	
E - 1301	Sluice Line A Jet Booster Pump	1
E - 1302	Sluice Line B Jet Booster Pump	1
E - 1303	Sluice Line D Jet Booster Pump	1
	PUMPS	
P - 1301 - A/C	Sluice Lines A and B Service Water Booster Pump	3
P - 1302 - A/B	Sluice Line D Service Water Booster Pump	2
P - 1303 - A/G	High Pressure Service Water Pump	7

AREA 1400 - PLANT ALLEN COAL PILE RUNOFF TRANSPORT SYSTEM

	PUMPS	
P - 1401 - A/C	Coal Yard Sump Pump	3

AREA 1500 - PLANT ALLEN MISCELLANEOUS PLANT WASTES TRANSPORT SYSTEM

	PUMPS	
P - 1501 - A/C	Plant Sump Pump	3

AREA 1600 - PLANT ALLEN COAL ASH/COAL PILE RUNOFF/MISCELLANEOUS PLANT WASTES DISPOSAL SYSTEM

	PONDS	
PD - 1601	Disposal Pond A	1
PD - 1602	Disposal Pond B	1
PD - 1603	Disposal Pond C	1

Source: Arthur D. Little, Inc.

TABLE 3

ELRAMA PLANT AREA ACCOUNTS

The following series of equipment numbers were assigned to the solid waste handling/disposal system at the Elrama Plant and are divided among the area accounts specified below:

2100 Series = Elrama Plant fly ash handling system
2200 Series = Elrama Plant fly ash storage system
2300 Series = Elrama Plant bottom ash handling system
2400 Series = Elrama Plant bottom ash transport system
2500 Series = Elrama Plant bottom ash placement/interim disposal system
2600 Series = CS stabilization process raw materials storage/handling
2700 Series = CS FGC waste processing system
2800 Series = CS stabilized FGC waste/bottom ash transport system
2900 Series = CS stabilized FGC waste/bottom ash placement and disposal system

Source: Arthur D. Little, Inc.

TABLE 4

ELRAMA PLANT EQUIPMENT LIST

AREA 2100 - ELRAMA PLANT FLY ASH HANDLING

Item No.	Description	No. Required
	BLOWERS	
B - 2101	Fly Ash Conveying Rotary Air Compressor	1
B - 2102	Fly Ash Conveying Rotary Air Compressor	1
	FEEDERS	
D - 2101	Units 1, 2, and 3 Fly Ash Fluidizing Chamber	1
D - 2102	Unit 4 Fly Ash Fluidizing Chamber	1
	EDUCTORS	
E - 2101	Units 1 and 2 Fly Ash/Water Jet Ejector	1
E - 2102	Units 1 and 2 Fly Ash Hydrovactor	1
E - 2103	Unit 3 Fly Ash Hydrovactor	1
E - 2104	Unit 3 Fly Ash/Water Jet Ejector	1
E - 2105	Unit 4 Fly Ash Hydrovactor	1
E - 2106	Unit 4 Fly Ash/Water Jet Ejector	1
	CYCLONES	
F - 2101	Units 1, 2, and 3 Fly Ash Cyclone	1
F - 2102	Unit 4 Fly Ash Cyclone	1
	VESSELS	
V - 2101	Units 1 and 2 Fly Ash/Air Separator Tank	1
V - 2102	Unit 3 Fly Ash/Air Separator Tank	1
V - 2103	Unit 4 Fly Ash/Air Separator Tank	1

AREA 2200 - ELRAMA PLANT FLY ASH STORAGE SYSTEM

	COMPRESSORS/FANS	
B - 2201	Ash Silo Scrubber Exhaust Fan	1
B - 2202	Fly Ash Conveying Blower	1

TABLE 4 (Continued)

ELRAMA PLANT EQUIPMENT LIST

AREA 2200 - ELRAMA PLANT FLY ASH STORAGE SYSTEM (Continued)

Item No.	Description	No. Required
	FEEDERS	
D - 2201	Fly Ash Silo Rotary Air Lock Feeder	1
D - 2202 - A/B	Fly Ash Silo Rotary Air Lock Feeder (Manual Op.)	2
D - 2203 - A/B	Fly Ash Silo Unloader (Pugmill)	2
	SCRUBBERS	
F - 2201	Fly Ash Storage Silo Venturi Scrubber	1
	PUMPS	
P - 2201 - A/B	Fly Ash Storage Silo Sump Pump	2
	STORAGE VESSELS	
S - 2201	Fly Ash Storage Silo	1
	SUMPS	
V - 2201	Fly Ash Storage Silo Sump	1

AREA 2300 - ELRAMA PLANT BOTTOM ASH HANDLING SYSTEM

	AGITATORS	
A - 2301	Bottom Ash Overflow Sump Agitator	1
	SLUICE TRENCHES	
C - 2301	Units 1 and 2 Bottom Ash Sluice Trench	1
C - 2302	Units 3 and 4 Bottom Ash Sluice Trench	1
	STRAINERS	
- 2301	Rotary Strainer	1
- 2302	Twin Strainer	1
F - 2303	Rotary Strainer	1

TABLE 4 (Continued)

ELRAMA PLANT EQUIPMENT LIST

AREA 2300 - ELRAMA PLANT BOTTOM ASH HANDLING SYSTEM (Continued)

Item No.	Description	No. Required
	PUMPS	
P - 2301 - A/B	Units 1 and 2 Ash Sluice Water Pump	2
P - 2302	Unit 3 Ash Sluice Water Pump	1
P - 2303 - A/B	Unit 4 Ash Sluice Water Pump	2
	SUMPS	
V - 2301	Bottom Ash Sump	1
V - 2302	Bottom Ash Overflow Sump	1
V - 2303	Surface Water Sump	1

AREA 2400 - ELRAMA PLANT BOTTOM ASH TRANSPORT SYSTEM

	PUMPS	
P - 2401 - A/B	Bottom Ash Handling Pump	2
P - 2402 - A/B	Bottom Ash Overflow Sump Pump	2
P - 2403 - A/B	Surface Water Sump Pump	2

AREA 2500 - ELRAMA PLANT BOTTOM ASH PLACEMENT/INTERIM DISPOSAL SYSTEM

	PONDS	
PD - 2501	Interim Bottom Ash Disposal Pond	1
PD - 2502	Interim Bottom Ash Disposal Pond	1
PD - 2503	Polishing Pond	1
	PUMPS	
P - 2501 - A/C	Bottom Ash Disposal Pond Overflow Sump Pump	3
	SUMPS	
V - 2501	Bottom Ash Disposal Pond Overflow Sump	1

TABLE 4 (Continued)

ELRAMA PLANT EQUIPMENT LIST

AREA 2600 - CS STABILIZATION PROCESS RAW MATERIALS STORAGE/HANDLING

Item No.	Description	No. Required
	BLOWERS	
B - 2601	Lime Baghouse Exhaust Blower	1
B - 2602	Fly Ash Baghouse Exhaust Blower	1
B - 2603	Bag Cleaning Air Compressor	1
	CONVEYORS	
C - 2601	Lime Screw Conveyor	1
C - 2602	Fly Ash Screw Conveyor	1
	FEEDERS	
D - 2601	Lime Storage Silo Screw Feeder	1
- 2602	Fly Ash Storage Silo Rotary Air Lock Feeder	1
- 2603	Fly Ash Storage Silo Screw Feeder	1
	BAGHOUSES	
F - 2601	Lime Storage Silo Baghouse	1
F - 2602	Fly Ash Storage Silo Baghouse	1
	SCALES	
H - 2601	Lime Scale	1
H - 2602	Fly Ash Scale	1
	STORAGE BINS	
S - 2601	Lime Storage Silo with Live Bin	1
S - 2602	Fly Ash Storage Silo with Live Bin	1

TABLE 4 (Continued)

ELRAMA PLANT EQUIPMENT LIST

AREA 2700 - CS FGC WASTE PROCESSING SYSTEM

Item No.	Description	No. Required
	AGITATORS	
A - 2701	FGD Sludge Distribution Tank Agitator	1
A - 2702	FGD Sludge Surge Tank Agitator	1
	BLOWERS	
B - 2701	Pugmill Baghouse Exhaust Blower	1
	CONVEYORS	
C - 2701 - A/B	Filter Cake Belt Conveyor (Drum Discharge)	2
C - 2702	Filter Cake Belt Conveyor (Mixer Feed)	1
C - 2703	Processed Waste Belt Conveyor (Mixer Discharge)	1
C - 2704	Processed Waste Belt Conveyor (Radial Stacker)	1
C - 2705	Pugmill Bypass Belt Conveyor	1
	FILTERS	
F - 2701 - A/B	Rotary Drum Vacuum Filter	2
F - 2702	Pugmill Baghouse	1
	MIXERS	
M - 2701	Pugmill	1
	PUMPS	
P - 2701 - A/C	Thickener Underflow Pump	3
P - 2702 - A/C	Thickener Overflow Pump	3
P - 2703	Excess Thickener Overflow Pump	1
P - 2704 - A/C	FGD Sludge Surge Tank Pump	3
P - 2705 - A/B	Rotary Drum Filter Vacuum Pump	2
P - 2706 - A/B	Filtrate Recycle Pump	2
P - 2707 - A/B	Filtrate Pump	2
	THICKENERS	
T - 2701 - A/B	FGD Sludge Thickener	2

TABLE 4 (Continued)

ELRAMA PLANT EQUIPMENT LIST

AREA 2700 - CS FGC WASTE PROCESSING SYSTEM (Continued)

Item No.	Description	No. Required
	VESSELS	
V - 2701	FGD Sludge Distribution Tank	1
V - 2702	FGD Sludge Thickener Overflow Sump	1
V - 2703	FGD Sludge Surge Tank	1
	AREA 2800 - CS STABILIZED FGC WASTE/BOTTOM ASH TRANSPORT SYSTEM	
	MOBILE EQUIPMENT	
Fl - 2801	Front End Loader	1
Tr - 2801 - A/T	Dump Truck	20
	AREA 2900 - CS STABILIZED WASTE/BOTTOM ASH PLACEMENT AND DISPOSAL SYSTEM	
	DISPOSAL OPERATION	
LF - 2901	Landfill	1
PD - 2901	Runoff Settling Pond	1
PD - 2902	Runoff Settling Pond	1
PD - 2903	Runoff Settling Pond	1
	MOBILE EQUIPMENT	
Dz - 2901 - A/B	Dozer	2
Dz - 2902	Dozer	1
Tr - 2901	Watering Truck	1
Tr - 2902	Motor Grader	1
Tr - 2903	Compactor	1
Tr - 2904	Road Sweeper	1

Source: Arthur D. Little, Inc.

TABLE 5

DAVE JOHNSTON PLANT AREA ACCOUNTS

The following series of equipment numbers were assigned to the dry fly ash waste handling/disposal system at the Dave Johnston Plant and are divided among the area accounts specified below:

3100 Series = Dave Johnston Plant dry fly ash handling system

3200 Series = Dave Johnston Plant dry fly ash storage system

3300 Series = Dave Johnston Plant dry fly ash transport system

3400 Series = Dave Johnston Plant dry fly ash disposal system

Source: Arthur D. Little, Inc.

TABLE 6

DAVE JOHNSTON PLANT EQUIPMENT LIST

AREA 3100 - DAVE JOHNSTON DRY FLY ASH HANDLING SYSTEM

Item No.	Description	No. Required
	BLOWERS	
) - 3101 - A/B	Unit 1 ESP Hopper Fluidizing Blower	2
B - 3102	Unit 2 ESP Hopper Fluidizing Blower	1
B - 3103 - A/B	Unit 3 ESP Hopper Fluidizing Blower	2
B - 3104 - A/B	Unit 1 Fly Ash Conveying Blower	2
B - 3105	Unit 2 Fly Ash Conveying Blower	1
B - 3106 - A/B	Unit 3 Fly Ash Conveying Blower	2
B - 3107 - A/C	Unit 3 Economizer Ash Conveying Blower	3
B - 3108 - A/B	Unit 4 Economizer Ash Conveying Blower	2
	FEEDERS	
D - 3101 - A/X	Unit 1 ESP Hopper Feeder	24
D - 3102 - A/X	Unit 2 ESP Hopper Feeder	24
- 3103 - A/VV	Unit 3 ESP Hopper Feeder	48
- 3104 - A/H	Unit 3 Economizer Hopper Feeder	8
D - 3105 - A/T	Unit 4 Economizer Hopper Feeder	6

AREA 3200 - DAVE JOHNSTON PLANT DRY FLY ASH STORAGE SYSTEM

	BLOWERS	
B - 3201 - A/B	Fly Ash Storage Bin Vent Fan	2
B - 3202 - A/B	Fly Ash Storage Bin Vent Fan	2
B - 3203	Fly Ash Storage Bin Fluidizing Blower	1
B - 3204	Fly Ash Storage Bin Fluidizing Blower	1
	FEEDERS	
D - 3201 - A/B	Fly Ash Storage Bin Unloader	2
D - 3202 - A/B	Fly Ash Storage Bin Unloader	2
	STORAGE VESSELS	
S - 3201	Fly Ash Storage Bin	1
S - 3202	Fly Ash Storage Bin	1

TABLE 6 (Continued)

DAVE JOHNSTON PLANT EQUIPMENT LIST

AREA 3300 - DAVE JOHNSTON PLANT DRY FLY ASH TRANSPORT SYSTEM

Item No.	Description	No. Required
	MOBILE EQUIPMENT	
Tr - 3301 - A/B	Haulpak Truck	2
	AREA 3400 - DAVE JOHNSTON PLANT DRY FLY ASH DISPOSAL SYSTEM	
	LANDFILL	
LF -3401	Dry Fly Ash Landfill	1
	MOBILE EQUIPMENT	
Dz - 3401	Dozer	1
Tr - 3401	Water Wagon	1
Tr - 3402	Water Wagon	1

Source: Arthur D. Little, Inc.

TABLE 7

SHERBURNE COUNTY PLANT AREA ACCOUNTS

The following series of equipment numbers were assigned to the solid waste handling/disposal system at the Sherco site and are divided among the area accounts specified below:

4100 Series	=	Sherco Plant fly ash/FGD waste processing system
4200 Series	=	Sherco Plant fly ash/FGD waste transport system
4300 Series	=	Sherco Plant fly ash/FGD waste disposal system
4400 Series	=	Sherco Plant scrubber recycle water system
4500 Series	=	Sherco Plant bottom ash/pyrites handling system
4600 Series	=	Sherco Plant bottom ash/pyrites transport system
4700 Series	=	Sherco Plant bottom ash/pyrites disposal system
4800 Series	=	Sherco Plant bottom ash/pyrites sluice water system recycle
4900 Series	=	Sherco Plant coal pile runoff/plant wastes transport

Source: Arthur D. Little, Inc.

TABLE 8

SHERBURNE COUNTY PLANT EQUIPMENT LIST

AREA 4100 - SHERBURNE COUNTY PLANT FLY ASH/FGD WASTE PROCESSING SYSTEM

Item No.	Description	No. Required
	EDUCTORS	
E-4101	Unit 1 Economizer Ash Jet Exhauster	1
E-4102	Unit 2 Economizer Ash Jet Exhauster	1
	PUMPS	
P-4101-A/L	Unit 1 Scrubber Bleed Pumps	12
P-4102-A/L	Unit 2 Scrubber Bleed Pumps	12
P-4103-A/D	Unit 1 Scrubber Drain Pumps	4
P-4104-A/D	Unit 2 Scrubber Drain Pumps	4
P-4105-A/D	Scrubber Sump Pumps	4
	THICKENERS	
T-4101-A/B	Thickener	2
	VESSELS	
V-4101	Unit 1 Slurry Transfer Tank	1
V-4102	Unit 2 Slurry Transfer Tank	1
V-4103	Unit 1 Boil Box	1
V-4104	Unit 2 Boil Box	1

AREA 4200 - SHERBURNE COUNTY PLANT FLY ASH/FGD WASTE TRANSPORT SYSTEM

P-4201-A/D	Thickener Sludge Pumps	4

AREA 4300 - SHERBURNE COUNTY PLANT FLY ASH/FGD WASTE DISPOSAL SYSTEM

PD-4301	Fly Asg/FGD Waste Disposal Pond	1
PD-4302	Scrubber Recycle Pond	1

AREA 4400 - SHERBURNE COUNTY PLANT SCRUBBER RECYCLE WATER SYSTEM

	PUMPS	
P-4401-A/B	Scrubber Makeup Water Pumps	2
P-4402-A/B	Unit 1 Scrubber Recirculation Pumps	2
P-4403-A/B	Unit 2 Scrubber Recirculation Pumps	2
P-4404-A/B	Unit 1 Economizer Ash Water Pumps	2
P-4405-A/B	Unit 2 Economizer Ash Water Pumps	2

TABLE 8 (continued)

SHERBURNE COUNTY PLANT EQUIPMENT LIST

AREA 4400 - SHERBURNE COUNTY PLANT SCRUBBER RECYCLE WATER SYSTEM (continued)

Item No.	Description	No. Required
	VESSELS	
V-4401	Unit 1 Scrubber Recirculation Water Tank	1
V-4402	Unit 2 Scrubber Recirculation Water Tank	1

AREA 4500 - SHERBURNE COUNTY PLANT BOTTOM ASH/PYRITES HANDLING SYSTEM

	EDUCTORS	
E-4501-A/G	Unit 1 Pyrite Jet Pumps	7
E-4502-A/G	Unit 2 Pyrite Jet Pumps	7
E-4503-A/F	Unit 1 Bottom Ash Jet Pumps	6
E-4504-A/F	Unit 2 Bottom Ash Jet Pumps	6

AREA 4600 - SHERBURNE COUNTY PLANT BOTTOM ASH/PYRITES TRANSPORT SYSTEM

No processing equipment is assigned to this account.

AREA 4700 - SHERBURNE COUNTY PLANT BOTTOM ASH/PYRITES DISPOSAL SYSTEM

PD-4701	Bottom Ash Disposal Pond	1
PD-4702	Bottom Ash Recycle Pond	1

AREA 4800 - SHERBURNE COUNTY PLANT BOTTOM ASH/PYRITES SLUICE WATER RECYCLE SYSTEM

	PUMPS	
P-4801-A/C	Recycle Water Pumps	3
P-4802-A/B	Pyrite Sluice Water Pumps	2
P-4803-A/B	Bottom Ash Sluice Water Pumps	2
P-4804-A/B	Recycle Seal Water Pumps	2

AREA 4900 - SHERBURNE COUNTY PLANT COAL PILE RUNOFF/PLANT WASTES TRANSPORT SYSTEM

No processing equipment is assigned to this account.

Source: Arthur D. Little, Inc.

TABLE 9

POWERTON PLANT AREA ACCOUNTS

The following series of equipment numbers were assigned to the solid waste handling/disposal system at the Powerton Plant and are divided among the area accounts specified below:

5100 Series	=	Powerton Plant fly ash handling system
5200 Series	=	Powerton Plant fly ash storage system
5300 Series	=	Powerton Plant slag handling system
5400 Series	=	Powerton Plant economizer ash handling system
5500 Series	=	Powerton Plant fly ash/slag/economizer ash transport system
5600 Series	=	Powerton Plant fly ash/bottom ash/economizer ash disposal system
5700 Series	=	Powerton Plant ash sluice water treatment system
5800 Series	=	Powerton Plant miscellaneous plant wastes handling system

Source: Arthur D. Little, Inc.

TABLE 10

POWERTON PLANT EQUIPMENT LIST

AREA 5100 - POWERTON PLANT FLY ASH HANDLING SYSTEM

Item No.	Description	No. Required
	BLOWERS	
B-5101-A/C	Vacuum Pump	3
B-5102-A/C	Vacuum Pump	3
	AREA 5200 - POWERTON PLANT FLY ASH STORAGE SYSTEM	
	BLOWERS	
B-5201-A/B	Fly Ash Fluidizing Blower	2
B-5202-A/B	Fly Ash Fluidizing Blower	2
	FEEDERS	
D-5201-A/L	Fly Ash Diffuser	12
D-5202-A/L	Fly Ash Diffuser	12
	CYCLONES/BAGFILTERS	
F-5201-A/C	Cyclone	3
F-5202-A/C	Bag Filter	3
F-5203-A/C	Cyclone	3
F-5204-A/C	Bag Filter	3
	MIXERS	
M-5201-A/B	Mixer/Rotary Unloader	2
M-5202-A/B	Mixer/Rotary Unloader	2
	STORAGE VESSELS	
S-5201	Unit 5 Fly Ash Storage Silo	1
S-5202	Unit 6 Fly Ash Storage Silo	1
S-5203-A/B	Unloading Chute	2
S-5204-A/B	Unloading Chute	2
	AREA 5300 - POWERTON PLANT SLAG HANDLING SYSTEM	
	EDUCTORS	
E-5301-A/D	Jet Pump	4
E-5302-A/D	Jet Pump	4

TABLE 10 (continued)

POWERTON PLANT EQUIPMENT LIST

AREA 5300 - POWERTON PLANT SLAG HANDLING SYSTEM (continued)

Item No.	Description	No. Required
	DEWATERING BINS	
F-5301-A/B	Unit 5 Slag Dewatering Bin	2
F-5302-A/B	Unit 6 Slag Dewatering Bin	2
	GRINDERS	
G-5301-A/D	Unit 5 Slag Breaker	4
G-5302-A/D	Unit 6 Slag Breaker	4
	PUMPS	
P-5301-A/C	Unit 5 Ash Sluice Pump	3
P-5302-A/C	Unit 6 Ash Sluice Pump	3

AREA 5400 - POWERTON PLANT ECONOMIZER ASH HANDLING SYSTEM

	EDUCTORS	
E-5401-A/B	Jet Pump	2
E-5402-A/B	Jet Pump	2
E-5403-A/B	Jet Pump	2
E-5404-A/B	Jet Pump	2
	VESSELS	
V-5401-A/B	Unit 5 Economizer Ash Auxiliary Hopper	2
V-5402-A/B	Unit 5 Economizer Ash Auxiliary Hopper	2
V-5403-A/B	Unit 6 Economizer Ash Auxiliary Hopper	2
V-5404-A/B	Unit 6 Economizer Ash Auxiliary Hopper	2

AREA 5500 - POWERTON PLANT FLY ASH/SLAG/ECONOMIZER ASH TRANSPORT SYSTEM

	MOBILE EQUIPMENT	
Tr-5501-A/F	Truck	6

AREA 5600 - POWERTON PLANT FLY ASH/SLAG/ECONOMIZER ASH DISPOSAL SYSTEM

	LANDFILLS	
LF-5601	Landfill (retired)	1
LF-5602	Landfill (retired)	1

TABLE 10 (continued)

POWERTON PLANT EQUIPMENT LIST

AREA 5600 - POWERTON PLANT FLY ASH/SLAG/ECONOMIZER ASH DISPOSAL SYSTEM (continued)

Item No.	Description	No. Required
	MOBILE EQUIPMENT	
Dz-5601	Dozer	1
Fl-5602	Front End Loader	1
	SETTLING PONDS	
PD-5601	Settling Pond	1
PD-5602	Auxiliary Settling Pond	1
	AREA 5700 - POWERTON PLANT SLUICE WATER TREATMENT SYSTEM	
	PUMPS	
P-5701-A/C	Settling Pond Overflow Sump Pump	3
P-5702-A/C	Service Water Supply Sump Pump	3
	VESSELS (SUMPS)	
V-5701	Settling Pond Overflow Sump	1
V-5702	Service Water Sump	1
	AREA 5800 - POWERTON PLANT MISCELLANEOUS PLANT WASTES HANDLING SYSTEM	
	PUMPS	
P-5801-A/D	Unit 5 Slag Overflow Sump Pump	4
P-5802-A/D	Unit 6 Slag Overflow Sump Pump	4
P-5803-A/B	Demineralizer Filter Sump Pump	2
P-5804-A/B	Ash Sluice Line Drain Sump Pump	2
	VESSELS (SUMPS)	
V-5801-A/B	Unit 5 Slag Overflow Sump	2
V-5802-A/B	Unit 6 Slag Overflow Sump	2
V-5803-A/B	Demineralizer Filter Backwash Sump	2
V-5804	Bottom Ash Sluice Line Drain Sump	1

Source: Arthur D. Little, Inc.

TABLE 11

LANSING SMITH PLANT AREA ACCOUNTS

The following series of equipment numbers were assigned to the solid waste handling/disposal system at Lansing Smith Plant and are divided among the area accounts specified below:

6100 Series	=	Lansing Smith Plant fly ash handling/transport system
6200 Series	=	Lansing Smith Plant bottom ash/mill rejects handling/transport system
6300 Series	=	Lansing Smith Plant coal pile runoff transport system
6400 Series	=	Lansing Smith Plant miscellaneous plant wastes transport system
6500 Series	=	Lansing Smith Plant coal ash/coal pile runoff/ miscellaneous plant wastes disposal system
6600 Series	=	Lansing Smith Plant coal ash sluice water recycle system

Source: Arthur D. Little, Inc.

TABLE 12

LANSING SMITH PLANT EQUIPMENT LIST

AREA 6100 - LANSING SMITH FLY ASH HANDLING AND TRANSPORT SYSTEM

Item No.	Description	No. Required
	EDUCTORS	
E-6101	Unit 1 Fly Ash/Water Jet Ejector	1
E-6102	Unit 2 Fly Ash/Water Jet Ejector	1
	VESSELS	
V-6101	Unit 1 Air Separator Tank	1
V-6102	Unit 2 Air Separator Tank	1
	PUMPS	
P-6101-A/B	Units 1 and 2 Fly Ash Service Water Booster Pump	2 (one for each unit)

AREA 6200 - LANSING SMITH PLANT BOTTOM ASH/MILL REJECTS HANDLING AND TRANSPORT SYSTEM

	EDUCTORS	
E-6201	Unit 1 Bottom Ash Jet Pump	1
E-6202	Unit 2 Bottom Ash Jet Pump	1
E-6203-A/D	Unit 1 Mill Rejects Jet Pump	4
E-6204-A/E	Unit 2 Mill Rejects Jet Pump	5
	VESSELS	
V-6201-A/D	Unit 1 Mill Rejects Storage/Transfer Hopper	4
V-6202-A/E	Unit 2 Mill Rejects Storage/Transfer Hopper	5
	PUMPS	
P-6201-A/B	Units 1 and 2 Bottom Ash Service Water Booster Pump	2 (one for each unit)
P-6202	Units 1 and 2 Mill Rejects Service Water Booster Pump	1 (services both units)

TABLE 12 (continued)

LANSING SMITH PLANT EQUIPMENT LIST

AREA 6300 - LANSING SMITH PLANT COAL PILE RUNOFF TRANSPORT SYSTEM

Item No.	Description	No. Required
	PUMPS	
P-6301	Coal Yard Sump Pump	1
P-6302	Coal Yard Sump Pump	1
P-6303	Coal Yard Sump Pump	1
	SUMPS	
V-6301	Coal Yard Sump	1
V-6302	Coal Yard Sump	1
V-6303	Coal Yard Sump	1

AREA 6400 - LANSING SMITH PLANT MISCELLANEOUS PLANT WASTES TRANSPORT SYSTEM

	PUMPS	
P-6401-A/C	Plant Sump Pump	3 (inside)
P-6402-A/B	Plant Sump Pump	2 (outside)
P-6403	Demineralizer/Blowdown Waste Pump	1
P-6404	Clarified Demineralizer/Blowdown Waste Pump	1
	SUMPS/VESSELS	
V-6401	Plant Sump	1
V-6402	Demineralizer/Blowdown Waste Tank	1

AREA 6500 - LANSING SMITH PLANT COAL ASH/COAL PILE RUNOFF/MISCELLANEOUS PLANT WASTES DISPOSAL SYSTEM

	PONDS	
PD-6501	Boiler Cleaning Waste Disposal Pond	1
PD-6502	Demineralizer/Blowdown Waste Disposal Pond	1
PD-6503	Coal Ash/Coal Pile Runoff/Plant Waste Disposal Pond	1

TABLE 12 (continued)

LANSING SMITH PLANT EQUIPMENT LIST

AREA 6600 - LANSING SMITH PLANT COAL ASH SLUICE WATER RECYCLE SYSTEM

Item No.	Description	No. Required
	PUMPS	
P-6601-A/B	Recycle Service Water Pump (recycles water from canal to plant)	2

Source: Arthur D. Little, Inc.

TABLE 13

DETAILED CAPITAL COST ESTIMATE

Plant Name: Allen
Plant Location: Gaston County, North Carolina
Utility Name: Duke Power Company
Nameplate Generating Capacity (MW): 1155

Basis: Late 1982 Estimates
ENR Index = 3931.11 (1913 = 100)
= 366.97 (1967 = 100)

Capital Costs (thousands of $)

	Area 1100	Area 1200	Area 1300		Area 1400	Area 1500	Area 1600		
	Air Pollution Control	Fly Ash Handling and Processing	Bottom Ash Handling and Processing	Fly Ash Transport	Bottom Ash Transport	Coal Pile Runoff Transport	Miscellaneous Plant Waste Handling and Transport	Placement and Fly Ash Disposal	Placement and Bottom Ash Disposal	Total
Direct Costs										
Process Equipment	48,127	178	168	282	97	69	59	–	–	48,948
Piping and Insulation	28	1,234	128	3,390	1,264	178	178	74	28	6,490
Foundations and Structures	4,364	38	9	99	37	28	58	137	51	4,819
Site Preparation and Earthwork	–	–	–	–	–	–	–	8,813	3,185	11,798
Electrical	1,120	214	296	524	194	204	203	25	9	2,789
Instrumentation	280	397	131	32	11	38	39	21	7	946
Buildings	–	–	–	–	–	–	–	–	–	–
Subtotal	53,919	2,047	730	4,307	1,593	607	537	8,870	3,280	75,790
Site Monitoring Wells	–	–	–	–	–	–	–	12	5	17
Reclamation	–	–	–	–	–	–	–	1,380	510	1,890
Services and Miscellaneous	–	41	16	87	32	10	11	178	66	440
Mobile Equipment	–	–	45	–	–	–	–	–	–	45
Total Direct Investment	53,919	2,088	790	4,394	1,625	617	548	10,440	3,861	78,182
Indirect Costs										
Contractors Overhead	5,392	313	119	659	244	78	82	1,357	502	8,746
Contractors Profit	1,078	104	40	220	81	26	27	462	167	2,195
Subtotal	60,389	2,505	949	5,273	1,950	621	657	12,249	4,530	89,123
Engineering Design and Supervision	3,019	261	96	527	195	62	66	1,088	402	5,703
Architect Engineering Fee	1,208	125	47	263	98	31	33	543	201	2,549
Subtotal	64,616	2,891	1,091	6,063	2,243	714	756	13,878	5,133	97,375
Contingency	19,471	870	331	1,828	678	218	230	3,748	1,386	28,766
Total Fixed Investment	84,087	3,761	1,422	7,891	2,919	932	986	17,624	6,518	126,139
Startup and Modifications	286	20	11	29	11	11	11	–	–	379
Interest During Construction (excluded)	–	–	–	–	–	–	–	–	–	–
Total Depreciable Investment	84,373	3,771	1,433	7,920	2,930	943	997	17,624	6,518	126,509
Other Costs										
Land	–	–	–	–	–	–	–	735	272	1,007
Working Capital (excluded)	–	–	–	–	–	–	–	–	–	–
Total Capital Investment	$84,373	$3,771	$1,433	$7,920	$2,930	$943	$997	$18,360	$6,790	$127,516 ($110/kW)

Source: Arthur D. Little, Inc., estimates.

- Doc. Ex. 9248 -

TABLE 14

DETAILED CAPITAL COST ESTIMATE

Plant Name: Elrama
Plant Location: Washington County, Pennsylvania
Utility Name: Duquesne Light Company
Nameplate Generation Capacity (MW): 510

Basis: Late 1982 Estimates
ENR Index = 3931.11 (1913 = 100)
= 386.87 (1967 = 100)

Capital Costs (thousands of $)

	Air Pollution Control	Area 2100 Fly Ash Handling and Processing (Dry)	Area 2200 Fly Ash Storage	Area 2300 Bottom Ash Handling and Processing (Wet)	Area 2400 Bottom Ash Transport (Wet)	Area 2500 Bottom Ash Interim Pond	Area 2600 Raw Material Handling and Storage	Area 2700 Fly Ash Handling and Processing (Wet)	Area 2700 FGD Waste Handling and Processing	Area 2800 Fly Ash Transport (Dry)	Area 2800 Bottom Ash Transport (Dry)	Area 2800 FGD Waste Transport (Dry)	Area 2900 Fly Ash Placement and Disposal	Area 2900 Bottom Ash Placement and Disposal	Area 2900 FGD Waste Placement and Disposal	Total
Direct Costs																
Process Equipment		178	866	226	126	22	133	1,783	4,170	–	–	–	–	–	–	7,619
Piping and Insulation		261	287	126	706	667	31	32	80	–	–	–	–	–	–	2,366
Foundations and Structures		12	28	43	2	41	9	180	442	–	–	–	–	–	–	757
Site Preparation and Earthwork		–	–	–	–	783	–	2	6	–	–	–	1,200	266	516	2,960
Electrical		137	146	224	167	128	144	106	257	–	–	–	–	–	–	1,298
Instrumentation		86	103	111	180	62	63	46	113	–	–	–	–	–	–	772
Buildings		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Subtotal	78,027	672	1,628	720	1,267	1,704	380	2,068	5,068	–	–	–	1,200	266	516	94,481
Site Monitoring Wells	–	–	–	–	–	–	–	–	–	–	–	–	17	6	6	29
Reclamation	–	–	–	–	–	–	–	–	–	–	–	–	845	244	344	1,433
Services and Miscellaneous	–	13	33	15	28	34	7	41	101	–	–	–	25	7	11	313
Mobile Equipment	–	–	–	–	–	–	–	–	–	939	326	661	486	140	198	2,760
Total Direct Investment	78,027	686	1,661	743	1,293	1,738	387	2,109	5,167	939	326	661	2,643	763	1,075	99,206
Indirect Costs																
Contractor Overhead	7,803	103	249	111	194	261	58	317	776	–	–	–	194	58	79	10,300
Contractor Profit	1,561	34	83	37	65	87	20	106	258	–	–	–	65	19	26	2,381
Subtotal	88,611	822	1,993	891	1,552	2,086	465	2,532	6,200	939	326	661	2,901	837	1,180	111,886
Engineering Design and Supervision	4,426	82	200	90	156	209	46	253	620	–	–	–	156	46	63	6,346
Architect Engineering Fee	1,771	41	100	45	77	104	24	127	310	–	–	–	78	22	32	2,731
Subtotal	94,708	945	2,293	1,026	1,785	2,398	535	2,912	7,130	939	326	661	3,134	906	1,275	120,962
Contingency	28,606	284	688	308	536	720	161	877	2,146	282	97	198	662	197	277	36,958
Total Fixed Investment	123,313	1,229	2,981	1,334	2,321	3,118	696	3,789	9,276	1,221	423	847	3,816	1,101	1,552	156,918
Startup and Modifications	308	1	1	1	1	–	1	10	26	–	–	–	–	–	–	349
Interest During Construction (excluded)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Total Depreciable Investment	123,622	1,230	2,982	1,335	2,322	3,118	697	3,799	9,301	1,221	423	847	3,816	1,101	1,552	157,267
Other Costs																
Land	–	–	–	–	–	30	–	2	4	–	–	–	301	110	152	599
Working Capital (excluded)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Total Capital Investment	$123,622	$1,230	$2,982	$1,335	$2,322	$3,148	$697	$3,801	$9,305	$1,221	$423	$847	$4,107	$1,211	$1,714	$157,866
																($310/kW)

Source: Arthur D. Little, Inc. estimates

TABLE 15

DETAILED CAPITAL COST ESTIMATE

Plant Name: Dave Johnston
Plant Location: Converse County, Wyoming
Utility Name: Pacific Power & Light Company
Nameplate Generating Capacity (MW): 420

Basis: Late 1982 Estimates
ENR Index = 3931.11 (1913 = 100)
= 366.97 (1967 = 100)

	Capital Costs (thousands of $)					
		Area 3100	Area 3200	Area 3300	Area 3400	
Direct Costs	Air Pollution Control	Fly Ash Handling and Processing	Fly Ash Storage	Fly Ash Transport	Fly Ash Placement and Disposal	Total
Process Equipment	26,438	1,509	1,248	–	–	28,195
Piping and Insulation	16	1,131	28	–	–	1,176
Foundations and Structures	2,545	23	106	–	–	2,674
Site Preparation and Earthwork	–	–	1	–	1,768	1,769
Electrical	385	167	43	–	–	595
Instrumentation	130	940	–	–	–	1,070
Buildings	–	–	–	–	–	–
Subtotal	28,514	3,770	1,427	–	1,768	35,479
Site Monitoring Wells	–	–	–	–	17	17
Reclamation	–	–	–	–	846	846
Services and Miscellaneous	670	75	29	–	35	709
Mobile Equipment	–	–	–	630	354	884
Total Direct Investment	29,084	3,845	1,456	630	3,019	37,934
Indirect Costs						
Contractors Overhead	2,909	577	218	–	270	3,974
Contractors Profit	681	192	73	–	90	936
Subtotal	32,674	4,614	1,747	630	3,379	42,844
Engineering Design & Supervision	1,629	462	75	–	216	2,382
Architect-Engineering Fee	651	231	87	–	108	1,077
Subtotal	34,854	5,307	1,909	630	3,703	46,303
Contingency	10,488	1,595	603	159	852	13,697
Total Fixed Investment	45,342	6,902	2,512	689	4,555	60,000
Startup and Modifications	106	10	–	–	–	116
Interest During Construction (excluded)	–	–	–	–	–	–
Total Depreciable Investment	45,448	6,912	2,512	689	4,555	60,116
Other Costs						
Land	–	–	–	–	41	41
Working Capital (excluded)	–	–	–	–	–	–
Total Capital Investment	$45,448	$6,912	$2,512	$689	$4,596	$60,157 ($143/kW)

Source: Arthur D. Little, Inc., estimates.

- Doc. Ex. 9250 -

TABLE 16

DETAILED CAPITAL COST ESTIMATE

Plant Name: Sherburne County
Plant Location: Sherburne County, Minnesota
Utility Name: Northern States Power Company
Nameplate Generating Capacity (MW): 1458

Basis: Late 1982 Estimates
EGR Index = 3631.11 (1913 = 100)
= 366.97 (1967 = 100)

Capital Costs (thousands of $)

	Area 4100		Area 4200		Area 4300		Area 4400		Area 4500	Area 4600	Area 4700	Area 4800	Area 4900	
	Particulate Control	SO_2 Control	Fly Ash Handling and Processing	FGD Waste Handling and Processing	Fly Ash Transport	FGD Waste Transport	Fly Ash Placement and Disposal	FGD Waste Placement and Disposal	Fly Ash Recycle Water System	FGD Waste Recycle Water System	Bottom Ash Handling and Processing	Bottom Ash Transport	Bottom Ash Placement and Disposal	Bottom Ash Recycle Water System	Coal Pile Runoff and Plant Waste Handling and Transport	Total
Direct Costs																
Process Equipment			4,650	1,811	88	34	27	10	207	80	42	–	37	230	–	7,223
Piping and Installation			149	58	626	204	148	58	606	314	15	529	361	949	–	4,015
Foundations and Structures			483	181	–	–	330	129	6	2	2	–	327	9	–	1,490
Site Preparation and Earthwork			–	–	–	–	8,300	3,617	–				5,506	–	27	18,448
Electrical			242	94	–	–	88	28	200	80		–	96	267	–	1,096
Instrumentation			111	43	21	8	11	4	223	87	1	17	15	204	–	745
Buildings	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Subtotal	97,200	37,000	5,654	2,197	632	248	9,884	3,843	1,446	563	60	546	8,339	1,648	27	187,686
Site Monitoring Wells		–	–	–	–	–	8	4				–	4	–	–	17
Reclamation	–	–	–		–	–	617	247				–	258	–	–	1,122
Services and Miscellaneous	–	–	113	44	13	5	168	77	28	11	2	8	127	31	1	650
Mobile Equipment	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Total Direct Investment	97,200	37,000	5,767	2,241	645	253	10,708	4,171	1,475	574	62	554	8,728	1,679	28	189,293
Indirect Costs																
Contractors Overhead	9,734	3,700	906	338	97	37	1,612	628	222	86	9	83	978	237	4	18,648
Contractors Profit	1,947	767	298	112	32	13	504	196	70	29	3	28	323	78	1	4,305
Subtotal	108,881	42,363	6,970	2,690	774	301	12,724	4,955	1,771	689	74	665	8,021	1,994	33	192,734
Engineering Design and Supervision	6,461	2,120	832	288	77	30	1,210	470	177	69	7	67	776	189	3	13,887
Architect-Engineering Fee	2,180	848	348	134	40	15	606	236	88	34	4	33	388	96	2	5,048
Subtotal	118,512	45,311	7,950	3,092	891	346	14,539	5,660	2,037	792	85	765	9,185	2,278	38	209,269
Contingency	36,018	13,818	2,386	930	267	104	4,174	1,623	611	238	26	230	2,877	664	11	62,507
Total Fixed Investment	151,831	58,929	10,343	4,022	1,158	450	18,713	7,283	2,648	1,030	111	995	11,062	2,932	49	271,996
Startup and Modifications	72	28	7	3	–	–	–	–	1	–	–	–	–	1	–	112
Interest During Construction (excluded)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Total Depreciable Investment	151,903	58,957	10,350	4,025	1,158	450	18,713	7,283	2,649	1,030	111	995	11,062	2,933	49	272,008
Other Costs																
Land	–	–	4	1	–	–	314	118	–	–	–	–	118	–	–	563
Working Capital (excluded)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Total Capital Investment	$151,903	$58,957	$10,354	$4,026	$1,158	$450	$19,027	$7,398	$2,649	$1,030	$111	$995	$11,180	$2,933	$49	$273,021
																($187/kW)

Source: Arthur D. Little, Inc., estimates

Plant Name: Powerton
Plant Location: Tazewell County, Illinois
Utility Name: Commonwealth Edison Company
Nameplate Generating Capacity (MW): 1788

TABLE 17

DETAILED CAPITAL COST ESTIMATE

Basis: Late 1982 Estimates
ENR Index = 3931.11 (1913 = 100)
= 385.97 (1967 = 100)

Capital Costs (thousands of $)

	Air Pollution Control	Area 5100 Fly Ash Handling and Processing (Dry)	Area 5200 Fly Ash Storage	Area 5300 Slag Handling and Processing (Wet)	Area 5400 Fly Ash Handling and Processing (Wet)	Area 6600 Fly Ash Transport (Dry)	Area 6600 Slag Transport (Dry)	Area 6800 Fly Ash Placement and Disposal	Area 6800 Slag Placement and Disposal	Area 6700 Slag Recycle Water System	Area 6500 Miscellaneous Waste Handling and Transport	Total
Direct Costs												
Process Equipment		237	2,606	2,258	101	–	–	–	–	53	92	5,344
Piping and Insulation		822	38	317	17	–	–	37	59	463	343	1,896
Foundations and Structures		11	62	80	10	–	–	87	137	32	681	980
Site Preparation and Earthwork		–	–	–	–	–	–	21,489	33,610	–	–	55,099
Electrical		98	418	488	–	–	–	–	–	230	207	1,441
Instrumentation		40	170	211	1	–	–	2	3	115	100	642
Buildings		–	–	–	–	–	–	–	–	–	–	–
Subtotal	19,860	1,008	3,293	3,362	129	–	–	21,615	33,809	893	1,303	85,202
Site Monitoring Wells	–	–	–	–	–	–	–	7	10	–	–	17
Reclamation	–	–	–	–	–	–	–	1,204	1,882	–	–	3,086
Services and Miscellaneous	–	20	68	67	3	–	–	432	676	18	26	1,308
Mobile Equipment	–	–	–	–	–	301	471	611	966	–	–	2,338
Total Direct Investment	19,860	1,028	3,369	3,419	132	301	471	23,869	37,332	911	1,329	92,011
Indirect Costs												
Construction Overhead	1,986	164	604	613	20	–	–	–	–	137	199	3,513
Contractor Profit	397	52	168	171	7	–	–	–	–	46	66	907
Subtotal	22,243	1,234	4,031	4,103	159	301	471	23,869	37,332	1,094	1,594	96,431
Engineering Design & Supervision	1,112	123	403	410	18	–	–	–	–	109	159	2,332
Architect - Engineering Fee	445	62	202	205	8	–	–	–	–	65	80	1,067
Subtotal	23,800	1,419	4,636	4,718	183	301	471	23,869	37,332	1,268	1,833	99,820
Contingency	7,193	426	1,391	1,416	55	91	141	6,798	10,632	377	550	29,069
Total Fixed Investment	30,993	1,845	6,027	6,133	238	392	612	30,667	47,964	1,636	2,383	128,889
Startup and Modifications	175	6	–	–	–	–	–	–	–	–	1	181
Interest During Construction (excluded)	–	–	–	–	–	–	–	–	–	–	–	–
Total Depreciable Investment (excluded)	31,168	1,850	6,027	6,133	238	392	612	30,667	47,964	1,636	2,384	129,070
Other Costs												
Land	–	–	–	–	–	–	–	562	882	–	–	1,444
Working Capital (excluded)	–	–	–	–	–	–	–	–	–	–	–	–
Total Capital Investment	$31,168	$1,850	$6,027	$6,133	$238	$392	$612	$31,229	$48,846	$1,636	$2,384	$130,514 ($73/kW)

Source: Arthur D. Little, Inc., estimates.

- Doc. Ex. 9252 -

TABLE 18

DETAILED CAPITAL COST ESTIMATE

Plant Name: Smith
Plant Location: Bay County, Florida
Utility Name: Gulf Power Company
Nameplate Generating Capacity (MW): 340

Basis: Late 1982 Estimates
ENR Index = 3031.11 (1913 = 100)
= 385.97 (1967 = 100)

Capital Costs (thousands of $)

	Area 8100			Area 8200		Area 8300	Area 8400	Area 8500		Area 8600		
	Air Pollution Control	Fly Ash Transport	Fly Ash Handling and Processing	Bottom Ash Transport	Bottom Ash Handling and Processing	Coal Pile Runoff Handling and Transport	Miscellaneous Plant Waste Handling and Transport	Fly Ash Placement and Disposal	Bottom Ash Placement and Disposal	Fly Ash Recycle Water System	Bottom Ash Recycle Water System	Total
Direct Costs												
Process Equipment	–	129	84	58	99	18	48	–	–	32	4	445
Piping and Insulation	–	717	367	117	208	594	590	5	1	86	9	2,693
Foundations and Structures	–	3	1	1	3	18	17	–	–	129	14	186
Site Preparation and Earthwork	–	–	–	–	–	–	–	3,656	406	–	–	4,062
Electrical	–	122	63	93	186	140	144	–	–	131	15	874
Instrumentation	–	81	31	40	71	63	68	1	–	57	6	398
Buildings	–	–	–	–	–	–	–	–	–	–	–	–
Subtotal	21,179	1,029	626	307	647	832	867	3,662	407	433	48	29,837
Site Monitoring Wells	–	–	–	–	–	–	–	15	2	–	–	17
Reclamation	–	–	–	–	–	–	–	1,899	208	–	–	2,077
Services and Miscellaneous	–	20	11	6	11	17	17	73	8	9	1	173
Mobile Equipment	–	–	–	–	–	–	–	–	–	–	–	–
Total Direct Investment	21,179	1,049	637	313	658	849	884	5,619	625	442	49	32,104
Indirect Costs												
Contractors Overhead	2,118	157	81	47	84	128	133	560	62	67	7	3,444
Contractors Profit	423	52	27	15	28	42	44	187	21	23	2	864
Subtotal	23,720	1,258	645	375	670	1,019	1,061	6,366	708	532	58	36,412
Engineering Design and Supervision	1,186	126	65	37	67	102	106	448	50	53	6	2,246
Architect Engineering Fee	474	63	32	19	33	50	53	224	25	27	3	1,003
Subtotal	25,380	1,447	742	431	770	1,171	1,220	7,038	783	612	67	39,661
Contingency	7,643	435	222	129	232	351	367	1,646	172	183	21	11,301
Total Fixed Investment	33,023	1,882	964	560	1,002	1,522	1,587	8,684	955	795	88	50,962
Startup and Modifications	99	–	–	–	–	–	–	–	–	–	–	99
Interest During Construction (excluded)	–	–	–	–	–	–	–	–	–	–	–	–
Total Depreciable Investment	33,122	1,882	964	560	1,002	1,522	1,587	8,684	955	795	88	51,061
Other Costs												
Land	–	–	–	–	–	–	–	892	97	–	–	989
Working Capital (excluded)	–	–	–	–	–	–	–	–	–	–	–	–
Total Capital Investment	$33,122	$1,882	$964	$560	$1,002	$1,522	$1,587	$9,476	$1,052	$795	$88	$52,050 ($153/kW)

Source: Arthur D. Little, Inc., estimates

- Doc. Ex. 9253 -

TABLE 19

DETAILED OPERATING COST ESTIMATE

Plant Name: Allen
Plant Location: Gaston County, North Carolina
Utility Name: Duke Power Company

Operating Load Factor (%): 70
Nameplate Generating Capacity (MW): 1155
Waste Generation (dry metric tons/yr):
Fly Ash 275,000
Bottom Ash 102,000

Operating Costs (thousands of $)

	Area 1100	Area 1200	Area 1300		Area 1400	Area 1500	Area 1600		
	Fly Ash Handling and Processing	Bottom Ash Handling and Processing	Fly Ash Transport	Bottom Ash Transport	Coal Pile Runoff Transport	Miscellaneous Plant Waste Handling and Transport	Placement and Fly Ash Disposal	Placement and Bottom Ash Disposal	Total
Utilities									
Process Water	147.2	220.6	87.3	32.3	–	–	–	–	487.6
Electricity	95.0	296.8	99.2	36.7	76.1	53.1	–	–	656.7
Subtotal	242.2	517.4	186.5	69.0	76.1	53.1	–	–	1,144.3
Operating Labor									
Process Equipment Operator	84.1	36.0	18.0	6.0	4.0	4.0	6.0	2.0	160.1
Chemist	–	–	–	–	–	–	6.8	2.6	9.3
Foreman	7.2	3.1	1.5	0.6	0.3	0.3	0.5	0.2	13.7
Supervisor	7.8	3.4	1.6	0.7	0.4	0.4	0.5	0.2	15.0
Subtotal	99.1	42.5	21.1	7.3	4.7	4.7	13.8	4.9	198.1
Maintenance – (Material and Labor)									
Process Equipment Maintenance	149.8	66.7	315.3	118.6	37.1	39.3	0.5	0.2	716.6
Disposal Site Maintenance	–	–	–	–	–	–	339.3	126.5	464.8
Subtotal	149.8	66.7	315.3	118.6	37.1	39.3	339.8	126.7	1,180.3
Overhead									
General and Administrative Plant Overhead	170.7	60.3	216.3	80.0	25.0	26.3	196.0	72.2	846.8
Capital Charges	554.3	210.7	1,184.4	430.6	138.6	148.6	2,644.3	941.0	6,130.6
Subtotal	725.0	271.0	1,380.7	510.6	163.6	172.9	2,739.3	1,013.2	6,976.3
Total Operating Cost	$1,216.1	$867.6	$1,903.6	$703.5	$281.5	$270.0	$3,092.9	$1,143.8	$9,499.0 ($26.16/dry metric ton)

Basis: Late 1982 Estimates
ENR = 3931.11 (1913 = 100)
= 365.97 (1967 = 100)

Source: Arthur D. Little, Inc., estimates.

TABLE 20

DETAILED OPERATING COST ESTIMATE

Plant Name: Ekonn
Plant Location: Washington County, Pennsylvania
Utility Name: Duquesne Light Company

Operating Load Factor (%): 70
Nameplate Generating Capacity (MW): 520
Waste Generation (dry metric tons/yr):
Fly Ash 196,300
Bottom Ash 49,000
FGD Waste 126,300

Operating Costs (thousands of $)

	Area 2100 Fly Ash Handling and Processing (Dry)	Area 2200 Fly Ash Storage	Area 2300 Bottom Ash Handling and Processing (Wet)	Area 2400 Bottom Ash Transport (Wet)	Area 2500 Bottom Ash Interim Pond	Area 2600 Raw Material Handling and Storage	Area 2700 Fly Ash Handling and Processing (Wet)	Area 2700 FGD Waste Handling and Processing	Area 2900 Fly Ash Transport (Dry)	Area 2900 Bottom Ash Transport (Dry)	Area 2900 FGD Waste Transport (Dry)	Area 2800 Fly Ash Placement and Disposal	Area 2800 Bottom Ash Placement and Disposal	Area 2800 FGD Waste Placement and Disposal	Total
Raw Materials															
Lime	–	–	–	–	–	1 253.0	–	–	–	–	–	–	–	–	1,253.0
Utilities															
Process Water	96.0	9.1	168.6	–	–					–	–	–	–	–	293.7
Electricity	77.6	8.6	107.1	20.7	23.8	7.3	42.2	120.6	–	–	–	–	–	–	407.9
Fuel	–	–	–	–	–	–	–	–	137.4	42.7	86.2	22.6	7.8	16.7	320.5
Subtotal	187.6	8.6	275.7	20.7	23.8	7.3	42.2	120.6	137.4	42.7	86.2	22.6	7.8	16.7	998.1
Operating Labor															
Process Equipment Operator	12.1	24.0	29.6	10.6	3.6	108.8	96.5	234.0	–	–	–	–	–	–	570.3
Mobile Equipment Operator	–	–	–	–	–	–	–	–	287.5	92.8	186.7	51.0	17.2	26.3	660.0
Chemist	–	–	–	–	6.3				–	–	–	4.6	1.6	2.1	15.6
Foreman	4.8	1.7	1.6	0.7	0.3	27.3	23.7	60.2	–	–	–	12.7	4.4	8.9	144.3
Supervisor	9.6	3.2	2.8	1.6	0.6	7.6	6.5	19.0	–	–	–	14.7	5.1	10.2	79.0
Subtotal	86.9	28.9	26.3	12.7	10.8	144.6	126.7	308.2	287.5	92.8	186.7	83.0	28.8	57.5	1,468.2
Maintenance															
(Materials & Labor)	49.2	118.2	63.4	42.8	96.2	27.8	161.4	320.8	368.7	124.8	248.6	106.5	37.6	75.2	1,910.9
Subcontracts															
Dredging	–	–	–	–	277.0	–	–	–	–	–	–	–	–	–	277.0
Overhead															
General and Administrative Plant Overhead	88.5	96.3	61.2	68.6	86.9	112.1	180.2	441.3	227.0	76.1	158.0	100.8	36.1	70.0	1,775.1
Capital Charges	180.8	438.4	198.3	341.3	468.3	102.6	658.7	1,357.9	342.1	118.7	237.4	601.7	174.9	349.1	5,376.2
Subtotal	269.3	534.7	247.5	409.8	534.2	214.8	738.9	1,899.2	570.0	197.8	395.4	602.6	209.1	419.1	7,151.3
Total Operating Cost	$672.9	$689.7	$613.9	$534.1	$941.5	$1,647.2	$1,096.2	$2,808.7	$1,334.6	$463.1	$926.8	$818.7	$283.4	$568.5	$13,063.4
															($32.60/dry metric ton)

Base: Late 1982 Estimates
ENR = 4931.11 (1913 = 100)
365.97 (1967 = 100)

Source: Arthur D. Little, Inc. estimates

TABLE 21

DETAILED OPERATING COST ESTIMATE

Plant Name: Dave Johnston
Plant Location: Converse County, Wyoming
Utility Name: Pacific Power & Light Company

Operating Load Factor (%): 70
Nameplate Generating Capacity (MW): 420
Waste Generation (dry metric tons/yr): Fly Ash -153,000

	Operating Costs (thousands of $)				
	Area 3100	Area 3200	Area 3300	Area 3400	
	Fly Ash Handling and Processing	Fly Ash Storage	Fly Ash Transport	Fly Ash Placement and Disposal	Total
Utilities					
Process Water	–	1.0	–	1.3	2.3
Electricity	280.7	3.3	–	–	284.0
Fuel	–	–	28.3	30.5	58.8
Subtotal	280.7	4.3	28.3	31.8	346.1
Operating Labor					
Process Equipment Operator	48.1	8.0	22.9	–	79.0
Mobile Equipment Operator	–	–	19.6	39.0	58.6
Chemist	–	–	–	9.3	9.3
Foreman	15.1	2.5	12.6	10.8	41.0
Supervisor	4.1	0.7	3.5	3.0	11.3
Subtotal	67.3	11.2	58.6	62.1	199.1
Maintenance (Materials and Labor)					
Process Equipment Maintenance	276.0	104.6	–	0.7	381.2
Mobile Equipment Maintenance	–	–	48.8	54.1	102.9
Disposal Site Maintenance	–	–	–	97.0	97.0
Subtotal	276.0	104.6	48.8	151.8	581.1
Overhead					
General and Administrative Plant Overhead	222.9	75.2	45.4	112.0	455.6
Capital Charges	1,016.1	384.0	193.1	642.4	2,235.6
Subtotal	1,239.0	459.2	238.5	754.4	2,691.1
Total Operating Cost	$1,863.0	$579.2	$374.1	$1,000.1	$3,816.4 ($24.90/dry metric ton)

Basis: Late 1982 Estimates
ENR = 3931.11 (1913 = 100)
= 365.97 (1967 = 100)

Source: Arthur D. Little, Inc., estimates.

TABLE 22

DETAILED OPERATING COST ESTIMATE

Plant Name: Sherburne County
Plant Location: Sherburne County Minnesota
Utility Name: Northern States Power Company

Operating Load Factor (%): 70
Nameplate Generating Capacity (MW): 1456
Waste Generation (dry metric tons/yr):
Fly Ash 267,000
Bottom Ash 110,900
FGD Waste 163,900

Operating Costs (thousands of $)

	Area 4100		Area 4200		Area 4300		Area 4400		Area 4500	Area 4600	Area 4700	Area 4800	Area 4900	
	Fly Ash Handling and Processing	FGD Waste Handling and Processing	Fly Ash Transport	FGD Waste Transport	Fly Ash Placement and Disposal	FGD Waste Placement and Disposal	Fly Ash Recycle Water System	FGD Waste Recycle Water System	Bottom Ash Handling and Processing	Bottom Ash Transport	Bottom Ash Placement and Disposal	Bottom Ash Recycle Water System	Coal Pile Runoff and Plant Waste Handling and Transport	Total
Utilities														
Process Water	–	–	–	–	–	–	1.7	0.7	–	–	–	0.6	–	3.0
Electricity	51.8	20.2	16.0	8.2	–	–	99.0	38.5	–	–	–	73.8	–	306.2
Subtotal	51.8	20.2	16.0	8.2	–	–	100.7	39.2	–	–	–	74.0	–	308.1
Operating Labor														
Process Equipment Operation	193.8	40.4	8.8	3.4	6.3	1.7	17.3	6.7	72.1	24.8	8.0	12.0	4.8	304.3
Chemist	–	–	–	–	5.1	2.1	–	–	–	–	2.4	–	–	9.3
Foreman	9.2	3.6	0.8	0.3	0.4	0.2	1.6	0.6	6.6	2.2	0.6	1.1	0.3	27.5
Supervision	5.1	2.0	0.4	0.2	0.2	0.1	0.9	0.3	3.6	1.2	0.3	0.6	0.1	15.0
Subtotal	118.1	46.0	9.8	3.9	10.0	4.1	19.8	7.6	82.3	27.4	8.8	13.7	4.4	360.1
Maintenance (Materials & Labor)														
Process Equipment Maintenance	413.8	160.9	46.2	18.0	0.4	0.1	105.9	41.2	4.4	39.6	0.2	115.3	2.0	948.2
Disposal Site Maintenance	–	–	–	–	383.4	149.1	–	–	–	–	282.2	–	–	784.7
Dredging	–	–	–	–	–	–	–	–	–	–	59.1	–	–	59.1
Subtotal	413.8	160.9	46.2	18.0	383.8	149.2	105.9	41.2	4.4	39.6	321.5	115.3	2.0	1,892.0
Overhead														
General & Administrative	345.7	134.5	38.6	14.2	266.8	99.7	88.7	31.2	56.4	43.7	178.6	83.7	4.2	1,384.2
Overhead Capital Charges	1,622.7	582.2	190.7	88.0	2,727.1	1,060.8	389.4	151.6	16.3	148.3	1,732.2	416.6	7.2	9,987.0
Subtotal	1,968.4	726.7	206.1	80.7	2,982.6	1,160.6	471.1	183.1	72.7	190.0	1,908.7	500.3	11.4	10,362.1
Total Operating Cost	$2,652.1	$963.8	$278.1	$190.3	$3,376.7	$1,313.8	$697.5	$271.1	$159.4	$257.2	$2,239.2	$703.3	$17.8	$12,626.3 ($26.60/dry metric ton)

Basis: Late 1982 Estimates
ENR = 3831.11 (1913 = 100)
= 365.97 (1967 = 100)

Source: Arthur D. Little, Inc. estimates.

- Doc. Ex. 9257 -

TABLE 23

DETAILED OPERATING COST ESTIMATE

Plant Name: Powerton
Plant Location: Tazewell County, Illinois
Utility Name: Commonwealth Edison Company

Operating Load Factor (%): 70
Nameplate Generating Capacity (MW): 1700
Waste Generation (dry metric tons/yr):
Fly Ash 300,000
Slag 472,000

	Operating Costs (thousands of $)										
	Area 6100	Area 6200	Area 6300	Area 6400	Area 6600		Area 6800		Area 6700	Area 6900	
	Fly Ash Handling and Processing (Dry)	Fly Ash Storage	Slag Handling and Processing (Wet)	Fly Ash Handling and Processing (Wet)	Fly Ash Transport (Dry)	Slag Transport (Dry)	Fly Ash Placement and Disposal	Slag Placement and Disposal	Slag Recycle Water System	Miscellaneous Wastes Handling and Transport	Total
Utilities											
Process Water	–	0.6	141.0	18.0	–	–	–	–	–	–	159.6
Electricity	36.1	15.3	109.9	3.7	–	–	–	–	12.4	0.3	177.7
Fuel	–	–	–	–	48.2	75.4	17.9	28.1	–	–	169.6
Subtotal	36.1	15.9	250.9	21.7	48.2	75.4	17.9	28.1	12.4	0.3	506.9
Operating Labor											
Process Equipment											
Operator	96.1	16.0	72.1	4.0	8.9	14.0	–	–	8.0	8.0	227.1
Mobile Equipment											
Operator	–	–	–	–	101.4	158.6	60.7	78.3	–	–	399.0
Chemist	–	–	–	–	–	–	3.6	6.7	–	–	9.3
Foreman	3.9	0.6	3.0	0.2	0.4	0.6	7.6	11.9	0.3	0.3	28.7
Supervisor	8.7	1.1	6.0	0.3	0.6	1.0	1.4	2.3	0.6	0.6	19.6
Subtotal	108.7	17.7	80.1	4.6	111.3	174.1	83.3	99.2	8.9	8.9	674.7
Maintenance (Materials & Labor)	73.9	241.1	246.3	9.6	129.4	202.6	903.6	1,413.2	66.4	96.3	3,379.0
Overhead											
General and Administrative Overhead	117.3	188.2	211.6	9.1	91.8	143.6	606.8	949.1	48.3	67.7	2,413.3
Capital Charges	272.0	886.0	901.6	35.0	109.8	171.5	4,661.8	7,135.0	240.3	350.4	14,663.2
Subtotal	389.3	1,054.2	1,113.1	44.1	201.4	315.0	5,168.6	8,084.1	288.6	418.1	17,076.5
Total Operating Cost	$606.9	$1,328.9	$1,689.4	$79.8	$490.3	$767.0	$6,163.3	$9,624.6	$375.3	$522.6	$21,637.1 ($28.00/dry metric ton)

Basis: Late 1982 Estimates
ENR = 3931.11 (1913 = 100)
= 365.97 (1967 = 100)

Source: Arthur D. Little, Inc., estimates.

- Doc. Ex. 9258 -

TABLE 24

DETAILED OPERATING COST ESTIMATE

Plant Name: Smith
Plant Location: Bay County, Florida
Utility Name: Gulf Power Company

Operating Load Factor (%): 70
Nameplate Generating Capacity (MW): 340
Waste Generation (dry metric tons/yr):
Fly Ash 109,000
Bottom Ash 12,500

Operating Costs (thousands of $)

	Area 6100		Area 6200		Area 6300	Area 6400	Area 6500		Area 6600		
	Fly Ash Transport	Fly Ash Handling and Processing	Bottom Ash Transport	Bottom Ash Handling and Processing	Coal Pile Runoff Handling and Transport	Miscellaneous Plant Waste Handling and Transport	Fly Ash Placement and Disposal	Bottom Ash Placement and Disposal	Fly Ash Recycle Water System	Bottom Ash Recycle Water System	Total
Utilities	0.8	1.6	0.2	0.4	–	–	–	–	–	–	3.1
Process Water	41.9	81.4	6.2	10.9	2.9	7.7	–	–	18.5	2.1	171.6
Electricity	42.8	83.0	6.4	11.3	2.9	7.7	–	–	18.5	2.1	174.7
Subtotal											
Operating Labor	12.2	23.6	8.6	16.4	4.0	4.0	7.2	0.8	10.8	1.2	88.0
Process Equipment Operator	–	–	–	–	–	–	8.4	0.9	–	–	9.3
Chemist	1.9	3.7	1.3	2.4	0.6	0.6	1.1	0.1	1.7	0.2	13.6
Foreman	2.1	4.0	1.4	2.6	0.7	0.7	1.3	0.1	1.9	0.2	15.0
Supervisor	16.2	31.5	11.3	20.4	5.3	5.3	18.0	1.9	14.4	1.6	125.9
Subtotal											
Maintenance (Materials & Labor)	38.7	75.1	22.5	40.0	60.9	63.5	0.6	0.1	31.8	3.6	336.7
Process Equipment Maintenance	–	–	–	–	–	–	134.0	14.9	–	–	148.9
Disposal Site	38.7	75.1	22.5	40.0	60.9	63.5	134.6	15.0	31.8	3.6	485.6
Subtotal											
Overhead											
General and Administrative	35.9	69.7	22.0	39.2	43.0	44.7	99.2	11.0	30.0	3.3	393.0
Plant Overhead	142.3	276.1	82.7	146.9	223.7	233.3	1,183.5	131.5	116.8	13.0	2,549.8
Capital Charges	178.2	345.9	104.7	186.1	266.7	278.0	1,282.7	142.5	146.8	16.3	2,947.8
Subtotal											
Total Operating Cost	$275.9	$535.4	$144.9	$257.8	$335.0	$354.5	$1,435.3	$159.4	$211.5	$23.5	$3,734.0 ($39.76/dry metric ton)

Basis: Late 1982 Estimates
ENR 3931.11 (1913 = 100)
÷ 385.97 (1967 = 100)

Source: Arthur D. Little, Inc., estimates.

APPENDIX H

ENVIRONMENTAL MATRIX EVALUATIONS

FULL-SCALE FIELD EVALUATION OF WASTE DISPOSAL FROM COAL-FIRED ELECTRIC GENERATING PLANTS

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APPENDIX H

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1 Introduction

Table 1, reproduced here from the main body of the report, presents a matrix of the sixty possible combinations of waste types, disposal methods and environmental settings that were considered in this study. In the subsequent section of this Exhibit, each matrix combination is discussed. The combinations are organized for discussion in accordance with the five categories of environmental settings.

TABLE 1

MATRIX SUMMARY OF INFORMATION AVAILABLE FOR COMBINATIONS OF WASTE TYPES, DISPOSAL METHODS, AND ENVIRONMENTAL SETTINGS

	Fly Ash[1]	Non-Fly Ash[2] Bo., FGD	Processed FGD	Dry FGD	Fly Ash[1]	Non-Fly Ash[2] Bo., FGD	Processed FGD	Dry FGD	Fly Ash[1]	Non-Fly Ash[2] Bo., FGD	Processed FGD	Dry FGD
COASTAL SETTING	X Smith	P	NA	NA	X/P[3] Chesapeake Cr. (USWAG)	P	P	NA	P	P	P	P[4]
ARID WESTERN SETTING: Not Highly Mineralized	P	P	NA	NA	P	P	P	NA	P	P	P	P[4]
ARID WESTERN SETTING: Highly Mineralized	P	P	NA	NA	P	P	P	NA	X Dave Johnston; North Dakota (DOE/EPA)	P	P	P[4]
INTERIOR SETTING: Not Highly Acidic	X Allen, Shawnee, Michigan City (USWAG), Wallingford (USWAG)	P	X Bruce Mansfield	NA	X/P[3] Bailly (USWAG)	P	P	NA	X Paterson, Zwillinger (USWAG) Burns Brook (USWAG) Hunlock (DOE)	P	X Greenville (EPRI/USWAG)	P[4]
INTERIOR SETTING: Highly Acidic (mine drainage)	P	P	P	NA	P	P	P	NA	P	P	X Elrama	P[4]

Notes: 1. Includes co-disposal of fly ash with other wastes.
2. Includes FGD wastes without fly ash, and bottom ash.
3. Either the interim pond or landfill aspect of operation studied at field scale, but not both.
4. Lab data only.

Key: X = Data available from full-scale field studies.
P = Data available from laboratory and/or limited-scale field studies for projection purposes.
NA = Matrix combination not applicable due to lack of present and future practice.

2 Combinations in Coastal Settings

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Fly Ash Waste, Pond Disposal, Coastal Setting

Summary of Effects Implications:

- A prevalent combination today, expected to remain important in future, especially with coal conversions (1).
- Leachate quality comparable in major species composition to tidally-influenced background waters (2)(3)(4).
- Leachate can have sufficiently elevated levels of leachable trace metals (e.g., As, Se) to be of concern in minority of cases (2)(3)(20).
- Heavy precipitation and pervious soils promote rapid leachate generation and movement (1)(4).
- Extensive admixing with tidally-influenced surface waters and near-surface aquifers mitigates against adverse impacts from major dissolved species; secondary drinking water standards are of little as no applicability in the receiving waters (4).
- Chemical attenuation of trace metals in soils can be expected case-by-case in some, but not all, of the prevalent soil types (1)(6).
- In minority of cases where elevated concentrations of As or Se may prevail, mitigation may be achieved by selection of a site set in attenuative soil, or placement of such soil as a site liner.

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Non-Fly Ash Waste (FGD, Bottom Ash), Pond Disposal, Coastal Setting

Summary of Effects Implications:

- Limited combination in practice today; some possible in future (1).
- Leachate quality comparable in major species composition to tidally-influenced background waters (2)(3)(4)(5)(6).
- Leachate can have sufficiently elevated levels of leachable trace metals (As, Se) to be of concern in minority of cases (5)(6).
- Heavy precipitation and pervious coastal soils promote rapid leachate generation and movement (1)(4).
- Extensive admixing with tidally-influenced surface waters and near-surface aquifers mitigates against adverse impacts from major dissolved species; secondary drinking water standards are of little or no applicability in the receiving waters (4).
- Chemical attenuation of trace metals in soils can be expected case-by-case in some, but not all, of the prevalent soil types (1)(7).
- In minority of cases, where elevated concentrations of As or Se may prevail, mitigation may be achieved by selection of a site set in attenuative soil, or placement of such soil as a site liner.

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Fly Ash Waste, Landfill Disposal, Coastal Setting

Summary of Effects Implications:

- Not presently prevalent, expected to become more prevalent in future (1).
- Leachate quality comparable in major species composition to tidally-influenced background waters (2)(3)(4)(13)(16).
- Leachate can have sufficiently elevated levels of leachable trace metals (e.g., As, Se) to be of concern in minority of cases (11)(13)(16).
- Heavy precipitation and pervious coastal soils promote rapid leachate generation and movement (1)(4)(7).
- Extensive admixing with tidally-influenced surface waters and near-surface aquifers mitigates against adverse impacts for major dissolved species; secondary drinking water standards of little or no applicability in the receiving water (4).
- Chemical attenuation of trace metals in soils can be expected case-by-case in some, but not all, of the prevalent soil types (1)(7).
- In minority of cases, where elevated concentrations of As or Se may prevail, mitigation may be achieved by selection of a site set in attenuative soil, or by placement of such soil as a site liner.

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Fly Ash Waste, Interim Pond-Landfill Disposal, Coastal Setting

Summary of Effects Implications:

- An uncommon but existing practice at present expected to be possible but not prevalent in future (1).
- Leachate quality comparable in major species composition to tidally-influenced background waters (2)(3)(4).
- Leachate from pond and landfill can have sufficiently elevated levels of leachable trace metals (e.g., As, Se) to be of concern in minority of cases (2)(3)(6).
- Heavy precipitation and pervious soils promote rapid leachate generation and movement for both pond and landfill (1)(4)(6).
- Extensive admixing with tidally-influenced surface waters and near-surface aquifers mitigates against adverse impacts from major dissolved species; secondary drinking water standards are of little or no applicability in the receiving waters (4).
- Chemical attenuation of trace metals in soils can be expected case-by-case in some, but not all, of the prevalent soil types (1)(6).
- In minority of cases where elevated concentrations of As or Se may prevail, mitigation may be achieved by selection of sites set in attenuative soil, or placement of such soil as site liners.

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Non-Fly Ash (Bottom Ash, FGD) Waste, Interim Pond-Landfill Disposal, Coastal Setting

Summary of Effects Implications:

- An uncommon practice, expected to be possible but not prevalent in future (1).
- Leachate quality comparable in major species composition to tidally-influenced background waters (1)(3)(4)(5)(6).
- Leachate can have sufficiently elevated levels of leachable trace metals (As, Se) to be of concern in minority of cases (5)(6).
- Heavy precipitation and pervious coastal soils promote rapid leachate generation and movement for both pond and landfill (1)(4)(7).
- Extensive admixing with tidally-influenced surface waters and near-surface aquifers mitigates against adverse impacts from major dissolved species; secondary drinking water standards of little or no applicability in the receiving waters (4).
- Chemical attenuation of trace metals in soils can be expected case-by-case in some, but not all, of the prevalent soil types (1)(7).
- In minority of cases, where elevated concentrations of As or Se may prevail, mitigation may be achieved by selection of a site set in attenuative soil, or placement of such soil as a site liner.

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Processed FGD Waste, Interim Pond-Landfill Disposal, Coastal Setting

Summary of Effects Implications:

- Not presently practiced, expected to be possible but not likely in future (1).
- Leachate quality comparable in major species composition to tidally-influenced background waters (2)(3)(4)(5)(6)(8)(9)(10).
- Leachate can have sufficiently elevated levels of leachable trace metals (e.g., As, Se) to be of concern in minority of cases (5)(6)(8)(9)(10).
- Heavy precipitation and pervious coastal soils promote rapid leachate generation and movement for both pond and landfill (1)(4)(7).
- Extensive admixing with tidally-influenced surface waters and near-surface aquifers mitigates against adverse impacts from major dissolved species; secondary drinking water standards of little or no applicability in the receiving waters (4).
- Chemical attenuation of trace metals in soils can be expected case-by-case in some, but not all, of the prevalent soil types (1)(7).
- In minority of cases, where elevated concentrations of As or Se may prevail, mitigation may be achieved by selection of a site set in attenuative soil, or by placement of such soil as a site liner.

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Non-Fly Ash Waste (Bottom, Ash, FGD), Landfill Disposal, Coastal Setting

Summary of Effects Implications:

- Not presently prevalent, may exist in future (1).
- Leachate quality comparable in major species composition to tidally-influenced background waters (2)(3)(4)(5)(6)(10).
- Leachate can have sufficiently elevated levels of leachable trace metals (e.g., As, Se) to be of concern in minority of cases (2)(3)(5)(6)(10).
- Heavy precipitation and pervious coastal soils promote rapid leachate generation and movement (1)(4)(7).
- Extensive admixing with tidally-influenced surface waters and near-surface aquifers mitigates against adverse impacts for major dissolved species; secondary drinking water standards of little or no applicability in the receiving water (4).
- Chemical attenuation of trace metals in soils can be expected case-by-case on some, but not all, of the prevalent soil types (1)(7).
- In minority of cases, where elevated concentrations of As or Se may prevail, mitigation may be achieved by selection of a site set in attenuative soil, or by placement of such soil as a site liner.

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Processed FGD Waste, Landfill Disposal, Coastal Setting

Summary of Effects Implications:

- Not presently practiced, may exist in future (1).
- Leachate quality comparable in major species composition to tidally-influenced background water (2)(3)(4)(5)(6)(8)(9)(10).
- Leachate can have sufficiently elevated levels of leachable trace metals (e.g., As, Se) to be of concern in minority of cases (5)(6)(8)(9)(10).
- Heavy precipitation and pervious coastal soils promote rapid leachate generation and movement (1)(4)(7).
- Extensive admixing with tidally-influenced surface waters and near-surface aquifers mitigates against adverse impacts for major dissolved species; secondary drinking water standards of little or no applicability in the receiving water (4).
- Chemical attenuation of trace metals in soils can be expected case-by-case in some, but not all, of the prevalent soil types (1)(7).
- In minority of cases, where elevated concentrations of As or Se may prevail, mitigation may be achieved by selection of a site set in attenuative soil, or by placement of such soil as a site liner.

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Dry FGD Waste, Landfill Disposal, Coastal Setting

Summary of Effects Implications:

- Not presently practiced, may exist in future (1)(3).
- Leachate quality comparable in major species composition to tidally-influenced background waters (5)(25).
- Leachate can have sufficiently elevated levels of leachable trace metals to be of concern in minority of cases (25).
- Heavy precipitation and pervious coastal soils promote rapid leachate generation and movement (1)(4)(7).
- Extensive admixing with tidally-influenced surface waters and near-surface aquifers mitigates against adverse impacts for major dissolved species; secondary drinking water standards of little or no applicability in the receiving water (4).
- Chemical attenuation of trace metals in soils can be expected case-by-case in some, but not all, of the prevalent soil types (1)(7).
- In minority of cases, where elevated concentrations of As or Se may prevail, mitigation may be achieved by selection of a site set in attenuative soil, or by placement of such soil as a site liner.

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Dry FGD Waste, Interim Pond-Landfill Disposal, Coastal Setting

Summary of Effects Implications:

Combination not presently applicable and not envisioned in future because of incongruity between production of dry FGD wastes and pond disposal.

Documentation: Not applicable.

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Dry FGD Waste, Pond Disposal, Coastal Setting

Summary of Effects Implications:

Combination not presently applicable and not envisioned in future because of incongruity between production of dry FGD wastes and pond disposal.

Documentation: Not applicable.

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Processed FGD Waste, Pond Disposal, Coastal Setting

Summary of Effects Implications:

Combination not presently applicable and not envisioned in future because of infeasibility of locating required size impoundments in coastal zone.

Documentation: Not applicable.

3 Combinations in Arid Settings: Not Highly Mineralized

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Fly Ash, Pond Disposal, Arid Western Setting (not highly mineralized)

Summary of Effects Implications:

- Practice employed at present, expected to be less prevalent in future (1).
- Leachate can be expected to have sufficiently elevated levels of leachable major species (e.g., sulfate) to be of potential concern with respect to secondary drinking water standards (2)(3)(11)(12)(13)(21).
- Leachate can have sufficiently elevated levels of leachable trace metals (e.g., As, Se) to be of concern in minority of cases (2)(3)(11)(12)(13)(21).
- Pond head can promote leaching, but minimal precipitation, high net evaporation and general absence of significant near-surface groundwater generally reduce the opportunities for leachate generation and movement (1)(12).
- Opportunities for admixing also generally reduced by lack of water (1).
- Chemical attenuation of trace metals in soils can be expected case-by-case in some, but not all, of the prevalent soil types (1)(11)(12).
- In extreme minority of cases, where elevated concentrations of major and/or minor leachate species could reach a small, immediately adjacent, usable surface water body or drinking water supply, mitigation may be achieved by selection of alternative disposal locations or lining of the disposal pond.

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Non-Fly Ash (Bottom Ash, FGD), Pond Disposal, Arid Western Setting (not highly mineralized)

Summary of Effects Implications:

- Practice employed at present and expected in future (1).
- Leachate can be expected to have sufficiently elevated levels of leachable major species (e.g., sulfate, chloride) to be of potential concern with respect to secondary drinking water standards (2)(3)(11)(21).
- Leachate can have sufficiently elevated levels of leachable trace metals (e.g., As, Se) to be of concern in minority of cases (2)(3)(11)(21).
- Pond head can promote leaching, but minimal precipitation, high net evaporation and general absence of significant near-surface groundwater generally reduce the opportunities for leachate generation, movement and admixing (1)(12).
- Chemical attenuation of trace metals in soils can be expected case-by-case in some, but not all, of the prevalent soil types (1)(11)(12).
- In the extreme minority of cases, where elevated concentrations of major and/or minor leachate species could reach a small, immediately adjacent, usable surface water body or drinking water supply, mitigation can be achieved by selection of alternative disposal locations or lining of the disposal pond.

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Fly Ash Waste, Interim Pond-Landfill Disposal/Arid Western Setting (not highly mineralized)

Summary of Effects Implications:

- Practice employed at present, expected to be less prevalent in future (1).
- Leachate can be expected to have sufficiently elevated levels of leachable major species (e.g., sulfate) to be of potential concern with respect to secondary drinking water standards (2)(3)(11)(12)(13)(21).
- Interim pond head can promote leaching, but minimal precipitation, high net evaporation and general absence of significant near-surface groundwater generally reduce the opportunities for leachate generation, movement and admixing, especially for the landfill (1)(12).
- Chemical attenuation of trace metals in soils can be expected case-by-case in some, but not all of the prevalent soil types (1)(11)(1[illegible].
- In the extreme minority of cases, where elevated concentrations of major and/or minor leachate species could reach a small, usable surface water body or drinking water supply immediately adjacent to an interim pond, mitigation may be achieved by selection of alternative disposal location or lining of the disposal site.

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Non-Fly Ash Waste (Bottom Ash, FGD Waste), Interim Pond-Landfill Disposal, Arid Western Setting (not highly mineralized)

Summary of Effects Implications:

- Practice employed at present, expected to be less prevalent in future (1).
- Leachate can be expected to have sufficiently elevated levels of leachable major species (e.g., sulfate, chloride) to be of potential concern with respect to secondary drinking water standards (2)(3)(11)(21).
- Leachate can have sufficiently elevated levels of trace metals (e.g., As, Se) to be of concern in minority of cases (2)(3)(11)(21).
- Interim pond head can promote leaching, but minimal precipitation, high net evaporation and general absence of significant near-surface groundwater generally reduce the opportunities for leachate generation, movement and admixing (1)(2).
- Chemical attenuation of trace metals in soils can be expected case-by-case in some, but not all, of the prevalent soil types (1)(11)(12).
- In the extreme minority of cases, where elevated concentrations of leachate species could reach a small, usable surface water body or drinking water supply immediately adjacent to an interim pond, mitigation can be achieved by selection of alternative disposal locations, or lining of the disposal site.

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Processed FGD Waste, Interim Pond-Landfill Disposal, Arid Western Setting (not highly mineralized)

Summary of Effects Implications:

- Practice not employed at present, possible but not expected to be prevalent in future (1).
- Leachate can be expected to have sufficiently elevated levels of leachable major species (e.g., sulfate) to be of potential concern with respect to secondary drinking water standards (2)(3)(5)(6)(8)(9)(10).
- Leachate can have sufficiently elevated levels of trace metals (e.g., As, Se) to be of concern in minority of cases (2)(3)(5)(6)(8)(9)(10).
- Interim pond head can promote leaching, but minimal precipitation, high net evaporation and general absence of significant near-surface groundwater generally reduce to acceptable levels the opportunities for leachate generation, movement, and admixing (1)(12).
- Chemical attenuation of trace metals in soils can be expected case-by-case in some, but not all, of the prevalent soil types (1)(11)(12).
- In the extremely rare case, where elevated concentrations of leachate species could reach a small, usable surface water body or drinking water supply immediately adjacent to an interim pond, mitigation can be achieved by selection of alternative disposal locations, or lining of the disposal site.

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Fly Ash Waste, Landfill Disposal, Arid Western Setting (not highly mineralized)

Summary of Effects Implications:

- Presently important practice, expected to be prevalent in future (1).
- Leachate can be expected to have sufficiently elevated levels of leachable major species (e.g., sulfate) to be of potential concern with respect to secondary drinking water standards (2)(3)(11)(12)(13).
- Leachate can have sufficiently elevated levels of trace metals (e.g., As, Se) to be of concern in minority of cases (2)(3)(11)(12)(13).
- Combination of dry disposal method with minimal precipitation, high net evaporation, and general absence of significant near-surface groundwater reduces opportunities for leachate generation, movement and admixing to a minimum (1)(11)(12).
- Chemical attenuation of trace metals in soils can be expected case-by-case in some, but not all, of the prevalent soil types (1)(11)(12).
- Opportunities for adverse impact are extremely rare, would be restricted to instances where landfill was actually developed in direct proximity to a usable drinking water supply. This circumstance could be mitigated by alternative disposal site selection or site lining.

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Non-Fly Ash (Bottom Ash, FGD) Waste, Landfill Disposal, Arid Western Setting (not highly mineralized)

Summary of Effects Implications:

- Uncommon practice, expected to exist but not be prevalent in future (1).
- Leachate can be expected to have sufficiently elevated levels of leachable major species (e.g., sulfate, chloride) to be of potential concern with respect to secondary drinking water standards (2)(3)(5)(6)(11).
- Leachate can have sufficiently elevated levels of trace metals (e.g., As, Se) to be of concern in minority of cases (2)(3)(5)(6)(11).
- Combination of dry disposal method with minimal precipitation, high net evaporation, and general absence of significant near-surface groundwater reduces opportunities for leachate generation, movement and admixing to a minimum (1)(11)(12).
- Chemical attenuation of trace metals in soils can be expected case-by-case in some, but not all, of the prevalent soil types (1)(11)(12).
- Opportunities for adverse impact are extremely rare, would be restricted to instances where landfill was actually developed in direct proximity to a usable drinking water supply. This circumstance could be mitigated by alaternative disposal site selection or site lining.

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Processed FGD Waste, Landfill Disposal, Arid Western Setting (not highly mineralized)

Summary fo Effects Implications:

- Not presently practiced, possible in future.
- Leachate can be expected to have sufficiently elevated levels of leachable major species (e.g., sulfate) to be of potential concern with respect to secondary drinking water standards (2)(3)(5)(6)(8)(9)(10)(11).
- Leachate can have sufficiently elevated levels of trace metals (e.g., As, Se) to be of concern in minority of cases (2)(3)(5)(6)(8)(9)(10)(11).
- Combination of dry disposal method with minimal precipitation, high net evaporation, and general absence of significant near-surface groundwater reduces opportunities for leachate generation, movement, and admixing to a minimum (1)(11)(12).
- Chemical attenuation of trace metals in soils can be expected case-by-case in some, but not all, of the prevalent soil types (1)(11)(12).
- Opportunities for adverse impact are extremely rare, would be restricted to instances where landfill was actually developed in direct proximity to a usable drinking water supply. This circumstance could be mitigated by alternative disposal site selection or site lining.

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Dry FGD Waste, Landfill Disposal, Arid Western Setting (not highly mineralized)

Summary of Effects Implications:

- Practice achieving commercialization, expected to become more prevalent in future (1)(3).
- Leachate can be expected to have sufficiently elevated levels of leachable major species (e.g., sulfate) to be of potential concern with respect to secondary drinking water standards (3)(25).
- Leachate can have sufficiently elevated levels of trace metals (e.g., As, Se) to be of concern in minority of cases (3)(25).
- Combination of dry disposal method with minimal precipitation, high net evaporation, and general absence of significant near-surface groundwater reduces opportunities for leachate generation, movement, and admixing to a minimum (1)(11)(12).
- Chemical attenuation of trace metals in soils can be expected case-by-case in some, but not all, of the prevalent soil types (1)(11)(12).
- Opportunities for adverse impact are extremely rare, would be restricted to instances where landfill was actually developed in direct proximity to a usable drinking water supply. This circumstance could be mitigated by alternative disposal site selection or site lining.

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Dry FGD Waste, Interim Pond-Landfill Disposal, Arid Western Setting (not highly mineralized)

Summary of Effects Implications:

Combination not presently applicable and not envisioned in future because of incongruity between production of dry FGD wastes and pond disposal.

Documentation: Not applicable.

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Dry FGD Waste, Pond Disposal, Arid Western Setting (not highly mineralized)

Summary of Effects Implications:

Combination not presently applicable and not envisioned in future because of incongruity between production of dry FGD wastes and pond disposal.

Documentation: Not applicable.

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Processed FGD Waste, Pond Disposal, Arid Western Setting (not highly mineralized)

Summary of Effects Implications:

Combination not presently applicable and not envisioned in future because of impracticality of fulfilling the extraordinary water requirements in an arid setting.

Documentation: Not applicable.

4 Combinations in Arid Settings: Highly Mineralized

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Fly Ash Waste, Pond Disposal, Arid Western Setting (highly mineralized)

Summary of Effects Implicated:

- Practiced at present, expected to become less prevalent in future (1).
- Leachate quality comparable in major species composition to highly mineralized background waters (1)(12)(13)(21).
- Leachate can have sufficiently elevated levels of trace metals (e.g., As, Se) to be of concern in minority of cases (1)(12)(13)(21).
- Pond head can promote leaching, but minimal precipitation, high net evaporation, and general absence of significant near-surface groundwater generally reduce the opportunities for leachate generation, movement, and admixing (1)(11)(12).
- Admixing with highly mineralized background waters effectively mitigates potential for adverse impacts of major leachate species on surface or groundwater (12).
- Chemical attenuation of trace metals in soils can be expected case-by-case in some, but not all, of the prevalent soil types (1)(11)(12).
- Opportunities for adverse impact are extremely rare, would be restricted to instances where disposal area with extremely high leachable trace metal concentrations (e.g., As or Se) is actually developed in direct proximity to water used for other purposes (e.g., livestock, fisheries). This circumstance could be mitigated by alternative disposal site selection or site lining.

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Non-Fly Ash Waste (Bottom Ash, FGD), Pond Disposal, Arid Western Setting (highly mineralized)

Summary of Effects Implications:

Same as for Fly Ash Waste, Pond Disposal, Arid Western Setting (highly mineralized), including same documentation.

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Fly Ash Waste, Interim Pond-Landfill Disposal, Arid Western Setting (highly mineralized)

Summary of Effects Implications:

Same as for Fly Ash Waste, Pond Disposal, Arid Western Setting (highly mineralized), including same documentation.

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Non-Fly Ash Waste, Interim Pond-Landfill Disposal, Arid Western Setting (highly mineralized)

Summary of Effects Implications:

- Practice possible but unlikely [1].
- Other points and references same as for Fly Ash Waste/Pond Disposal/Arid Western Setting (highly mineralized).

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Processed FGD Waste, Interim Pond-Landfill Disposal, Arid Western Setting (highly mineralized)

Summary of Effects Implications:

- Not practiced at present, possible but unlikely in future (1).
- Leachate quality comparable in major species composition to highly mineralized background waters (2)(3)(5)(6)(8)(9)(10)(11)(12).
- Leachate can have sufficiently elevated levels of trace metals (e.g., As, Se) to be of concern in minority of cases (2)(3)(5)(6)(8)(9)(10)(11)(12).
- Remaining points and references same as final four points for Fly Ash Waste, Pond Disposal, Arid Western Setting (highly mineralized).

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Fly Ash Waste, Landfill Disposal, Arid Western Setting (highly mineralized)

Summary of Effects Implications:

- Important practice at present, expected to be more prevalent in future (1).
- Leachate quality comparable in major species composition to highly-mineralized background waters (2)(3)(11)(12)(13).
- Leachate can have sufficiently elevated levels of trace metals (e.g., As, Se) to be of concern in minority of cases (2)(3)(11)(12)(13).
- Combination of dry disposal method with minimal precipitation, high net evaporation, and general absence of significant near-surface groundwater reduces opportunities for leachate generation, movement and admixing to a minimum (1)(11)(12).
- Admixing with highly mineralized background waters effectively mitigates remaining potential for adverse impacts of major leachate species on surface as groundwater (12).
- Chemical attenuation of trace metals in soils can be expected case-by-case in some, but not all, of the prevalent soil types (1)(11)(12).
- Opportunities for adverse impact are extremely rare, would be restricted to instances where a landfill of wastes with extremely high levels of leachable trace metals (e.g., As, Se) was actually developed in direct proximity to water used for other purposes (e.g., livestock, fisheries). This circumstance could be mitigated by alternative disposal site selection or site lining.

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Non-Fly Ash Waste (Bottom Ash, FGD), Landfill Disposal, Arid Western Setting (highly mineralized)

Summary of Effects Implications:

- Rare practice at present, expected to be possible but not prevalent in future (6).
- Remaining points and references same as for Fly Ash Waste, Landfill Disposal, Arid Western Setting (highly mineralized).

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Processed FGD Waste, Landfill Disposal, Arid Western Setting (highly mineralized)

Summary of Effects Implications:

- Not practiced at present, possible in future (1).
- Leachate quality comparable in major species composition to highly mineralized background waters (2)(3)(5)(6)(8)(9)(10)(11)(12).
- Leachate can have sufficiently elevated levels of trace metals (e.g., As, Se) to be of concern in minority of cases (2)(3)(5)(6)(8)(9)(10)(11)(12).
- Remaining points and references the same as last 4 points for Fly Ash Waste, Landfill Disposal, Arid Western Setting (highly mineralized).

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Dry FGD Waste, Landfill Disposal, Arid Western Setting (highly mineralized)

Summary of Effects Implications:

- Presently in early stage of commercial practice, expected to be of future importance (1)(3).
- Leachate quality comparable in major species composition to highly mineralized background waters (3)(12)(25).
- Leachate can have sufficiently elevated levels of trace metals (e.g., As, Se) to be of concern in minority of cases (25).
- Remaining points and references same as final 4 points for Fly Ash Waste, Landfill Disposal, Arid Western Setting (highly mineralized).

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Dry FGD Waste, Interim Pond-Landfill Disposal, Arid Western Setting (highly mineralized)

Summary of Effects Implications:

Combination not presently applicable and not envisioned in future because of incongruity between production of dry FGD wastes and pond disposal.

Documentation: Not applicable.

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Dry FGD Waste, Pond Disposal, Arid Western Setting (highly mineralized)

Summary of Effects Implications:

Combination not presently applicable and not envisioned in future because of incongruity between production of dry FGD wastes and pond disposal.

Documentation: Not applicable.

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Processed FGD Waste, Pond Disposal, Arid Western Setting (highly mineralized)

Summary of Effects Implications:

Combination not presently applicable and not envisioned in future because of impracticality of fulfilling the extraordinary water requirements in an arid setting.

Documentation: Not applicable.

5 Combinations in Typical Interior Settings

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Fly Ash Waste, Pond Disposal Interior Setting (not highly acidic)

Summary of Effects Implications:

- Single most prevalent existing practice, expected to remain important (1).
- Leachate can be expected to have sufficiently elevated levels of major species (e.g., sulfate) to be of potential concern with respect to secondary drinking water standards (2)(3)(13)(14)(16)(17)(21)(22).
- Leachate can have sufficiently elevated levels of trace metals (e.g., As, Se) to be of concern in minority of cases (2)(3)(14)(16)(17)(19)(21)(22).
- Pond head can promote leaching; typical range of interior climatic and hydrogeologic conditions can provide opportunities for waste leachates to effect measurable downgradient groundwater quality (1)(8)(13)(17)(19)(21)(22).
- Admixing with even small surface water bodies can have major dilution impact, mitigating potential leachate impacts on surface water and groundwater quality (13)(15)(17)(23).
- Chemical attenuation of trace metals in soils can be expected case-by-case in some, but not all, of the prevalent soil types (1)(13)(17)(19)(21)(22).
- Opportunities for adverse impact would be expected in instances where disposal site is developed in pervious, non-attenuative soil in proximity to a useful groundwater supply; this circumstance could be mitigated by selection of a site set in relatively impermeable, chemically attenuative soil, or placement of such soil as a site liner.

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Non-Fly Ash Waste (Bottom Ash, FGD), Pond Disposal, Interior Setting (not highly acidic)

Summary of Effects Implications:

- Common practice, expected to remain so in future (1).
- Leachate can be expected to have sufficiently elevated levels of major species (e.g., sulfate) to be of potential concern with respect to secondary drinking water standards (2)(3)(5)(6)(10)(11)(21).
- Leachate can have sufficiently elevated levels of trace metals (e.g., As, Se) to be of concern in minority of cases (2)(3)(5)(6)(10)(11)(21).
- Remaining points and references some as final 4 points for Fly Ash Waste.

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Processed FGD Waste, Pond Disposal, Interior Setting (not highly acidic)

Summary of Effects Implications:

- Existing but rare practice, expected to remain so in future (1).
- Leachate can be expected to have sufficiently elevated levels of major species (e.g., sulfate) to be of potential concern with respect to secondary drinking water standards (2)(3)(5)(18).
- Leachate can have sufficiently elevated levels of trace metals (e.g., As, Se) to be of concern in minority of cases (2)(3)(5).
- Size of ponds (can be greater than 1,000 acres) and high major species concentrations requires larger mixing volumes in receiving waters to achieve dilution by admixing comparable to that typical of other disposal combinations (18).
- Remaining points and references same as final 4 points for Fly Ash Waste, Pond Disposal, Interior Setting (not highly acidic).

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Fly Ash Waste, Interim Pond-Landfill Disposal, Interior Setting (not highly acidic)

Summary of Effects Implications:

- Common practice at present, expected to be less prevalent in future [1].
- Remaining points and references same as final 6 points for Fly Ash Waste, Pond Disposal, Interior Setting (not highly acidic).

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Non-Fly Ash Waste (Bottom Ash, FGD Waste), Interim Pond-Landfill Disposal, Interior Setting (not highly acidic)

Summary of Effects Implications:

- Common practice for bottom ash, rare for FGD waste; expected to become less prevalent in future (1).
- Leachate can be expected to have sufficiently elevated levels of major species (e.g., sulfate) to be of potential concern with respect to secondary drinking water standards (2)(3)(5)(6)(10)(11)(21).
- Leachate can have sufficiently elevated levels of trace metals (e.g., As, Se) to be of concern in minority of cases (2)(3)(5)(6)(10)(11)(21).
- Remaining points and references same as final 4 points for Fly Ash Waste, Pond Disposal, Interior Setting (not highly acidic).

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Processed FGD Waste, Interim Pond-Landfill Disposal, Interior Setting (not highly acidic)

Summary of Effects Implications:

- Not presently practiced, unlikely but possible in future (1).
- Leachate can be expected to have sufficiently elevated levels of major species (e.g., sulfate) to be of potential concern with respect to secondary drinking water standards (2)(3)(5).
- Leachate can have sufficiently elevated levels of trace metals (e.g., As, Se) to be of concern in minority of cases (2)(3)(5).
- Remaining points and references same as points 4, 6 and 7 for Fly Ash Waste, Pond Disposal, Interior Setting (not highly acidic).

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Fly Ash Waste, Landfill Disposal, Interior Setting (not highly acidic)

Summary of Effects Implications:

- Important practice at present, expected to be more prevalent in future (1).
- Leachate can be expected to have sufficiently elevated levels of major species (e.g., sulfate) to be of potential concern with respect to secondary drinking water standards (2)(3)(13)(14)(16)(17)(22).
- Leachate can have sufficiently elevated levels of trace metals (e.g., As, Se) to be of concern in minority of cases (2)(3)(13)(14)(16)(17)(19)(21)(22)(24).
- Dry disposal reduces volume and rate of leachate generation and movement; however, field studies confirm that typical range of interior climatic and geohydrologic conditions can provide opportunities for landfill leachate to effect measurably downgradient groundwater quality (1)(8)(9)(13)(14)(16)(17).
- Remaining three points and references same as for Fly Ash Waste, Pond Disposal, Interior Setting (not highly acidic).

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Non-Fly Ash Waste (Bottom Ash, FGD), Landfill Disposal, Interior Setting (not highly acidic)

Summary of Effects Implications:

- Existing minority practice, expected to become more prevalent in future (1).
- Leachate can be expected to have sufficiently elevated levels of major species (e.g., sulfate) to be of potential concern with respect to secondary drinking water standards (2)(3)(5)(6)(10)(11)(21).
- Leachate can have sufficiently elevated levels of trace metals (e.g., As, Se) to be of concern in minority of cases (2)(3)(5)(6)(10)(11)(21).
- Dry disposal reduces volume and rate of leachate generation and movement; however, field studies confirm that typical range of interior climatic and geohydrologic conditions can provide opportunities for landfill leachate to effect measurably downgradient groundwater quality (1)(8)(9)(13)(14)(16)(17).
- Remaining points and references same as last 3 points for Fly Ash Waste, Pond Disposal, Interior Setting (not highly acidic).

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Processed FGD Waste, Landfill Disposal, Interior Setting (not highly acidic)

Summary of Effects Implications:

- Practice recently initiated at several sites, expected to be significantly more prevalent in future (1).
- Leachate can be expected to have sufficiently elevated levels of major species (e.g., sulfate) to be of potential concern with respect to secondary drinking water standards (2)(3)(5)(6)(8)(9)(10).
- Leachate can have sufficiently elevated levels of trace metals (e.g., As, Se) to be of concern in minority of cases (2)(3)(5)(6)(8)(9)(10).
- Dry disposal reduces volume and rate of leachate generation and movement; however, field studies confirm that typical range of interior climatic and hydrogeologic conditions can provide opportunities for landfill leachate to effect measurably downgradient groundwater quality (1)(8)(9)(13)(14)(16)(17).
- Remaining points and references same as last 3 points for Fly Ash Waste, Pond Disposal, Interior Setting (not highly acidic).

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Dry FGD Waste Landfill Disposal, Interior Setting (not highly acidic)

Summary of Effects Implications:

- Practice in early stages of commercialization, expected to become more important in future (1) (3).
- Leachate can be expected to have sufficiently elevated levels of major species (e.g., sulfate) to be of potential concern with respect to secondary drinking water standards (3) (25).
- Leachate can have sufficiently elevated levels of trace metals (e.g., Se) to be of concern in minority of cases (25).
- Dry disposal method significantly reduces volume and rate of leachate generation and movement; however, field study results have shown that typical range of interior climatic and geohydrologic conditions provide opportunities for landfill leachate to effect measurably downgradient groundwater (1)(8)(9)(13)(14)(16).
- Remaining points and references same as final 3 points for Fly Ash Waste, Pond Disposal, Interior Setting (not highly acidic).

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Dry FGD Waste, Pond Disposal, Interior Setting (not highly acidic)

Summary of Effects Implications:

Combination not presently applicable and not envisioned in future because of incongruity between production of dry FGD wastes and pond disposal.

Documentation: Not applicable.

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Dry FGD Waste, Interim Pond-Landfill Disposal, Interior Setting (not highly acidic)

Summary of Effects Implications:

Combination not presently applicable and not envisioned in future because of incongruity between production of dry FGD wastes and ponding disposal.

Documentation: Not applicable.

6 Combinations in Interior Acid Mine Drainage Settings

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Fly Ash Waste, Pond Disposal, Interior Setting (acid mine drainage)

Summary of Effects Implications:

- Practice relatively uncommon, may continue to exist in future (1).
- Leachate quality comparable in major (and many minor) species composition (e.g., sulfate) to background waters affected by acid-mine drainage (2)(3)(8)(10)(14)(16)(17)(19)(21)(22)(23).
- Leachate can have sufficiently elevated levels of some trace metals (e.g., As) to be of concern in minority of cases (2)(3)(8)(10)(14)(16)(17)(19)(21)(22)(23).
- Pond head can promote leaching; typical range of interior climatic and hydrogeologic conditions can provide opportunities for waste leachates to effect measurably downgradient groundwater quality (1)(8)(13)(17)(19)(21)(22).
- Admixing with acid mine drainage in background waters mitigates against incremental adverse impacts from major dissolved species and several trace metals, secondary drinking water standards of limited applicability in receiving water (8).
- Admixing with even small surface water bodies can have major dilution impact on leachate, further mitigating potential leachate impacts on surface water and groundwater quality (8)(13)(15)(16)(23).
- Chemical attenuation of trace metals in soils can be expected case-by-case in some, but not all of the prevalent soil types (1)(13)(17)(19)(22).
- Opportunities for adverse impact would be rare, and are limited to situations in which leachate from a disposal area with extremely high leachable trace metal concentrations could reach and concentrate in a small water-body still used for such purposes as fishing in spite of prevalent acid mine drainage. Mitigation of this circumstance could be achieved by alternative disposal site selection or use of an appropriately attenuative soil as a site liner.

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Non-Fly Ash Waste (Bottom Ash, FGD Waste), Pond Disposal, Interior Setting (acid mine drainage)

Summary of Effects Implications:

Same points and references as for Fly Ash Waste, Pond Disposal, Interior Setting (acid mine drainage).

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Processed FGD Waste, Pond Disposal, Interior Setting (acid mine drainage)

Summary of Effects Implications:

- Uncommon practice presently restricted to Appalachian Region, where sites set in acid mine drainage may exist now or in future (1)(18).
- Leachate quality comparable in major (and many minor) species composition (e.g., sulfate) to background waters affected by acid mine drainage (2)(3)(5)(8)(18).
- Leachate can have sufficiently elevated levels of some trace metals (e.g., As, Se) to be of concern in minority of cases (2)(5).
- Size of ponds (can be greater than 1,000 acres) and high major species concentrations requires larger mixing volumes in receiving waters to achieve dilution by admixing comparable to that typical of other disposal combinations (18).
- Remaining points and references same as points 4, 5, 7 and 8 for Fly Ash Waste, Pond Disposal, Interior Setting (acid mine drainage).

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Fly Ash Waste, Interim Pond-Landfill Disposal, Interior Setting (acid mine drainage)

Summary of Effects Implications:

Same points and references as for Fly Ash Waste, Pond Disposal, Interior Setting (acid mine drainage).

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Non-Fly Ash Waste (Bottom Ash, FGD Waste), Interim Pond-Landfill Disposal, Interior Setting (acid mine drainage)

Summary of Effects Implications:

Same points and references as for Fly Ash Waste, Pond Disposal, Interior Setting (acid mine drainage).

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Processed FGD Waste, Interim Pond-Landfill Disposal, Interior Setting (acid mine drainage)

Summary of Effects Implications:

- Not a present practice, possible but unlikely in future (1).
- Remaining points and references same as last seven points for Processed FGD Waste, Pond Disposal, Interior Setting (acid mine drainage), including by references points 4, 5, 7 and 8 for Fly Ash Waste, Pond Disposal, Interior Setting (acid mine drainage).

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Fly Ash Waste, Landfill Disposal, Interior Setting (acid mine drainage)

Summary of Effects Implications:

- Existing practice in Appalachian Region, expected to continue in future (11).
- Dry disposal method significantly reduces volume and rate of leachate generation and movement; however, field study results have shown that typical range of interior climatic and geohydrologic conditions provide opportunities for landfill leachate to affect measurably downgradient groundwater quality (1)(8)(9)(13)(14)(16).
- Remaining points and references same as for points 2, 3, 5, 6, 7 and 8 for Fly Ash Waste, Pond Disposal, Interior Setting (acid mine drainage).

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Non-Fly Ash Waste (Bottom Ash, FGD Waste), Landfill Disposal, Interior Setting (acid mine drainage)

Summary of Effects Implications:

- May be practiced for bottom ash in Appalachian Region at present, possible for bottom ash and/or FGD waste in future (1).
- Leachate quality comparable in major (and many minor) species composition to background waters affected by acid mine drainage (2)(3)(5)(6)(8)(10)(21).
- Leachate can have sufficiently elevated levels of some trace metals (e.g., Se) to be of concern in minority of cases (2)(3)(5)(6)(8)(10)(21).
- Dry disposal method significantly reduces volume and rate of leachate generation and movement; however, field study results have shown that typical range of interior climatic and geohydrologic conditions provide opportunities for landfill leachate to effect measurably downgradient groundwater quality (1)(8)(9)(13)(14)(16).
- Remaining points and references same as final four points for Fly Ash Waste, Pond Disposal, Interior Setting (acid mine drainage).

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Processed FGD Waste, Landfill Disposal, Interior Setting (acid mine drainage)

Summary of Effects Implications:

- Existing practice in Appalachian Region, may occur with increased frequency in the future (1).
- Leachate quality comparable in major (and many minor) species composition (e.g., sulfate) to background waters affected by acid mine drainage (2)(3)(5)(6)(8)(9)(10).
- Leachate can have sufficiently elevated levels of some trace metals (e.g., As) to be of concern in minority of cases (2)(3)(5)(6)(8)(9)(10).
- Remaining points and references same as final two points for Non-Fly Ash Waste, Landfill Disposal, Interior Setting (acid mine drainage); including by reference final four points for Fly Ash Waste, Pond Disposal, Interior Setting (acid mine drainage).

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Dry FGD Waste, Landfill Disposal, Interior Setting (acid mine drainage).

Summary of Effects Implications:

- Not a present practice; as technology is commercialized it is possible that this combination might be realized at a small number of sites effected by acid mine drainage (1)(3).
- Leachate quality comparable in major (and many minor) species composition to background waters affected by acid mine drainage (3)(25).
- Leachate can have sufficiently elevated levels of some trace metals (e.g., Se) to be of concern in minority of cases (3)(25).
- Remaining points and references same as final two points for Non-Fly Ash Waste, Landfill Disposal, Interior Setting (acid mine drainage); including by reference final four points for Fly Ash Waste Pond Disposal, Interior Setting (acid mine drainage).

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Dry FGD Waste, Pond Disposal, Interior Setting (highly acidic).

Summary of Effects Implications:

Combination not presently applicable and not envisioned in future because of incongruity between production of dry FGD wastes and pond disposal.

Documentation: Not applicable.

MATRIX ASSESSMENT OF WASTE/DISPOSAL MODE/SETTING COMBINATIONS

Combination: Dry FGD Waste, Interim Pond-Landfill Disposal, Interior Setting (highly acidic)

Summary of Effects Implications:

Combination not presently applicable and not envisioned in future because of incongruity between production of dry FGD wastes and ponding disposal.

Documentation: Not applicable.

7 References

7 References

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APPENDIX I

QUALITY ASSURANCE/QUALITY CONTROL TESTING PROGRAM

PHYSICAL AND CHEMICAL SAMPLING AND ANALYSIS

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1.0 PHYSICAL TESTING PROGRAM

1.1 PREPARATION AND APPROVAL OF WORK PLANS

1.1.1 Preparation of Procedures Manuals

Between December 1979 and July 1980, two procedures manuals were prepared for guidance in conducting the field and laboratory portions of the physical testing aspects of this program. The "Hydrologic and Geotechnical Procedures Manual," which gave guidance for field procedures, is designated as Appendix B. The "Sampling and Analysis Procedures Manual" specified laboratory procedures and is designated as Appendix C.

1.1.2 Inspection and Approval of Laboratory Facilities

Physical testing for this program was performed at Bowser-Morner Testing Laboratories, Dayton, Ohio. On December 19, 1979, before program samples were tested, D.J. Hagerty of the University of Louisville, a Quality Assurance (QA) Advisor, conducted a detailed inspection of the Bowser-Morner laboratories and equipment and found them suitable for the forthcoming work. During the testing program, periodic visits to the Bowser-Morner laboratories were conducted by Barry Thacker of Geologic Associates, Inc., as part of his day-to-day QA oversight of the physical testing aspects of the program.

Additional testing of samples from the sites was performed at the Department of Civil Engineering of the University of Louisville to supplement the Bowser-Morner results. Thacker also visited these facilities periodically during the program.

1.1.3 Preparation and Review of Site Evaluation Plans

The physical sampling and analysis portions of the Site Evaluation Plan for each site were prepared by Bowser-Morner under the supervision of Geologic Associates and Arthur D. Little. The University of Louisville provided further QA review of these documents to Arthur D. Little. Each participating utility also reviewed and approved its site evaluation plan.

1.1.4 Procurement of Contract Drilling Services

Bowser-Morner Testing Labs conducted the drilling operations at the Allen, Elrama and Dave Johnston sites and were supervised by the Project Geologist and/or Project Manager from Haley and Aldrich, Inc. At the Sherburne County site, Bowser-Morner performed the drilling under the supervision of Hickock Associates, Inc. The Haley and Aldrich Project Manager, working closely with Arthur D. Little, secured contract drilling services at the Powerton and Smith sites and supervised the drilling activities in the field.

1.2 MEASUREMENT PROGRAM

1.2.1 Sample Collection and Chain of Custody

A Haley and Aldrich staff geologist supervised the collection and handling of samples for physical testing at all sites except Sherburne County to confirm that the activities were in accordance with the two Procedures Manuals and any other special procedures in the individual Site Evaluation Plans. The Haley and Aldrich Project Geologist/Project Manager visited the same five sites near the end of the site development activity to verify further that the samples were collected and recorded properly. At the Sherburne County site, these functions were performed by the staff of Hickock Associates.

Samples from the Allen, Elrama, and Sherburne County sites were delivered to the Bowser-Morner laboratories by the returning Bowser-Morner field team. The Dave Johnston, Powerton, and Smith samples were shipped to Bowser-Morner by the Haley and Aldrich field personnel. At Bowser-Morner, sample custody was the responsibility of Ms. Judy Costello.

Additional samples from the Allen, Elrama, and Sherburne County sites were delivered directly to the University of Louisville by the Bowser-Morner field team. Samples from the Dave Johnston, Powerton, and Smith sites were shipped to the University of Louisville by the Haley and Aldrich field representative. At the University of Louisville, C.R. Ullrich was responsible for the custody of the samples.

1.2.2 Assessment of Precision, Accuracy, Completeness, Representativeness and Comparability

1.2.2.1 Routine Measurements

The following types of routine measurements were performed in the physical testing aspects of the program:

- field permeability tests (various heads),
- particle size tests,
- specific gravity tests,
- moisture content determinations,
- unified soil classification tests,
- compaction tests,
- unconfined compression tests, and
- constant head permeability tests (laboratory).

The tests were all conducted according to the procedures outlined in the two Procedures Manuals referenced above and also according to the relevant protocols of the American Society for Testing and Materials (ASTM):

- D422 Particle Size Analysis,
- D854 Specific Gravity of Soil Solids,
- D2487 Classification for Engineering Purposes,
- D698 Standard Compaction Test,

- D2166 Unconfined Compression Test, and
- D2434 Constant Head Permeability Test.

The assessment of precision, accuracy, completeness, representativeness, and comparability of the physical testing was conducted in two phases. The initial phase occurred during the actual field or laboratory test and involved verifying that the test was conducted in accordance with the "Hydrogeologic and Geotechnical Procedures Manual" and the "Sampling and Analysis Procedures Manual." The second phase of assessment consisted of comparing the results of the individual tests with the entire data base.

During the first phase of assessment, QA/QC field personnel from Haley and Aldrich, Hickock Associates, and Geologic Associates selected test locations at each site that were representative of conditions across the site. They then supervised the specific field testing to verify that the tests were being conducted as specified in the procedures manuals. As long as the correct procedures were being followed, the testing was continued to completion. If a complication developed during a test, that test was aborted and a new test location was selected. For example, during many of the field permeability tests, flow was measured through an open hole formed within the strata in question. In cases where the hole collapsed before the test was completed, the data were voided and a new test was initiated at an adjacent location.

Similarly, in the laboratory, Bowser-Morner and University of Louisville personnel performed the physical testing under the supervision of their appropriate QC personnel. As long as the tests were conducted according to the procedures manuals, the testing was continued. Otherwise, the tests were aborted. A summary of the laboratory tests performed is shown in Table 1.

During the second phase of the assessment, the applicable data developed at each site was compiled as shown in Figure 1. Data from testing of nearly identical samples was generally accepted when the results fell within about 2 standard deviations from the mean. For the field permeability tests, this corresponds to an accuracy of about ½ order of magnitude. However, in most cases, the samples were not identical and more qualitative assessment was required.

For example, at the Allen site, samples recovered from Boring 3-1 were visually classified. The ash became coarser grained and more pervious with increasing depth. These visual classifications were later verified by the results of Unified Soil Classification Tests. As indicated in Figure 1, both field and laboratory permeability test results showed that the finer grained fly ash near the surface of the basin had a coefficient of permeability ranging between $1x10^{-4}$ and $1x10^{-5}$ cm/sec. The coefficient of permeability of the ash increased with depth to $9x10^{-3}$ cm/sec. at a depth of 20 feet beneath the surface of the basin. Because of the excellent agreement of results from classification tests and results from field and laboratory permeability tests, the data were considered accurate within the previously described bounds for nearly identical samples.

As an independent assessment of the precision, accuracy, completeness, representativeness, and comparability of data developed by the Bowser-Morner

TABLE 1

SUMMARY OF PHYSICAL LABORATORY TESTS

Site	Permeability Tests	Classification Tests	Proctor Tests	Moisture Content Determinations	Shear Strength Tests
Proposed Model Fill (F)	5	6	6	20	1
Proposed Model Pond (P)	1	15	-	40	-
Allen (P)	5	8	1	28	1
Elrama (F)	12	10	1	36	9
Dave Johnston (F)	8	7	1	44	-
Powerton (F)	8	21	1	41	1
Sherco (P)	8	6	-	24	1
Smith (P)	4	5	-	15	-
Total Planned*	18	63	18	180	3
Total Performed*	45	57	4	188	12

*Note: 282 total tests were planned and 306 total tests were actually performed.

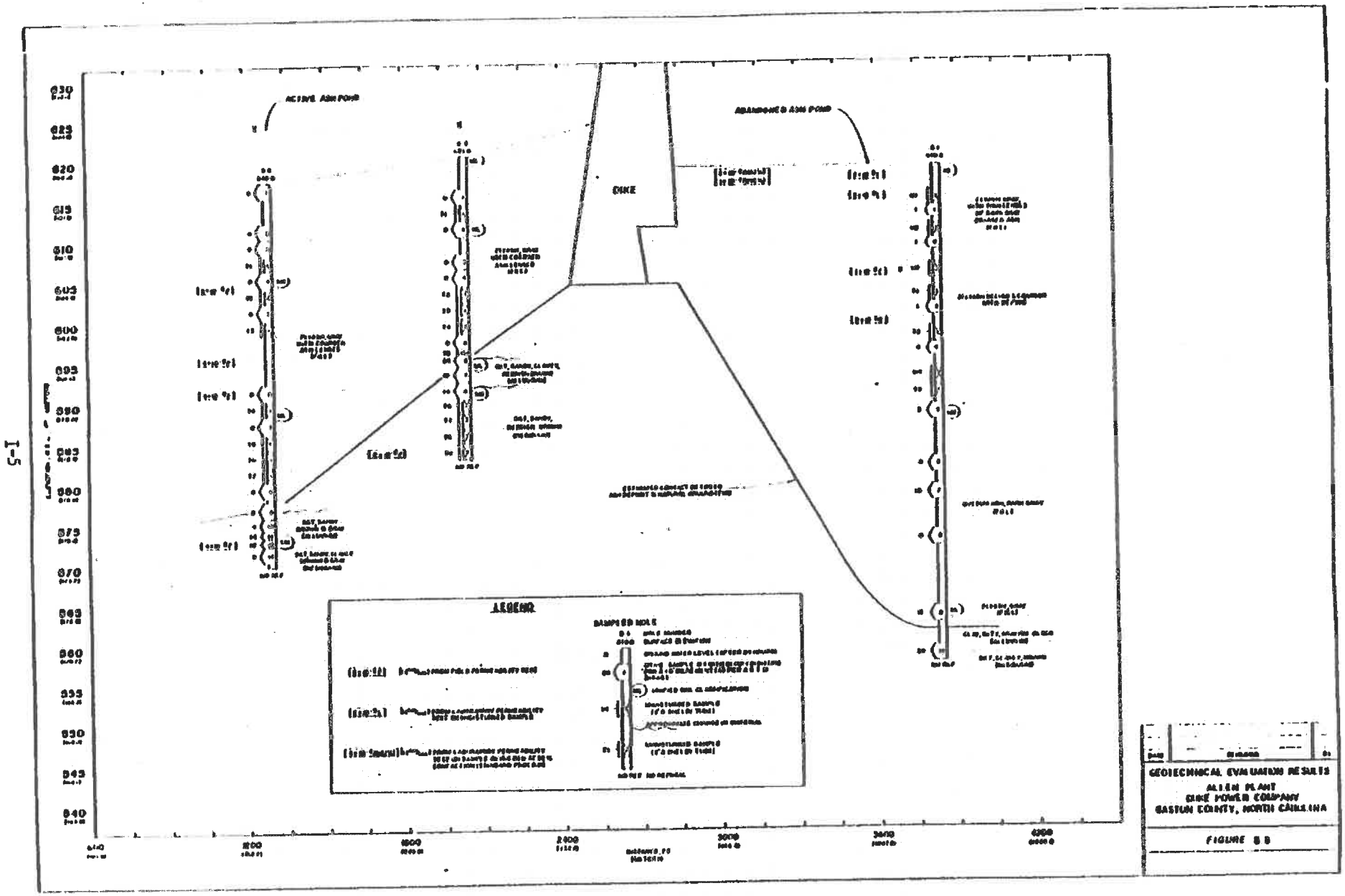

FIGURE 1 GEOTECHNICAL EVALUATION RESULTS FROM THE ALLEN PLANT

laboratories, the QA/QC personnel reviewed the results of Bowser-Morner's participation in the American Association of State Highway and Transportation Officials (AASHTO) program for soils testing. This program (known as A.M.R.C.) consists of procedures generally identical to those approved by the ASTM, and, by agreement between AASHTO and ASTM, serves as the reference program for both organizations. On a scale of 0 to 5 (5 being the highest score), Bowser-Morner's scores in this program averaged higher than 4.5 for the 1980-83 period (i.e., their data was within 1.25 standard deviations of the mean).

As a result of this high score in the A.M.R.C. program and the favorable assessment by the QA/QC personnel during the testing laboratory, Bowser-Morner's results for the routine laboratory measurements performed in this program are considered within the generally accepted bounds of precision, accuracy, completeness, representativeness and comparability.

1.2.2.2 Non-Standard Measurements

Only one non-standard physical laboratory test, the extended permeability test, was performed in this program. At the time of testing, neither ASTM nor AASHTO had published a protocol or developed a refereed testing program for measuring the extended permeability of fine-grained, undisturbed samples. In late 1983, ASTM reportedly had such a protocol under development, and its specifications required the use of triaxial-type equipment and constant-head conditions, key features traditionally employed at Bowser-Morner that were also used in this program. The Bowser-Morner procedure was reviewed and approved by the QA Advisors from the University of Louisville before its use. They concluded that it represented a combination of the triaxial test apparatus approved by ASTM's standardized triaxial compression test and a permeability measurement procedure similar to that used in the ASTM-approved constant-head permeability test.

The data developed at Bowser-Morner was compared to data developed at the University of Louisville. As an example, Figure 2 shows a comparison of dry density to the log of the coefficient of permeability for samples of FGC waste recovered from the Sherburne County site. The comparison shows that the coefficient of permeability of the waste does not change at dry densities greater than about 78 pcf. However, the permeability drastically increases when its dry density falls below about 74 pcf. Such a relationship is common for fine grained cohesionless soil and would be expected from an FGC waste with similar grain size distribution.

Based on this and similar assessments, the QA/QC supervisors from Geologic Associates (who reviewed the results of each test) and the University of Louisville (who conducted reference tests of the same type on samples from the six sites) concluded that the results of Bowser-Morner's permeability tests were within the previously described bounds of precision, accuracy, completeness, representativeness and comparability (i.e., within 2 standard deviations of the mean for identical samples).

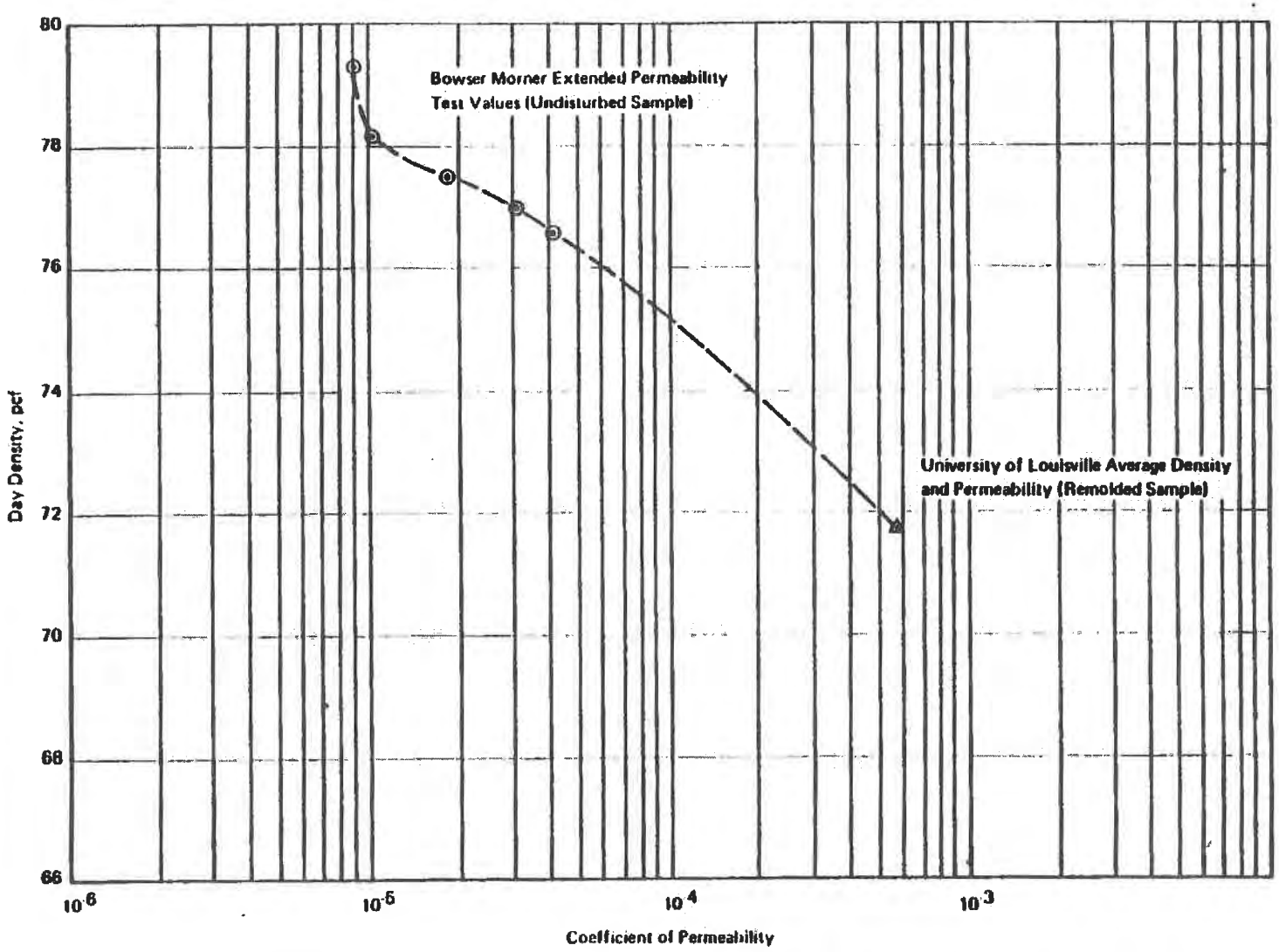

FIGURE 2 COMPARISON OF SHERBURNE COUNTY DATA FROM BOWSER-MORNER AND UNIVERSITY OF LOUISVILLE (COMPARABLE DEPTH AND MATERIAL)

1.3 LIMITATIONS ON USE OF THE DATA

There were no significant limitations on the use of the field and laboratory physical testing results. Questionable values were clearly flagged and had no effect on the continuing assessment. As previously described, the QA/QC program identified the tests where incorrect data were being generated. These tests were aborted. Excellent agreement between related data from various tests (i.e., field permeability tests, laboratory permeability tests, etc.) verified that the initial QA/QC screening process was successful in eliminating potential "outliers."

The physical testing data were considered along with other information in the overall assessment effort. Available information on waste permeability derived from field testing, extensive literature documentation, and results from the laboratory physical testing were used (along with other data) in four types of assessment activities:

- Development of site water balances.
- Evaluation of site cause-effect relationships.
- Projections of future conditions at the sites.
- Evaluation of the broader (industry-wide or generic implications of the disposal practices under study).

The following points show how the laboratory physical testing data were used in these assessment activities:

- In each of the three site-specific assessment activities, the physical testing data supplemented and supported both earlier field data (e.g., field permeability test results and water level measurements) and the evidence for leachate migration already provided by chemical correlations between in-waste and downgradient water samples.
- At each site where permeabilities at or greater than about 10^{-4} cm/sec were measured or anticipated (Allen, Dave Johnston, Powerton, and Smith), the chemical measurements appeared to provide early, relatively precise, and important "bottom line" indications of the history and importance of leachate movement over time. Thus, the chemical and physical testing results corroborated one another for the higher permeability waste deposits.
- When the rate of water movement through a waste deposi. was important in the assessment calculations, the inherent uncertainty in both field and laboratory conditions was acknowledged by using boundary assumptions in the calculations. Invariably, there was less certainty and more need for assumptions with other parameters (e.g., liner thickness or permeability and stratigraphy of unmeasured, inhomogeneous natural soils) than the comparatively well-documented field and laboratory-measured waste permeabilities.

- The evaluation of the broader (industry-wide) implications of the disposal practices under study was partly based on the substantial body of permeability data from more than 15 field studies of full-scale sites and from many more laboratory studies. As discussed in Section 1.2.2.2, the Bowser-Morner and University of Louisville physical testing results were consistent with those of other investigations of similar wastes. The values for identical samples were within 2 standard deviations of the mean.

Examples of how the physical testing data were used in the assessment for each site are given below.

Allen Site

- The water balance was based on measurements made in the field before laboratory data were generated. As laboratory data became available, the results supported the assumptions used in the water balance.

- Chemical data from in-waste and downgradient wells provided the major basis for investigation of cause-effect relationships.

- The major assessment variables at this site were chemical attenuation of leachate trace metals in surrounding soils and the inhomogeneous nature of water movement patterns in the surrounding soils, not the waste deposit.

Elrama Site

- In the absence of field and laboratory data, the preliminary water balance was based on estimated hydraulic conductivities. When the laboratory permeability test data were available, they showed values within the expected range of variance from the original estimate. These laboratory data were then used in the revised water balance.

- The assessment of cause-effect relationships focused on the chemical interactions between contaminated acid-mine drainage and waste leachate at the site.

Dave Johnston Site

- The water balance was based on measurements made in the field before the laboratory data were generated. As laboratory data became available, the results supported the assumptions used in the water balance.

- Evaluation of cause-effect relationships focused on the extensive similarity of the leachate and the highly mineralized natural groundwater and on the minimal water movement in the relatively arid western setting.

- Future conditions were not projected for this site because of the minimal opportunities for incremental impacts.

Sherburne County Site

- The preliminary water balance was based on measurements made in the field before the laboratory physical testing data were generated. The laboratory data were consistent, within expectations, and provided a basis for calibrating the assessment without resolving the more important uncertainties over liner homogeneity (both composition and in thickness).

- Because of the inherent uncertainties in any attempt to characterize the inhomogeneities in the pond liner and the near-downgradient groundwater flow patterns at the site, the assessment of cause-effect relationships and future conditions relied primarily on chemical data, together with boundary assumptions governing the range of reasonable water movement possibilities at the site.

Powerton Site

- The water balance was based on measurements made in the field before the laboratory data had been generated. The laboratory physical testing data gave values in the expected range.

- The data on chemical quality of in-waste versus downgradient well concentrations of several waste-related chemicals provided early and clear "bottom-line" evidence of plume movement away from the waste deposit.

Smith Site

- The water balance was based on results of field measurements and results of the laboratory physical testing, which were in good agreement.

- The data on chemical quality of in-waste versus downgradient well and seep concentrations of two waste-related chemicals provided "bottom-line" evidence of plume movement consistent with the water balance.

1.4 RESULTS OF SYSTEMS AUDIT

On March 11, 1982, Alvia Gaskill, Jr., an environmental chemist from Research Triangle Institute (RTI) and Roy H. Borden, a civil engineer from North Carolina State University, Raleigh, North Carolina, who was serving as a consultant to RTI, visited Bowser-Morner Testing Laboratories to perform an audit of the physical testing activities under this program. The audit team and Bowser-Morner personnel participated in the audit visit.

The auditor's report* contained three summary conclusions. The first expressed a belief that there was no interaction between the University of Louisville and Bowser-Morner Laboratories, and that there were no QA audits during the program. The second was that field sampling, sample custody and shipping procedures, and laboratory facilities, equipment and procedures were acceptable with the exception of certain aspects of the permeability test apparatus. The final conclusion related to the second, was that the manner in which the permeability tests were conducted by Bowser-Morner could have led to erroneously low values.

After extensive investigation of the auditors' conclusions, the team responsible for this project concluded that:

1. The auditors had not accurately reflected the history of interaction between Bowser-Morner and the University of Louisville, and the extensive role of Geologic Associates in systematic QA oversight of the Bowser-Morner work.

2. The permeability test apparatus and its use reflected an appropriate combination of standardized test apparatus and procedures from other ASTM-approved procedures.

3. The Bowser-Morner and University of Louisville laboratory permeability test results and the field permeability tests results were generally in excellent agreement. Any differences accurately depicted the variations that were expected. See, for example, Figure 2 in Section 1.2.2.2.

4. None of the lower permeability values reported by Bowser-Morner had any major importance in the environmental assessment work for this project. As discussed in Section 1.3, chemical sampling and analysis results were available to document leachate movement and distribution downgradient at the sites where the lower permeabilities were obtained.

1.5 IDENTIFICATION AND RESOLUTION OF ANY SIGNIFICANT QA/QC PROBLEMS

No significant QA/QC problems remained unresolved in the physical testing aspects of this project. One problem thought to have some potential significance at the time was the discovery of some apparent corrosion of some Shelby-tube samples from the Elrama site. Sufficient uncorroded material was available to allow all the required analyses, and a protocol of frequent inspection and rapid processing of samples was initiated to avoid the potential for a similar problem at other sites. The problem did not recur with samples from any of the other sites.

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*"Systems Audit of Physical Testing Activities Performed for EPA Under Program for Characterization and Monitoring of Full Scale Utility Waste Disposal Sites" by Alvia Gaskill, Jr., RTI and Roy H. Borden, NCSU, EPA Contract No.: 68-02-3146, Task 184, EPA Project officer G.L. Johnson, Prepared for Technical Support Staff, EPA/IERL-RTP, North Carolina 27711, August 1982.

2.0 CHEMICAL SAMPLING AND ANALYSIS TESTING PROGRAM

2.1 OVERVIEW

Chemical sampling and analysis were conducted to:

- characterize the chemical concentrations of species of interest in waste solids, background soils, groundwater and surface water;
- identify potential waste-related chemical "tracers," i.e., those chemicals whose elevated concentrations in the waste and relative absence in background samples made them candidates for use in mapping the extent of waste-related contamination;
- map chemical concentration gradients to the waste deposits; and
- provide data to structure and test hypothesis to explain phenomena suspected to occur at the site (such as soil attenuation of trace metals).

2.2 PROGRAM PLANNING AND DOCUMENTATION

2.2.1 Preparation of Procedures Manual

An early activity in this program was to prepare a comprehensive set of procedure manuals that recommended and defined techniques that would be used during subsequent work. Among the documents prepared was a chemical sampling and analysis manual (Appendix C). This manual specified the types of analytical samples that would be collected and recommended procedures for how these samples would be collected and analyzed. It was intended to serve as a basis for all the chemical sampling and analysis activities.

2.2.2 Preparation and Review of Sampling Work Plans

Once the sample collection activities began, the recommended chemical analysis procedures were found to be appropriate and required no modification. However, time constraints and site-specific conditions required that several of the recommended sampling procedures be altered. To document these changes and control the amount of procedural variability that was introduced, a detailed sampling activities work plan was prepared before each field trip. This plan became the basis of all sampling activities. It was distributed among all members of the sampling crew, the chemical analysis quality assurance/quality control (QA/QC) overseer, the chemical analysis activities manager, and the overall program manager. This plan was also provided to the EPA Project Officer and to designated representatives of the participating electric utilities for their review.

The main purpose of this document was to state the objectives of each particular sampling activity and define how each scheduled field sampling and analysis activity was to be conducted. A second function was to provide an easy mechanism by which all sampling procedures could be monitored and so give program continuity between consecutive sampling trips to an individual

disposal site as well as scheduled trips to all six disposal sites. This document also clearly identified and listed where and how many QA/QC samples were to be collected during each sampling trip.

2.2.3 Oversight of Contract Laboratories

During the program, TRW, Inc., served as a subcontractor for some facets of the sampling and analysis program. TRW performed IC analyses on field samples. Barringer Magenta, Inc., Toronto, Canada, performed ICAP analyses for metals on the samples obtained by both TRW and Arthur D. Little. Arthur D. Little supervised TRW's activities by reviewing sampling and analysis plans and by performing IC check analyses of selected TRW field samples.

The role of Barringer Magenta in the program was an important one, since they were responsible for generating the bulk of the analytical data. Before selection of Barringer Magenta, a set of qualification samples was submitted to them and to a competitor. Subsequently, the Arthur D. Little personnel responsible for chemical sampling and analysis and chemical QA/QC visited both organizations to inspect their laboratories and instrumentation and to evaluate their knowledge, capabilities and experience in performing ICAP analyses.

Blind QC samples were included with each lot of field samples submitted for ICAP analyses to monitor analytical performance. All samples submitted were identified only by a sample code number. The order of samples in each lot was intentionally randomized to make the identity of replicates less obvious. Throughout the program, Arthur D. Little personnel remained in close contact with Barringer Magenta. Whenever a potential problem in the ICAP data was discovered, Barringer Magenta was informed and Arthur D. Little personnel monitored their progress toward solving it. Barringer Magenta's cooperation throughout the program was excellent.

2.3 FIELD SAMPLING QUALITY ASSURANCE/QUALITY CONTROL

2.3.1 Sampling Protocols

With one exception, all the field sampling and analysis protocols used during this program were those that were initially defined in Appendix C. The exception was the manner in which samples of the groundwater in the saturated zone were obtained. The sampling methods are described below.

A. Waste and Soil Samples

Shelby tube and split-spoon sampling techniques were used during site development to obtain all waste and soil samples (including pond liner samples). The Shelby tube samples were shipped "as is" in tubes to the laboratory. The split-spoon samples were transferred to precleaned glass mason jars on-site and then shipped. Some waste samples were also collected during the subsequent sampling and analysis trips. These samples (mostly liquids and slurries) were obtained using grab sampling techniques. Wells were thoroughly flushed with in-situ water before grab sample collection, as required by the Procedures Manual.

3. Groundwater and Surface Water Samples

Samples were collected from groundwater monitoring points and several types of surface water sources. Sample types included saturated zone groundwater, samples from wells and piezometers, unsaturated zone groundwater samples from lysimeters, and samples of surface water (i.e., ponds, lakes, rivers, streams, swamps and tidal basins). Collected samples were split into two fractions, one for metal analysis and one for anion analysis. The metals fractions recovered were preserved with nitric acid as per pertinent DOT/EPA regulations, while the anion fractions were preserved by packing in ice. A comprehensive chain of custody record system adapted from NEIC (National Environmental Investigation Center) protocol was imposed on all field samples collected. Table 1 summarizes the sampling equipment used. Figure 3 is a schematic of the pneumatic pumping system used to sample groundwater.

C. Groundwater Well/Piezometer Sampling (Saturated Zone)

The intended procedure at the beginning of this project was to remove three to five well volumes before sample collection, as described in Appendix C. This proved impractical because of time limitations during sampling trips. The following procedure was developed instead. It saved time and provided the appropriate samples. In addition, the consistency of analyses results from trip to trip indicated the validity of this approach.

Any water above the screened section of a well was considered "stagnant" with respect to the "fresh" water located in the screened section (see Figure 3). This distinction is based on the fact that water can flow through the screened section and constantly replace water contained there. This new water has been more recently exposed to the geological formations outside the well casing. Water contained above the screened area is trapped, and its composition may change because of prolonged exposure to the atmosphere and to well casing materials. Therefore, the sample was withdrawn from below the fresh/stagnant water interface, with care to prevent any stagnant water from contaminating the sample. The following procedure was used:

1. Groundwater depth was measured to calculate the overall well volume and volume of stagnant water in the well (the well diameter was known). Before the sampling location was assessed, data were gathered as to the well diameter, screen volume (screen length times well cross-sectional area), screen/upriser interface depth, and overall well depth.

2. One well volume (overall well depth minus depth to water times well cross-sectional area) was removed from a location in the well that was as high above the fresh/stagnant water interface as possible. The fresh/stagnant water interface was assumed to coincide with the upper elevation of the screened section of the well. The point from which the initial well volume was removed was determined by the individual characteristics of each well, including factors such as well depth, groundwater depth, and the rate of well recharge. If the well did not recharge as quickly as the water was removed, the location of the sampling point was positioned at or just below the fresh/stagnant

TABLE 2

CHEMICAL SAMPLING EQUIPMENT

PUMPS:		
Peristaltic Pump	-	Master flex portable sampling pump Horizon Ecology Co.
Pneumatic Pump	-	Designed and built at Arthur D. Little, Inc. The pump body consists of PVC pipe (1½", schedule 80 PVC), a check valve on the bottom to allow water to flow in, and a check valve at the top to prevent water from flowing back into the pump body once the pressure is released. Figure 1 shows the pump body along with the ancillary equipment needed for sample collection.
INSTRUMENTS:		
pH Meters	-	Horizon Ecology Co. (Type 5995) portable pH meter and a Beckman portable field (Model Monitor II System).
Dissolved Oxygen Meter	-	YSI Model 57 with built-in temperature probe.
Conductivity Meter	-	Chemtax, Inc., Type 70.
FILTER HOLDER:	-	Millipore 316 stainless sanitary XY3024236
FILTERS:	-	Millipore 0.45 HAWP14250
	-	Millipore prefilter AW0614250
GRAB BUCKET:	-	Polyethylene
SAMPLE CONTAINERS:	-	Polyethylene
TUBING:	-	All sampling lines in the wells were polyethylene tubing.
	-	Surface water samples were collected through Tygon® tubing.
PNEUMATIC FLUID:	-	Nitrogen

Source: Arthur D. Little, Inc.

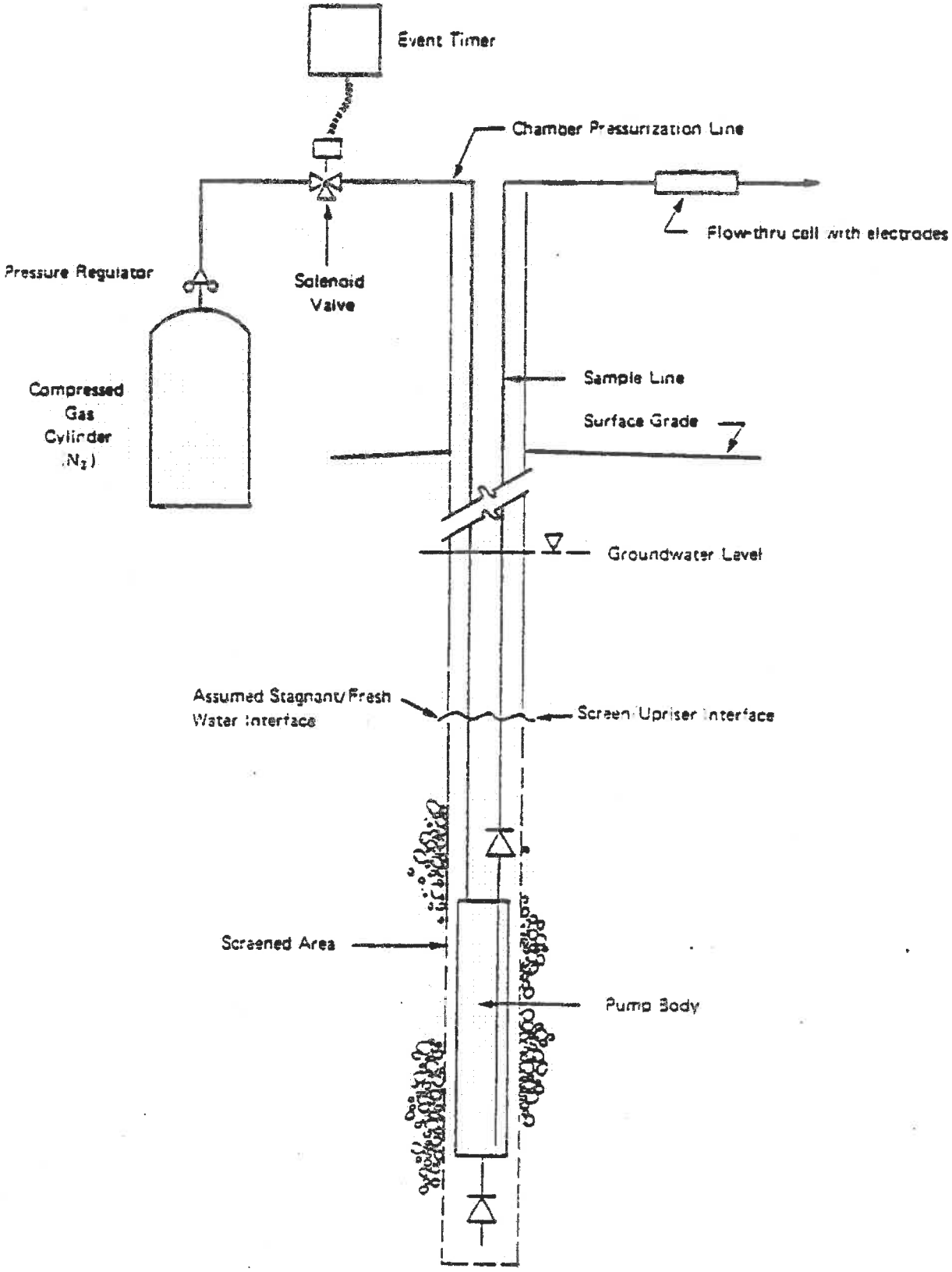

FIGURE 3 SCHEMATIC OF PNEUMATIC PUMPING SYSTEM

water interface. Once the stagnant water was removed, the sampling location was dropped to a point near the bottom of the screened section.

3. Successive screen volumes of water were removed from the bottom of the well and pumped through a flowthrough cell made from 2-inch acrylic tubing and electrodes to measure chemical parameters of the flowing water. Conductivity, pH, dissolved oxygen (D.O.), and temperatures were measured. Stabilization of these measurements indicated that the well water composition had reached equilibrium (minimal changes with successive pumping). When two consecutive parameter readings fell within the allowed tolerances (the allowed tolerances were pH ±0.3 units, conductivity ±10% relative; D.O. readings relatively consistent), the well was sampled.

This type of multilevel sampling approach greatly reduced the time required to sample each well by decreasing the volume of water that had to be removed before sample collection.

Two kinds of pumps served to evacuate the wells, pneumatic pumps and peristaltic pumps. The pneumatic pump was used when the water level in the well was below the suction lift capacity of the peristaltic pump. The pumping sequence and the volumes of water removed were the same for both types of pumps. One difference in procedure between the two pumps was that two separate tubes were placed in the well at the desired depths when the peristaltic pump was used. The peristaltic pump was connected to the appropriate tube to remove stagnant or fresh water. The pneumatic pump, however, was physically raised or lowered to locations above or below the screen/upriser interface to remove the desired type of water from the well.

Any exceptions to these procedures were fully documented in the field log of the sampling team, which was reviewed by the assessment team.

D. Lysimeter Sampling (Unsaturated Zone)

Lysimeters located in the unsaturated zone were sampled by a pressure-vacuum hand pump. The lysimeter was pressurized and evacuated of the accumulated standing water. A vacuum was applied to the lysimeter for six hours. The water collected in the lysimeter after this period was pumped into a container, and chemical parameters (pH, conductivity) were measured on a small aliquot of the unfiltered sample. The water was then filtered and preserved.

E. Surface Water Sampling

Surface water samples were collected with a peristaltic pump or a grab bucket. With the pump method, the pumping sequence applied was similar to the one used in sampling the groundwater wells. A volume of water (approximately 1000 mls) was pumped from the surface water source. Successive volumes (3500 mls) were then removed. Chemical parameters were measured (in the sampling stream) on each successive volume. A sample was taken after two consecutive

parameter readings fell within the allowed tolerances. The sample volume was removed, filtered, split into anion and metal fractions, and preserved.

The grab bucket method was used at locations where it was impractical to collect surface water samples with the pump. In this approach, a volume of water was collected, and the sample was filtered, split and preserved. The excess unfiltered sample was used for measuring chemical parameters.

2.3.2 Field Quality Control Samples

Six types of quality control samples were usually collected during each field sampling visit. These were acid blanks, Milli Q® blanks, field blanks, other blanks, field duplicates, and sequential well or surface water duplicates, as described below:

- Acid Blanks - distilled and deionized water (Milli Q® water) containing the exact amount of nitric acid (HNO_3) used to stabilize samples for metal analysis. These samples were used for two determinations: (1) to provide a means of assessing whether precleaned sample bottles carried into the field became contaminated during the scheduled sampling activities; and (2) to determine if a particular lot of the preservation reagent used contained inordinate levels of undesirable contaminants. Assessing the quality of preservation reagent was considered extremely important because many lots of nitric acid had to be purchased and left at visited facilities due to shipping regulations imposed by the Department of Transportation.

- Milli Q® Blanks - distilled and deionized water (Milli Q® water) with no additives. These served as a blank for anion analyses and also provided a mechanism by which sample bottle contamination could be assessed independently of other possible field contaminant sources.

- Field Blanks - distilled water passed through the sampling devices (pneumatic pump, peristaltic pump, bailer and filtration apparatus) to check for equipment contamination. Aliquots were collected for both heavy metal and anion determinations.

- Other Blanks - samples of distilled water obtained at or near each of the visited test facilities. These samples had been used to rinse sampling equipment between successive applications. Aliquots collected for heavy metal and anion determinations were used to assess whether rinse water could have contributed any contamination.

- Field Duplicates - split of a field sample obtained from a well or a surface water location after all field collection activities (e.g., prebailing, parameter measurement, filtration but not sample preservation and packaging) had been completed. The split was taken immediately after the filtration step, and each sample aliquot was returned, preserved, and packaged as a unique field sample. These samples were shipped to the laboratory as blind replicates and used to assess precision of repetitive analysis of equivalent samples.

- Sequential Well or Surface Water Duplicates - equivalent but different volumes of sample water obtained from a monitoring well or a surface water sampling location. These samples were collected after one entire sample collection sequence had been completed at a sampling location and were treated as completely unique field samples. The data generated from the analysis of these samples were used to assess whether removing additional volumes of sample water caused any variability in the concentration of species found in samples. Table 2 lists all the field quality control samples obtained during this program.

2.3.3 Field Quality Control Procedures

In addition to the numerous quality control samples that were collected during each sampling trip, all field instrumentation used was routinely calibrated. Details of the standards used to calibrate and monitor the performance of field instrumentation are described below.

- Dissolved Oxygen. The response of the meter to humid air and to a sodium sulfite solution (D.O. = 0) was measured. This was performed at the beginning and end of each day's sampling.

- Conductivity. Standard potassium chloride (KCl) solutions (0.1, 0.029 and 0.001 N) were measured before and after sampling each day.

- pH. Buffers (pH 4, 7, 10) were checked at the beginning, end, and at least two other times during each sampling day.

- Temperature. Checks were made of the instrument with a mercury thermometer at the beginning and end of each sampling day.

2.3.4 Sample Documentation and Chain of Custody

A chain of custody record keeping system was used to track and control all samples that were collected during this program. This chain of custody system was based upon procedures recommended by the National Enforcement Investigation Center (NEIC) of the U.S. EPA which are outlined in the "NEIC Policies and Procedures Manual" (EPA-330/9/78/001-R).

Before any sampling was conducted, a field sample custodian and a laboratory sample custodian were identified. The role of this field sample custodian was to ensure that all samples were properly labeled, packaged, and maintained from the time of their collection until they were delivered to a common carrier for transport back to the analytical laboratory. The field sample custodian was also responsible for initiating the chain of custody record on all of the collected samples.

The laboratory custodian's role was to unpack samples upon receipt at the laboratory, inspect samples for obvious signs of tampering, and distribute samples for analysis. The laboratory custodian was also responsible for maintaining the chain of custody record.

TABLE 3

SUMMARY OF FIELD QUALITY CONTROL PROGRAM

Types of Samples	Plant 1 Elrama	Plant 3 Allen	Plant 5 Sherburne County	Plant 6 Powerton	Plant 7 Dave Johnson	Plant 9 Smith	Total
Blanks							
Field Blanks	7	7	5	6	2	10	37
Milli Q® or Distilled Water Blanks	9	7	6	4	2	5	33
Duplicates							
Field Duplicates	6	6	6	6	6	10	40
Sequential Duplicates	9	13	8	7	6	13	56
Laboratory	5	7	6	5	0	18	41
	36	40	31	28	16	56	207

When samples were collected, they were immediately identified with a sample label. Solid samples obtained during site development activities were assigned numbers starting with an F and followed by a sequential four-digit number between 0000 and 9999. All groundwater, surface water, and solid samples obtained during subsequent sampling trips were identified with a label similar to the one shown in Figure 4.

As shown in Figure 4, the labels used to identify field samples contain five lines of preprinted information and space for the sampling personnel to write sampling date, name of collectors and comments. The key for the five lines of preprinted labeling information is explained below.

Contractor: ADL = Arthur D. Little, Inc.; TRW = TRW Systems, Inc.; Other = any other contractor collecting samples with name written in the comment section

Site Descriptor:
01 = Elrama
03 = Allen
05 = Sherburne County
06 = Powerton
07 = Dave Johnston
09 = Smith

Type of Sample: GW = Groundwater; SW = Surface Water; RO = Runoff; WA = Waste; SO = Soil or Solid other than Waste; Other = All others (with description written)

Location Index: Sampling Location Number

Analysis Index: M+ = Metals; AN = Anionic Species, OR = Organic Species; Other = All other analyses; BLK = Blank with appropriate descriptor; DUP = Duplicate with appropriate descriptor; SPK = Spike

Once sample bottles had been filled and appropriately preserved, they were closed and sealed with a band of vinyl tape around the bottle cap and bottle neck. The sealed sample bottles were then placed into polyethylene bags which were sealed with signed chain of custody tags. These sealed bags were then individually packed into ice chests. When an ice chest was filled, the ice chest was closed, tagged with a signed and dated chain of custody tag, and sealed with fiberglass tape.

During the sample packing operation, label information from each bottle placed into the ice chest was recorded into a bound duplicating notebook. Entries made into the notebook included date of collection and packaging, sample location details, and analysis requested. This entry page was then signed and dated by the field custodian. The duplicate page was removed and attached to the sealed ice chest. This duplicate page served as a packing list for all shipments. When the packed samples were delivered to the common carrier (truck or air freight agent) for transport, the field sample custodian obtained a signed and dated copy of the bill of lading which became part of the chain of custody record.

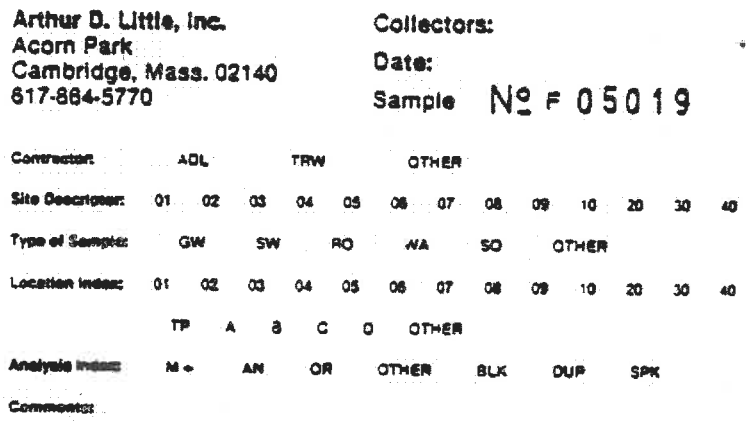

FIGURE 4 EXAMPLE OF SHIPPING LABEL

Upon receipt of the sample shipment in the laboratory, the laboratory sample custodian retrieved the packing lists and inspected the integrity of the chain of custody tag on each chest. The chests were then opened, and all samples were recovered. Each polyethylene bag was then opened and the sample bottle was recovered and inspected. The chain of custody tags attached to individual sample bottles were inspected for evidence of tampering.

Samples were checked for: 1) integrity of the seal placed on each bottle cap; 2) the presence of solid precipitates which sometimes formed during sample transport; and 3) pH (for the acidified samples). If a sample did not conform to the required condition, a remedial action was taken, such as adding nitric acid to dissolve solids or to lower the pH. Non-acidified samples containing particulates were filtered. Any manipulation of the samples was noted. If problems had been encountered with any field pH or conductivity equipment, a value for these parameters was obtained in the lab at this time.

The acidified water samples were then assigned "MF numbers" (MF for metals fraction), and the unacidified fraction of the same sample was assigned an "ICF number" (ICF for ion chromatography fraction). The ICF samples were stored in the refrigerator until analysis. Metal samples were stored at room temperature, as were soil samples and wastes. A list of sample numbers and a description of each sample were prepared for each batch of samples received (generally representing a particular sampling period for a particular site).

At this point, laboratory QC samples were prepared. These included laboratory splits, blind standards, and laboratory blanks. Liquid samples were then aliquoted into three plastic bottles (30 ml) and distributed as follows. A complete set of MF samples (including splits and blind standards) was sent to Barringer Magenta, Ltd. (Toronto, Canada) for inductively-coupled argon plasma (ICAP) analysis. These samples were prepared for shipment by the laboratory custodian, and these samples were transported under the same type of chain of custody procedures as described above. Another set was reserved for in-house metals analysis (As and Se) on selected samples. The third complete set of ICF samples was provided for in-house IC analysis.

Waste and soil samples were distributed after the site development boring logs had been reviewed and the particular samples designated for further chemical analysis had been identified.

2.4 LABORATORY ANALYSIS QUALITY ASSURANCE/QUALITY CONTROL

2.4.1 Analytical Protocols

All laboratory sample preparation and analysis protocols used during this program are defined in Appendix C. Synopses of each technique are provided below.

2.4.1.1 Laboratory Sample Preparation

A. Liquid Samples

The ICAP and IC liquid samples required no preparation (other than dilution) before they were introduced to the ICAP spectrometer or ion chromatograph. Analyses of As and Se based on hydride evolution were performed on as-received and stabilized water samples. In cases where the presence of organics was suspected, e.g., extracts of soils, samples were digested with HNO_3 and $HClO_4$, as explained in Appendix C. A check on a cross section of groundwater samples from the various sites generally showed small differences between digested and undigested samples.

B. Solid Samples

Solid samples of wastes and soils were freeze-dried under vacuum before they were shipped for analysis. The analysis, performed by Barringer Magenta, Ltd., involved a "total" digestion of the solids with a mixture of $HF/HNO_3/HClO_4$ before ICAP analysis. Solid samples for As and Se analysis were digested with $HNO_3/HClO_4$ before the AA/hydride evolution analysis of the digest.

C. Pore Liquid Samples

Pore liquids were obtained from moist or saturated waste solid and soil samples by the pressing technique described in Appendix C. Waste solids and liner solid samples were pressed under N_2 to obtain samples of the liquid phase. The samples were then passed through a 0.45 µm filter. Portions of the liquid were then acidified for metals analysis, and a portion was cooled for anion analysis.

D. Extracts

In cases where the pressing technique did not produce any liquid for analysis, a water extract was obtained by mixing distilled water with the solid and agitating the slurry in a shaker for one hour. The extract was separated from the slurry by filtration through a 0.45 µm filter.

2.4.1.2 Laboratory Analyses

Table 3 lists the analytes of interest in this program. The laboratory analyses are described below.

A. Inductively Coupled Argon Plasma Spectroscopy

Inductively coupled argon plasma (ICAP) spectroscopy was performed by Barringer Magenta, Ltd. The ICAP unit was a model QA-137 Applied Research Laboratories spectrometer with a 1920 rulings/mm grating. Reciprocal linear dispersion detectors (0.48-0.52/mm, first order R300) from Hamamatsu Corp. were used. The plasma observation height was 16 mm above load coil, 4-mm vertical section. Sample uptake was 2.25 ml/min by a cross-flow pneumatic

TABLE 4

ANALYTES, ANALYTE NUMBER DESIGNATION, AND ABBREVIATIONS

Liquids			Solids		
1	Fluoride	F	7	Silver	AG
2	Chloride	CL	8	Aluminum	AL
3	Nitrate	NO_3	11	Beryllium	BE
4	Sulfate	SO_4	12	Calcium	CA
5	Phosphate	PO_4	13	Cadmium	CD
6	Bromide	BR	14	Cobolt	CO
7	Silver	AG	15	Chromium	CR
8	Aluminum	AL	16	Copper	CU
9	Boron	B	17	Iron	FE
10	Barium	BA	18	Potassium	K
11	Beryllium	BE	19	Magnesium	MG
12	Calcium	CA	20	Manganese	MN
13	Cadmium	CD	21	Molybdenum	MO
14	Cobolt	CO	22	Sodium	NA
15	Chromium	CR	23	Nickel	NI
16	Copper	CU	24	Phosphorus	P
17	Iron	FE	25	Lead	PB
18	Potassium	K	27	Strontium	SR
19	Magnesium	MG	28	Thorium	TH
20	Manganese	MN	29	Titanium	TI
21	Molybdenum	MO	30	Vanadium	V
22	Sodium	NA	31	Zinc	ZN
23	Nickel	NI	32	Zirconium	ZR
24	Phosphorus	P	43	Arsenic	AS
25	Lead	PB	44	Selenium	SE
26	Silicon	SI	45	TOS (Sulfite)	TOS
27	Strontium	SR	46	Sulfate	SO_4
28	Thorium	TH	47	pH-Slurry	pH
29	Titanium	TI	48	Acid Insolubles	AI
30	Vanadium	V	49	Solids (%)	% SOL
31	Zinc	ZN	50	F (Extractable)	F
32	Zirconium	ZR	51	CL (")	Cl
33	Arsenic	AS	52	NO_3 (")	NO_3
34	Selenium	SE	53	SO_4 (")	SO_4
37	pH Lab	pH-L	54	CO_4 (")	CO_4
38	pH Field	pH-F	55	Alkalinity (OH)	OH
39	Conductivity Lab	C-L			
40	Conductivity Field	C-F			
41	Groundwater Level	GRW			
42	Dissolved Oxygen	DO			
57	Bromate	BrO			
60	Lead Graphite Furnace	PB-GR			

Source: Arthur D. Little, Inc.

nebulizer with Scot chamber. A Jarrel-Ash monochromator (1/2 M Ebert) and a R787 Hamamatsu Corp. photomultiplier were used. Generator output was 1600 W at 27.12 MHz.

The ICAP analysis was performed by aspirating the undiluted sample. This analysis provides emission data for trace components as well as major species (up to 1000 ppm). A computer-based program, which corrects for interelement spectral interferences, is used to quantify trace elements. The major species (>100 ppm) are quantitated by diluting the original sample and reanalyzing it. These reanalyzed values are then used as input concentrations for major species in the interelement computer program.

The following elements were analyzed simultaneously for liquid samples: Ag, Al, B, Ba, Be, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Si, Sr, Th, Ti, V, Zn, Zr. In the case of solid samples that had been digested with a mixture containing HF, the ICAP reports did not contain data for B and Si, which are at least partially lost due to formation of volatile fluorides. Data for Ba also were not available because of erratic results, probably due to formation of insoluble sulfate.

B. Ion Chromatography

Ion chromatography (IC) was performed on liquid samples with a Dionex Model 10 ion chromatograph equipped with a Varian autoinjector (Model 805500). The anion analysis system consisted of a precolumn, anion separator column, and a suppressor column followed by conductivity detector. Conditions for performing the analysis with $NaHCO_3/Na_2CO_3$ eluent were as specified in the instrument operator manual. Appendix C provides further details.

Analytes quantitated were F^-, Cl^-, NO_3^-, and $SO_4^=$. Chromatograms were also reviewed for the presence of Br^- and $PO_4^=$.

C. Atomic Absorption

Atomic absorption (AA) measurements were performed for As, Se and Pb. Arsenic and selenium were analyzed by Arthur D. Little, Inc. The method was to use the hydride evolution technique on a Perkin Elmer Model 503 spectrometer equipped with an Instrumentation Laboratory Model 440 atomic vapor accessory. The detailed procedure is described in Appendix C.

Atomic absorption was also used to quantitate Pb in various amples. This analysis was performed by Barringer Magenta, Ltd., as part of the "ICAP analysis" suite. The methodology was either flame AA (with a Varian Techtron Model AAS under conditions specified by EPA Method 239.1) or flameless AA (with a Varian Techtron Model 475 and a Perkin Elmer Model HGA 2100 furnace under conditions specified in EPA Method 239.2).

D. Other Analyses

Total Organic Carbon -- Total organic carbon in soils was determined by Barringer Magenta, Ltd., with a LECO induction furnace Model 521-000 used according to manufacturer specifications. Sulfurous acid was added to remove

inorganic carbonate, and the sample was then dried. The dried sample was combusted under O_2, and the CO_2 produced was absorbed in KOH. The change in gas volume was measured volumetrically.

Silicon in Solids -- Silicon in soils was determined by $LiBO_3$ fusion, dissolution of the solid residue in 10% HNO_3, and determination of Si in the solution by ICAP analysis (performed by Barringer Magenta, Ltd.).

Bromate Analysis -- Bromate analysis of boiler cleaning samples was performed by adding an aliquot of the sample (5-25 ml) to 10 ml of 2N hydrochloric acid (HCl) and 5 ml of 0.5N potassium iodide (KI) solution, with a few drops of ammonium paramolybdate solution to catalyze the reaction. The iodine (I_2) produced was titrated with standardized sodium thiosulfate. Starch was the end point indicator.

Other Solid Waste Characterization -- Measurement of total oxidizable sulfur (S), sulfate (SO_4^{-2}), acid insolubles, slurry pH, and % solids were made on selected FGD solid waste samples, as described in Appendix C. Solid samples were freeze-dried to constant weight to determine % solids before other analyses were carried out.

2.5 SPECIAL LABORATORY STUDIES

2.5.1 Soil Attenuation Measurements

Soil samples from each site were analyzed to determine the extent of attenuation of certain major and trace elements. Two leachate solutions (from the Allen site and from the Sherburne County site) were contacted with nine different soils from the various sites. These two solutions were "spiked" with Cd^{+2}, CrO_4^{-2}, Cu^{+2}, Pb^{+2}, and SeO_2^{-2}. (Spiking, the addition of a substance in known concentrations to a solution, is used when the original concentrations may be below detection limits. The procedure establishes measurable baseline concentrations that can be observed for changes when samples are then added to the solution.) A constant volume of spiked solution (50 ml) was mixed with various amounts of as-received soil (0.05, 0.5, 5 and 25 g). The resultant slurries were mixed for 24 hours in a rotary shaker. The slurry was then passed through a 0.45-um filter, and the aqueous phase was preserved by addition of nitric acid and analyzed for pH, As, Se, and a suite of metals via ICAP analysis. A few unacidified extracts were subjected to ion chromatography to determine anions present. Calculations of the amount of analyte sorbed (removed from solution) onto the soil were based on the difference in concentrations in the starting solution and the solution equilibrated with the soil. A t-test (90% confidence level) was performed to determine if this difference in solution concentrations was significant. More information is given in Appendix F.

2.5.2 Extraction Procedure and Radioactivity Measurements

Twenty-three waste samples (fly ash and FGD wastes) were obtained from 18 utilities and subjected to the EPA Extraction Procedure (EP). Samples were used as-received, without drying or grinding. About 100 g of sample were extracted at pH 5.0± 0.2 for 24 hours. The separated aqueous phase was

stabilized with nitric acid and analyzed for Ag, As, Se, Hg, Cr, Cd, Pb, and Ba. As and Se were analyzed by hydride-evolution AA. Hg analysis was conducted with the cold vapor atomic absorption method. Graphite furnace AA techniques were used to analyze all other elements.

Radioactivity measurements were made on 34 waste samples (fly ash, bottom ash, FGD, and boiler slag wastes) from 18 utilities. Gamma-ray spectroscopy was applied to analyze these samples for radium-226. Gamma-ray energies in the 0 to 2 MeV were screened, and emitting nuclides were identified by the characteristic energies of the gamma rays. Several samples were analyzed for radium-228, thorium-228, potassium-40, uranium-238, total uranium and radon emanation.

Appendix D, Application of the EPA Extraction Procedure and Radioactivity Measurements to Coal-Fired Utility Wastes, provides further information on these experiments, including QA/QC data.

2.6 LABORATORY QUALITY CONTROL PROCEDURES

Laboratory QC activities included inserting "blind" quality control samples into each batch of samples to be analyzed. In addition to this level of QC, ICAP analyses performed by Barringer Magenta, Ltd., were subject to that organization's internal routine laboratory QC program.

The following quality control samples (in addition to the field QC samples) were generated in-house:

- Laboratory Duplicate - a split of the field duplicate sample was made upon receipt of samples in the laboratory.
- Blind Standards - a triplicate set of blind standards was inserted routinely into each batch of samples. For larger batches, two triplicate sets were included.
- Digestion Blanks - for samples requiring in-house digestion, a blank was carried along with each batch.
- Spiked Samples - known amounts of standard solutions were added to the various liquid matrices observed during the project.

Quality control procedures were also practiced by Barringer Magenta, Ltd., during their ICAP analyses. Every 10th sample in a batch represented a quality control check sample in the form of a blank, repeat, or certified standard. If the sample was digested before analysis (e.g., solids), reagent blanks, repeat digestions, and appropriate certified solid samples were run. In addition, a drift standard was run after every 10th sample to check instrument stability.

The reference standards used by Arthur D. Little, Inc. throughout this project for liquid samples were Environmental Resource Associates (ERA, Chicago, Illinois) water quality control samples from various lots (MINERALS WasteWatR^{tm}, HARDNESS WasteWatR^{tm}, DEMAND WasteWatR^{tm}, NUTRIENTS WasteWatR^{tm},

TRACE METALS WasteWatR^{tm}). In addition, National Bureau of Standards (NBS) Trace Elements in Water reference standard (1643a) was routinely used. High concentration standards of certain elements (e.g., Si) were prepared from atomic absorption standards (Fischer Scientific). Results are discussed in Section 2.7.3.2.

For solid samples, the reference standards were NBS fly ash (1633 and 1633a) as well as River Sediment (1645). Results are discussed in Section 2.7.3.3.

Table 4 lists the laboratory quality control samples analyzed during this program. These are not categorized according to each individual site since, in most cases, samples from a variety of locations were analyzed simultaneously by the analytical technique.

2.7 ANALYTICAL DATA REVIEW AND ASSESSMENT OF QUALITY

The quality of the analytical chemical data generated during the program was assessed at three points--immediately upon receipt, after incorporation into the on-line data base, and, finally, after all data had been received.

2.7.1 Initial Review of Raw Data

When the analytical report for a batch of samples was received, the results obtained for blind QC samples were inspected before the data were entered into the data base. Reference standards were usually submitted in triplicate. Reproducible, but low or high recoveries for one or a few particular analytes were occasionally observed, suggesting instrument or calculation problems which were then investigated and corrected. The samples were reanalyzed, if necessary. Occasionally results from one member of a set differed substantially from the other members. These were discussed with the ICAP services vendor. Problems with their computerized report generator were identified and corrected.

2.7.2 Review of Data Base Summary Reports

After the problems detected in the initial review had been corrected, the data were entered into the on-line data base developed for the program. A site report containing the new data along with all the data from preceding trips was then printed out.

At the same time, an updated QC site report was prepared which summarized the results for all QC samples--blank levels, recoveries of standards, reproducibility of replicates, and recovery of spikes--analyzed up to that time. Reasons for high blanks [criteria: greater than three times the detection limit (DL)], bad standard or spike recoveries (outside the criteria range of 100 ±25%) or poor replicate precision (criteria: less than 75% RSD) were noted, investigated, and corrected. The newest data for each sampling location were compared to the data obtained during previous sampling trips. Any substantial changes were noted and checked.

TABLE 5

SUMMARY OF LABORATORY QUALITY CONTROL PROGRAM

ICAP	
Blanks	70
Duplicates	137
Standards	117
Spikes	30
IC	
Blanks	70
Duplicates	137
Standards	78
Spikes	12
AA (As, Se)	
Blanks	14
Standards	31
Spikes	18
Solids	
Standards	9
Duplicates	10

Source: Arthur D. Little, Inc.

2.7.3 Retrospective Assessment of Overall Data Quality

After all analyses were complete, the entire QC data file developed during the program was analyzed for an estimate of the overall quality of the data. This analysis was based on the criteria described in the preceding paragraph. Results are discussed below.

2.7.3.1 Behavior of Blanks

A total of 75 blanks were analyzed by ICAP during the program. Only a relatively small percentage showed detectable levels of the analytes sought. Table 5 shows for each element the number of positive blanks that fell into each of three concentration ranges--great than DL but less than or equal to 3 DL, greater than 3 DL but less than or equal to 10 DL, and greater than 10 DL. Included in the table are the corresponding detection limits for each element. The detection limits for ICAP were taken as reported by Barringer-Magenta based on their own internal QC program. In some instances the ICAP detection limits for particular elements changed somewhat (by a factor of 2-5) during the course of the program due to degradation or improvement in instrument performance. In those cases, the highest reported detection limits are shown in the table.

With only a few exceptions, the percentage of positive blanks was very small, and these were at levels very close to the detection limit. Calcium and magnesium were two exceptions. They were quite ubiquitous, and their ICAP detection limits were low. The blank levels observed were not significant when compared to the actual levels measured in field samples. A number of high cobalt and iron blanks were observed primarily during the first two sampling visits to Plant 5 (Sherburne County). Their possible impact on the site data was noted for the assessment team. Similarly, high silicon blanks were observed in samples from Plant 9 (Smith)--particularly blank samples of the local demineralized water used to rinse equipment. Again, their presence was noted. In many instances, samples taken from upgradient, background wells showed levels considerably below levels observed in the few positive blanks at that site; thus there was no effect on the assessment.

The behavior of 70 IC blanks is shown in Table 6. In only three instances was a value greater than 3 DL observed.

2.7.3.2 Behavior of Replicates

As discussed earlier, three types of replicate groundwater samples were taken during the program--sequential duplicate samples from the same source, field splits of a particular sample, and lab splits of a sample. Since sequential samples taken from the same sampling point are the best indicators of overall sampling and analysis precision, the results of an analysis of sequential well duplicates in shown in Table 7. The summary includes all duplicate pairs in which one of the two measurements was greater than the detection limits. In cases where one of the two measurements was less than the detection limit, the detection limit value was substituted for the missing value. Because Barringer-Magenta tends to set conservative detection limits well above instrument noise levels, it was more appropriate to use the

TABLE 6

LEVELS OF POSITIVE ICAP BLANKS[a]

Element	Detection Limit (ppm)	Number of Blanks in Range ≥DL-3DL	>3DL-10DL	>10DL
Silver	0.01	5	0	0
Aluminum	0.05	0	0	0
Boron	0.02	6	2	0
Barium	0.01	4	1	0
Beryllium	0.0005	2	0	0
Calcium	0.05	22	12	5
Cadmium	0.1	0	0	0
Cobalt	0.05	8	1	3
Chromium	0.05	3	0	0
Copper	0.008	8	5	1
Iron	0.01	6	12	7
Potassium	1.0	12	0	0
Magnesium	0.01	18	9	6
Manganese	0.01	5	0	1
Molybdenum	0.3	2	0	0
Sodium	2.0	5	1	1
Nickel	0.05	4	0	0
Phosphorous	0.6	0	0	0
Lead	0.05	2	0	0
Silicon	0.05	4	3	5
Strontium	0.001	23	5	3
Thorium	0.05	6	2	0
Titanium	0.005	7	0	0
Vanadium	0.005	15	4	0
Zinc	0.05	1	2	0
Zirconium	0.05	3	0	0

[a]A total of 75 blanks were analyzed.

Source: Arthur D. Little, Inc.

TABLE 7

LEVELS OF POSITIVE IC BLANKS[a]

Anion	Detection Limit (ppm)	Number of Blanks in Range		
		≥DL-3DL	>3DL-10DL	>10DL
Fluoride	0.1	4	0	0
Chloride	0.5	5	1	0
Nitrate	0.5	3	1	0
Sulfate	2.0	6	1	0

[a] A total of 70 blanks were analyzed.

Source: Arthur D. Little, Inc.

TABLE 8

ANALYTICAL PRECISION FOR DUPLICATE WELL SAMPLES

Element	Percent Relative Standard Deviation for Various Concentration Levels		
Silver	0.005 – 0.009[a]		
	– [b]		
	0[c]		
Aluminum	0.01 – 0.22	0.22 – 0.78	0.78 – 42.8
	25%	10%	20%
	6	14	3
Boron	0.004 – 0.068	0.068 – 0.854	0.854 – 103
	12%	10%	2.6%
	16	15	15
Barium	0.005 – 0.22		
	7.8%		
	43		
Beryllium	0.0005 – 0.0075		
	0.5%		
	4		
Calcium	0.81 – 52	52 – 118	118 – 1840
	3.5%	1.7%	3.1%
	14	18	24
Cadmium	0.007 – 0.045	0.045 – 0.2	
	17%	24%	
	19	1	
Cobalt	0.05 – 0.115		
	3.6%		
	7		
Chromium	0.008 – 0.15		
	2.2%		
	9		

TABLE 8 (continued)

ANALYTICAL PRECISION FOR DUPLICATE WELL SAMPLES

Element	Percent Relative Standard Deviation for Various Concentration Levels		
Copper	0.005 - 0.041[a] 10.5%[b] 17[c]		
Iron	0.01 - 0.105 22% 24	0.105 - 0.94 19% 6	0.94 - 101 20% 11
Potassium	1.0 - 1.5 7.9% 6	1.5 - 67.5 4.6% 30	67.5 - 596 3.9% 3
Magnesium	0.79 - 9.27 5.7% 17	9.27 - 191 2.1% 36	191 - 2040 10.7% 3
Manganese	0.01 - 0.085 16% 16	0.085 - 0.84 11% 9	0.84 - 30.4 12% 14
Molybdenum	1.2 - 2.25 4.9% 2		
Sodium	2 - 68 3.6% 34	68 - 183 2.1% 6	183 - 7280 2.2% 13
Nickel	0.01 - 0.125 10.5% 15	0.125 - 0.28 5.4% 11	
Phosphorous	0.5 - 3.5 2.6% 19		

TABLE 8 (continued)

ANALYTICAL PRECISION FOR DUPLICATE WELL SAMPLES

Element	Percent Relative Standard Deviation for Various Concentration Levels		
Lead	0.05 - 1[a] 0%[b] 1[c]		
Silicon	0.05 - 0.82 29% 4	0.82 - 0 1.8 27% 3	1.8 - 30 4.5% 27
Strontium	0.007 - 63 4.0% 56		
Thorium	0.01 - 0.25 7.4% 23		
Titanium	0.005 - 0.0205 8.5% 6		
Vanadium	0.005 - 0.0905 12.4% 22		
Zinc	0.02 - 0.19 8% 18	0.19 - 0.485 33% 2	
Zirconium	0.02 - 0.085 12.5% 2		
Fluoride	0.1 - 0.5[a] 3.2%[b] 17[c]	0.5 - 1.45 14% 7	1.45 - 48 10% 7

TABLE 8 (continued)

ANALYTICAL PRECISION FOR DUPLICATE WELL SAMPLES

Element	Percent Relative Standard Deviation for Various Concentration Levels		
Chloride	0.5 - 2.5	2.5 - 7	7 - 14,700
	6.7%	14%	8.9%
	4	15	35
Nitrate	0.5 - 2.45	2.45 - 6.5	6.5 - 1;580
	8.8%	14%	11%
	14	9	16
Sulfate	2 - 6.45	6.45 - 27.5	27.5 - 8,370
	7.4%	7.8%	8.1%
	5	8	33

[a] Concentration ranges (ppm)
[b] Relative Standard Deviation
[c] Number of sample pairs compared

Source: Arthur D. Little, Inc.

detection limit value for a less-than value than to use zero. In many of the entries shown in Table 7, reproducibilities have been calculated for two or three ranges of concentrations encountered during the program. For example, six pairs of aluminum duplicates ranging in concentration from 0.01 to 0.22 ppm were observed to have a relative standard deviation (RSD) of 25%. Fourteen aluminum samples in the range of 0.22 to 0.78 ppm had an RSD of 10% and three pairs ranging in concentration from 0.78 to 42.8 ppm had an RSD of 20%.

In general, reproducibility was quite good. Except for silicon and two pairs of zinc samples, all the RSD's were 25% or less, consistent with program goals.

2.7.3.3 Recoveries of Analytical Standards

Analytical standards at various concentrations were submitted blind with each set of samples for ICAP and IC. The recoveries of analytical standards observed throughout the program are summarized for one to three different concentration ranges in Tables 8 and 9. Listed beneath each concentration range is the average percent recovery followed by the standard deviation for that set of percent recoveries. Below the recovery data is shown the number of standards which comprised the set. Many of the results were within ±10% of the expected value; with only a few exceptions all were within ±25%. Aluminum measurements at the relatively low levels studied were scattered and on the average high. Cobalt and nickel recoveries at the lowest concentration range (less than 2 DL) were high and low, respectively. These observations for aluminum, cobalt, and nickel were communicated to the assessment team. In all cases, the assessment team was able to complete the required analysis without using questionable data. Lead standards at concentrations up to about five times the detection limit were erratic and low. To better quantitate lead at low concentrations, selected samples were analyzed by graphite furnace atomic absorption spectroscopy. Nitrate standards in the concentration range 0.5 to 2 ppm were also quite imprecise and the recoveries were high. Nitrate measurements at those concentration levels were not important in the assessment process.

2.7.3.4 Results of Spiking Experiments

Throughout the program, selected samples were spiked with known amounts of elements of particular interest. Spiking studies were most important in the samples obtained from Plant 9 (Smith), because many contained constituents of sea water at relatively high concentrations. The results of the spiking studies are tabulated in Attachment 1. For each element, the information in the first column at the left identifies the nature of the sample that was spiked. The next two columns to the right identify the concentration or range of concentrations added to the sample. The next column contains the number of samples spiked, followed by the average percent recovery for the spike, the standard deviation of those recoveries and finally, the percent relative standard deviation.

Most recoveries lay within the 75% to 125% recovery range. Aluminum, as noted above, was erratic and on the average high. Barium recovery from sea

TABLE 9

RECOVERIES OF ANALYTICAL REFERENCE STANDARDS
FOR WATER SAMPLES

Element	Percent Recovery ± Standard Deviation for Various Concentration Levels		
Silver	0.05 - 0.1[a] 97 ± 8[b] 10[c]	0.1 - 0.2 100 ± 3 2	
Aluminum	0.24 - 0.96 166 ± 63 24		
Boron	0.1 - 0.9 93 ± 17 35	0.9 - 95 93 ± 1.8 5	
Barium	0.046 - 0.141 83 ± 12 21	0.141 - 2.64 94 ± 12 65	2.64 - 4.4 102 ± 6.5 3
Beryllium	0.019 - 0.099 90 ± 7.6 30	0.099 - 0.6 91 ± 8.1 57	0.6 - 1 100 ± 3.6 3
Calcium	52 - 118 99 ± 2.9 21	118 - 829 100 ± 6 21	
Cadmium	0.05 - 0.54 101 ± 42 65	0.54 - 0.9 89 ± 5 3	
Cobalt	0.082 - 0.096 131 ± 23 2	0.096 - 1.7 91 ± 39 65	1.7 - 2.55 101 ± 3 3
Chromium	0.017 - 0.08 117 ± 73 19	0.08 - 1.5 93 ± 17 56	1.5 - 2.5 110 ± 5.3 3

TABLE 9 (continued)

RECOVERIES OF ANALYTICAL REFERENCE STANDARDS
FOR WATER SAMPLES

Element	Percent Recovery ± Standard Deviation for Various Concentration Levels		
Copper	0.018 - 0.064 89 ± 38 25	0.064 - 1.2 97 ± 6.6 65	1.2 - 2.0 100 ± 2.0 3
Iron	0.078 - 0.109[a] 78 ± 39[b] 25[c]	0.109 - 2.0 106 ± 22 65	2.0 - 3.4 103 ± 3.3 3
Potassium	1.5 - 100 105 ± 22 32	100 - 591 106 ± 9.8 11	
Magnesium	10 - 200 102 ± 7.2 39	200 - 500 99 ± 4.0 3	
Manganese	0.031 - 0.0832 94 ± 6 22	0.0832 - 1.56 101 ± 12 65	1.56 - 26 120 ± 4.2 3
Molybdenum	1.14 - 1.9 99 ± 4.9 3	94.7 ± 0 3	
Sodium	100 - 210 102 ± 3.1 27	210 - 502 98 ± 3.3 14	
Nickel	0.055 - 0.096 35 ± 51 21	0.096 - 1.08 103 ± 22 65	1.08 - 1.3 89 ± 2.7 3
Phosphorous	5.7 113 ± 1.4 2		

TABLE 9 (continued)

RECOVERIES OF ANALYTICAL REFERENCE STANDARDS
FOR WATER SAMPLES

Element	Percent Recovery ± Standard Deviation for Various Concentration Levels		
Lead	0.1 - 0.24 55 ± 49 54	0.24 - 0.82 97 ± 5.2 9	0.82 - 1.15 95.7 ± 0 3
Silicon	1 - 2[a] 90 ± 9.5[b] 6[c]	2 - 5 81 ± 2.1 2	
Strontium	0.239 84 ± 5.5 20		
Thorium	No Standards		
Titanium	0.032 106 1	0.054 - 0.6 95 ± 10 56	0.6 - 1.0 105 ± 3.8 3
Vanadium	0.0384 - 0.098 87 ± 20 33	0.098 - 0.72 99 ± 8.8 42	0.72 - 1.2 98 ± 2.9 3
Zinc	0.072 - 0.11 80 ± 31 21	0.11 - 2.07 97 ± 14 65	2.07 - 3.45 97 ± 5 3
Zirconium	0.2 97 ± 2.9 3	0.8 102 ± 1.4 2	
Fluoride	0.1 - 0.4 112 ± 17 11	0.4 - 1.1 97 ± 4.7 6	1.1 - 50 105 ± 16 45

TABLE 9 (continued)

RECOVERIES OF ANALYTICAL REFERENCE STANDARDS
FOR WATER SAMPLES

Element	Percent Recovery ± Standard Deviation for Various Concentration Levels		
Chloride	0.5 107 ± 31 3	5 - 6 98 ± 17 8	6 - 10,000 107 ± 27 63
Nitrate	0.5 - 2 155 ± 47 5	2 - 7.5 108 ± 15 8	7.5 - 250 100 ± 15 42
Sulfate	2 - 5[a] 122 ± 14[b] 5[c]	5 - 25 107 ± 21 13	25 - 1,400 96 ± 11 57
Phosphate	2.5 100 ± 11 3	10.1 - 17.5 108 ± 8.7 9	

[a] [b] Concentration Range (ppm)
[b] [c] Percent Recovery ± Standard Deviation
[c] Number of samples in set

Source: Arthur D. Little, Inc.

TABLE 10

SUMMARY OF NBS STANDARDS RECOVERY (SOLIDS) BY ICAP
(all in ppm)

	NBS 1633 Fly Ash			NBS 1633a Fly Ash			NBS 1645 River Sediment		
	Ref. Value	Analyzed[a]	Rec %	Ref. Value	Analyzed[b]	Rec %	Ref. Value	Analyzed[c]	Rec %
Be	12	8±3	67±25	12	10.9±0.4	91±3	--	--	--
Cd	1.45	11.6±11.2	800±772	1	10.4±8.2	1040±820	10.2	11.7±15.1	115±148
Co	38	46.3±18.2	119±48	46	38±9.5	83±21	8	<5±0	<63
Cr	131	105±15	80±11	196	124±69	63±35	29600	20200±3680	68±12
Cu	128	110±50	86±39	118	117±3	99±3	109	106±4	97±4
K	17200	16770±2750	98±16	18800	18470±305	98±2	12000	12350±71	103±1
Mn	493	405±70	82±14	190	169±8	89±4	785	715±27	91±3
Ni	98	74.5±31.6	76±39	127	119±16	94±13	46	41.5±14.8	90±32
Pb[d]	70	50±25	71±36	72	60±5	83±7	714	740±28	104±4
Sr	1380	1079±33	78±2	830	695±16	84±2	--	--	--
Th	24	28±7	117±29	23	25±3.6	140±14	1.6	<1±0	<63
V	214	164±55	77±26	300	281±7.5	94±3	23.5	27.2±2.8	116±12
Zn	210	189±78	90±37	220	230±37	105±17	1720	1695±304	87±18
Ca	--	--	--	11100	10800±529	97±5	--	--	--
Fe	--	--	--	94000	97600±3990	104±4	113000	110500±4950	98±4
Mg	--	--	--	4550	4343±152	95±3	--	--	--
Mo	--	--	--	29	<43±23	<148	--	--	--
Na	--	--	--	1700	2930±451	166±27	5500	5550±354	101±6
Ti	--	--	--	8000	8070±174	101±2	--	--	--
Al	--	--	--	140000	134700±5130	96±4	--	--	--

[a] 4 Values
[b] 3 Values
[c] 2 Values
[d] Analysis using atomic absorption

water was very poor; these results were not used in the Plant 9 (Smith) assessment. For several of the spikings, beryllium recoveries were somewhat low. Low level cobalt spikes into 100% sea water were imprecise, and, on the average, low; the assessment team was appraised of the problem. Recoveries of chromium in the two samples spiked from Plant 1 (Elrama) were about 60%; chromium was not important in the assessment for Plant 1. The low level iron recoveries for the Plant 1 (Elrama) and 6 (Powerton) samples were erratic and, on the average, high. The assessment team was cautioned to avoid using data for iron in this concentration range. Recoveries of all the lead spikes were low. As noted in the preceding subsection, selected important samples were rechecked by graphite furnace atomic absorption spectroscopy. Silicon was disregarded in the Plant 9 assessment. In all cases, the assessment team was able to complete the required analysis without using any questionable data.

2.8 RESULTS FOR PERFORMANCE AUDIT SAMPLES

Two performance audit samples, one a liquid and the other a solid, were received from Mr. Alvia Gaskill, Jr., of Research Triangle Institute, on April 26, 1982. Portions of the samples were submitted to Barringer-Magenta for ICAP analyses. Measurements of arsenic and selenium were performed in the ADL laboratories. The results of the analyses were returned to Mr. Gaskill on August 2, 1982. Included with the results was a discussion of the analytical procedures used and the quality control samples that were submitted along with the performance audit samples.

The results obtained for the liquid and solid performance audit samples are shown in Tables 10 and 11, respectively. Based on the quality control samples which were submitted as part of the lot, the ICAP results for several elements were doubtful and a value was not reported. The notes accompanying Tables 9 and 10 discuss the analytical problems. The RTI auditor indicated that the results were satisfactory.

2.9 IDENTIFICATION AND RESOLUTION OF SIGNIFICANT SAMPLING AND ANALYSIS PROBLEMS

As noted previously, a variety of analytical problems were encountered throughout the ongoing QA/QC program. By far the most frequent problem which required corrective action was the appearance of a result which was grossly in error. For example, one member of a triplicate set of standards might have zero recovery while the other two members showed good recovery. In other instances, the results for the analysis of two samples appeared interchanged. These problems were communicated to Barringer-Magenta and resolved either by examination of the raw ICAP data or by reanalyzing retained samples.

From time to time, inter-element interferences and matrix effects were detected. While Barringer-Magenta attempted to correct for known inter-element interferences, certain inter-element effects were observed in the data. Detailed QC analyses sufficient for accurate mathematical corrections were beyond the scope of this program. The general nature of the effects were communicated from time to time to the assessment team so that they would be aware of the limitations of data validity as they were proceding with their assessment. For example, on February 1, 1982, a memorandum was

TABLE 11

SUMMARY OF ANALYTICAL RESULTS
RTI "LIQUID" AUDIT SAMPLE

Element	Concentration (mg/L)[b]	Long-Term Method Performance
Ag	AP[c]	Note 1
Al	AP	Note 2
B	0.047 ± 0.012	Recovery of 100 ± 25% at 0.3 mg/L
Ba	0.037 ± 0.001	Recovery of 100 ± 25% at 1 mg/L
Be	0.017 ± 0.0002	Recovery of 100 ± 25% at 0.02 to 0.1 mg/L
Ca	23.6 ± 0.5	Recovery of 100 ± 25% at 50-500 mg/L
Cd	<0.01	Recovery of 100 ± 25% at 0.1 mg/L
Co	<0.05	Recovery of 100 ± 25% at 0.1-0.3 mg/L
Cr	0.053 ± 0.006	Recovery of 100 ± 25% at 0.2 mg/L[e]
Cu	0.015 ± 0.002	Recovery of 100 ± 25% at 0.2 mg/L
Fe	0.11 ±0.01	Recvoery of 100 ± 25% at 0.3 mg/L
K	<1	Recovery of 100 ± 25% at 30 mg/L
Mg	6.7 ± 0.2	Recovery of 100 ± 25% at 10-500 mg/L
Mn	0.03 ±0.000	Recovery of 100 ± 25% of 0.1-0.3 mg/L
Mo	AP	Note 3
Na	8 ± 0	Recovery of 100 ± 25% at 100-800 mg/L
Ni	0.06 ±0.006	Recovery of 100 ± 25% at 0.1-0.3 mg/L
P	AP	Note 4
Pb[d]	AP	Note 5
Si	AP	Note 6
Sr	0.181 ± 0.002	Recovery of 100 ± 25% at 0.2 mg/L
Th	AP	Note 7
Ti	0.013 ± 0.000	Recovery of 100 ± 25% at 0.1 mg/L
V	0.052 ± 0.002	Recovery of 100 ± 25% at 0.1 mg/L
Zn	0.06 ± 0.006	Recovery of 100 ± 25% at 0.3 mg/L
Zr	AP	Note 8
As[d]	0.079 ± 0.003	Recovery of 100 ± 25% at 0.080 mg/L
Se[d]	0.010 ± 0.001	Recovery of 100 ± 25% at 0.010 mg/L

(a) Based on analyses of blind standards sent with each lot of samples to be analyzed. (See cover letter.)
(b) Mean and standard deviation for triplicate analyses.
(c) Analysis problem. (See cover letter and series of explanatory notes attached to this table.)
(d) These elements were analyzed by AA. The remainder by ICAP.
(e) For Cr standards at 0.017 mg/L, results raning from <0.010-0.030 mg/L have been obtained.

Source: Arthur D. Little, Inc.

NOTES FOR TABLE 11 DATA

Note 1: The performance for Ag recovery of 100 ± 25% at 0.050 mg/L was not met. Barringer reported a value of <0.005 mg/L for the RTI sample. We are aware of at least one instance of low recovery on blind standards. We are investigating these values, since Ag is a relatively important element with regard to the proposed primary drinking water criteria.

Note 2: Throughout the program, recovery of Al has been variable in the range of 0 to 200% for 0.2-1 mg/L concentration range. Recovery of blind standards for this analysis set showed very poor recovery. Barringer reported a value of <0.01 mg/L. Since Al is not in the proposed primary or secondary drinking water criteria and is not expected to be a major FGC waste tracer, it has been viewed as a low priority element and no corrective action has been taken.

Note 3: Barringer reported a value of < 0.3 mg/L for the RTI sample. The reference value for the blind standard is below the ICAP detection limit. We are investigating the behavior of Mo at higher levels.

Note 4: Barringer reported a value of <0.6 mg/L. This element is considered low priority because it is not in the proposed drinking water criteria and it is not expected to be a good FGC waste tracer. In addition, phosphate is measurable in the liquids using ion chromatography.

Note 5: The performance target for Pb recovery of 100 ± 25% at 0.1-0.8 mg/L was not met for this set of samples. A recovery of <50% at 0.1 mg/L was observed. Barringer reported a value of <0.05 mg/L. Since this is an important element with regard to the proposed drinking water criteria, reanalysis of this particular set of samples has been requested of Barringer-Magenta.

Note 6: This is regarded as a low priority element. No standards containing Si were sent with the particular batch of samples. Barringer reported a value of <0.05 mg/L. We are currently in the process of investigating recovery of blind standards.

Note 7: This is regarded as a low priority element. No standards containing Th have been analyzed during the program. Barringer reported a value of <0.01 mg/L.

Note 8: This is regarded as a low priority element. No standards containing Zr have been analyzed during the program. Barringer reported a value of <0.05 mg/L.

TABLE 12

SUMMARY OF ANALYTICAL RESULTS
RTI "SOLID" AUDIT SAMPLE

Element	Concentration (mg/L)[b]	Long-Term Method Performance[a]
Ag	AP[c]	Note 1
Al	85000 ± 4200	Recovery of 100 ± 25% at 140000 µg/g
Be	1.45 ± 0.04	Recovery of 100 ± 25% at 12 µg/g
Ca	24500 ± 1100	Recovery of 100 ± 25% at 11000 µg/g
Cd	AP	Note 2
Co	<5	Recovery of 100 ± 50% at 50 µg/g
Cr	2, <1, <1	Recovery of 100 ± 50% at 200 µg/g
Cu	90 ± 3	Recovery of 100 ± 25% at 100 µg/g
Fe	51000 ± 5000	Recovery of 100 ± 25% at 94000 µg/g
K	21300 ± 700	Recovery of 100 ± 25 at 12000 µg/g
Mg	12800 ± 600	Reocvery of 100 ± 25% at 4500 µg/g
Mn	900 ± 100	Recovery of 100 ± 25% at 190 µg/g
Mo	AP	Note 3
Na	AP	Note 4
Ni	7 ±1	Recovery of 100 ± 50% at 45 µg/g
P	AP	Note 5
Pb[d]	140 ± 20	Recovery of 100 ± 50% at 70 µg/g
Sr	342 ± 6	Recovery of 100 ± 25% at 800 µg/g
Th	10 ± 7	Recovery of 100 ± 50% at 25 µg/g
Ti	5200 ± 400	Recovery of 100 ± 25% at 8000 µg/g
V	143 ± 7	Recovery of 100 ± 25% at 25 µg/g
Zn	360 ± 20	Recovery of 100 ± 25% at 220 µg/g
Zr	AP	Note 6
As[d]	106 ± 7	Recovery of 100 ± 25% at 70 µg/g
Se[d]	0.20 ± 0.05	Recovery of 100 ± 30% at 10 µg/g

(a) Based on analyses of blind standards sent with each lot of samples to be analyzed. (See cover letter.)
(b) Mean and standard deviation for triplicate analyses.
(c) Analysis problem. (See cover letter and series of explanatory notes attached to this table.)
(d) These elements were analyzed by AA. The remainder by ICAP.

Source: Arthur D. Little, Inc.

NOTES FOR TABLE 12 DATA

Note 1: No value for Ag is available for the blind standards we have used, and thus, recovery is not known. Barringer reported a value of <0.5ug/g for the RTI check sample.

Note 2: Our recovery target of 100 ± 25% at 10 ug/g was not met. Barringer reported a value of <1 ug/g for the RTI check sample. Variable Cd recoveries are under investigation.

Note 3: The reference values available for the blind standard we have used are just at the ICAP detection limit. Reliable recovery data is thus not available. Barringer reported a value of <30 ug/g for the RTI check sample. Mo recoveries are under investigation.

Note 4: Our recovery target of 100 ± 25% at 5500 ug/g was met for river sediment blind standards but not for flyash blind standards. This problem is under review. Barringer reported a value of 23200 ± 900 ug/g for the RTI check sample.

Note 5: Reference values for P in our blind standards are not available and thus recovery is unknown. Barringer reported a value of 1380 ± 50 ug/g.

Note 6: Reference values for Zr in our blind standards are not available and thus recovery is unknown. Barringer reported a value of 121 ± 7 ug/g for the RTI check sample.

submitted which pointed out a number of problems which had been observed. They included:

- Values for vanadium were much lower in the presence of high levels of magnesium. In the presence of 80 ppm or less of Mg, recoveries of V were observed to be 84 ±12%. However, for levels of Mg higher than 80 ppm, V recoveries decreased, e.g., at 159 ppm Mg a recovery of 7% was observed for V.

- Levels of Mg above 80 ppm were also found to depress the recovery of chromium.

- Measured concentrations of aluminum in samples containing calcium in the vicinity of 800 ppm were found to be high by a factor of 1-3 when Al was present in the 0.2 - 1 ppm range. The enhancement of Al resulted from the fact that Al is measured at an emission line located between two closely spaced, intense calcium lines. It was recommended that the assessment team request reanalysis of selected samples for chromium or vanadium if the values for those samples were deemed to be important in the assessment effort.

The resolution of other ICAP analysis problems was reported in a memorandum dated July 30, 1982.

- High values of silver were observed in certain samples of an analyses lot including several blanks. The analyses were repeated, and no silver was found in any of the samples. The problem was traced to an incorrect value for a silver reference standard.

- Another interaction between chromium and magnesium which had been detected was finally attributed to a mechanical problem in the ICAP optics. Barringer-Magenta corrected the program and reanalyzed the set of samples in question.

ATTACHMENT 1

SUMMARY OF ICAP SPIKE RECOVERIES

ICAP SPIKE RECOVERIES

Type of Sample	Spike Conc. (ppm)		#Samples	% Recov.	S.D.	% RSD
ELEMENT: 7 SILVER						
DET. LIMIT: <0.005 <0.01						
ERA 8301 (1:100) IN 100 PC SEA			0			
ERA 8301 (1:100) IN 10 PC SEA			0			
ERA 8301 (1:10) IN 10 PC SEA			0			
OTHERS IN 100 PC SEA	0.05	0.1	3	78.3	6.03	8.12
PLANT ONE SPIKES			0			
PLANT SIX SPIKES			0			
PLANT THREE SPIKES			0			
ELEMENT: 8 ALUMINUM						
DET. LIMIT: <0.01 <0.1						
ERA 8301 (1:100) IN 100 PC SEA			0			
ERA 8301 (1:100) IN 10 PC SEA			0			
ERA 8301 (1:10) IN 10 PC SEA			0			
OTHERS IN 100 PC SEA			0			
PLANT ONE SPIKES	0.24	0.24	2	138	124	89.9
PLANT SIX SPIKES			0			
PLANT THREE SPIKES			0			
ELEMENT: 9 BORON						
DET. LIMIT: <0.004 <0.02						
ERA 8301 (1:100) IN 100 PC SEA			0			
ERA 8301 (1:100) IN 10 PC SEA			0			
ERA 8301 (1:10) IN 10 PC SEA			0			
OTHERS IN 100 PC SEA	2	2	3	96.2	2.47	2.74
PLANT ONE SPIKES			0			
PLANT SIX SPIKES			0			
PLANT THREE SPIKES			0			
ELEMENT: 10 BARIUM						
DET. LIMIT: <0.005						
ERA 8301 (1:100) IN 100 PC SEA			0			
ERA 8301 (1:100) IN 10 PC SEA			0			
ERA 8301 (1:10) IN 10 PC SEA	4.4	4.4	2	2.15	0.177	8.23
OTHERS IN 100 PC SEA			0			
PLANT ONE SPIKES			0			
PLANT SIX SPIKES			0			
PLANT THREE SPIKES			0			

ELEMENT: 11 BERYLLIUM
DET. LIMIT: <0.0005

Type of Sample	Spike Conc. (ppm)		#Samples	% Recov	S.D.	% RSD
ERA 8301 (1:100) IN 100 PC SEA	0.1	0.1	8	72.1	6.64	9.21
ERA 8301 (1:100) IN 10 PC SEA	0.1	0.1	9	90.2	4.58	5.08
ERA 8301 (1:10) IN 10 PC SEA	1	1	2	71.8	0.354	0.493
OTHERS IN 100 PC SEA			0			
PLANT ONE SPIKES	0.04	0.04	2	67.2	0.212	0.315
PLANT SIX SPIKES	0.01	0.01	2	84	5.66	6.74
PLANT THREE SPIKES	0.2	0.2	1	100	0	0

ELEMENT: 12 CALCIUM
DET. LIMIT: <0.01

ERA 8301 (1:100) IN 100 PC SEA			0			
ERA 8301 (1:100) IN 10 PC SEA			0			
ERA 8301 (1:10) IN 10 PC SEA			0			
OTHERS IN 100 PC SEA	200	200	3	108	2	1.85
PLANT ONE SPIKES	166	166	2	97.9	24.3	24.8
PLANT SIX SPIKES			0			
PLANT THREE SPIKES			0			

ELEMENT: 13 CADMIUM
DET. LIMIT: <0.01 <0.1

ERA 8301 (1:100) IN 100 PC SEA	0.09	0.09	8	75	15.4	20.5
ERA 8301 (1:100) IN 10 PC SEA	0.09	0.09	9	99.9	16.6	16.6
ERA 8301 (1:10) IN 10 PC SEA	0.9	0.9	2	85	3.96	4.66
OTHERS IN 100 PC SEA			0			
PLANT ONE SPIKES	0.062	0.062	2	105	11.5	11
PLANT SIX SPIKES			0			
PLANT THREE SPIKES	0.18	0.18	1	88.9	0	0

ELEMENT: 14 COBALT
DET. LIMIT: <0.05 <0.1

Type of Sample	Spike Conc. (ppm)		# Samples	% Recov.	S.D.	% RSD
ERA 8301 (1:100) IN 100 PC SEA	0.255	0.255	8	62.3	35.8	57.5
ERA 8301 (1:100) IN 10 PC SEA	0.255	0.255	9	96.3	64.2	66.7
ERA 8301 (1:10) IN 10 PC SEA	2.55	2.55	2	97.5	16.3	16.7
OTHERS IN 100 PC SEA			0			
PLANT ONE SPIKES	0.424	0.424	2	117	8.49	7.26
PLANT SIX SPIKES			0			
PLANT THREE SPIKES	0.51	0.51	1	112	0	0

ELEMENT: 15 CHROMIUM
DET. LIMIT: <0.01 <0.05

ERA 8301 (1:100) IN 100 PC SEA	0.25	0.25	8	118	23	19.5
ERA 8301 (1:100) IN 10 PC SEA	0.25	0.25	9	118	14.6	12.4
ERA 8301 (1:10) IN 10 PC SEA	2.5	2.5	2	92.7	14.6	15.7
OTHERS IN 100 PC SEA			0			
PLANT ONE SPIKES	0.315	0.315	2	60.4	44.9	74.3
PLANT SIX SPIKES	0.01	0.01	2	100	0	0
PLANT THREE SPIKES	0.5	0.5	1	104	0	0

ELEMENT: 16 COPPER
DET. LIMIT: <0.008 <0.02

ERA 8301 (1:100) IN 100 PC SEA	0.2	0.2	8	84.4	8.41	9.96
ERA 8301 (1:100) IN 10 PC SEA	0.2	0.2	9	90.4	7.81	8.64
ERA 8301 (1:10) IN 10 PC SEA	2	2	2	85.1	2.19	2.57
OTHERS IN 100 PC SEA			0			
PLANT ONE SPIKES	0.19	0.19	2	95.8	4.45	4.65
PLANT SIX SPIKES	0.009	0.009	2	111	0	0
PLANT THREE SPIKES	0.4	0.4	1	101	0	0

ELEMENT: 17 IRON
DET. LIMIT: <0.01

Type of Sample	Conc. (ppm)		#Samples	% Recov.	S.D.	% RSD
ERA 8301 (1:100) IN 100 PC SEA	0.34	0.34	7	92	29.8	32.4
ERA 8301 (1:100) IN 10 PC SEA	0.34	0.34	9	86	28.1	32.7
ERA 8301 (1:10) IN 10 PC SEA	3.4	3.4	2	90.9	1.7	1.87
OTHERS IN 100 PC SEA			0			
PLANT ONE SPIKES	0.11	0.11	1	245	0	0
PLANT SIX SPIKES	0.04	0.04	2	213	159	74.6
PLANT THREE SPIKES	0.68	0.68	1	104	0	0

ELEMENT: 18 POTASSIUM
DET. LIMIT: <1

ERA 8301 (1:100) IN 100 PC SEA			0			
ERA 8301 (1:100) IN 10 PC SEA			0			
ERA 8301 (1:10) IN 10 PC SEA			0			
OTHERS IN 100 PC SEA	148	148	3	123	3.79	3.08
PLANT ONE SPIKES	7.87	78.7	2	102	14.1	9.93
PLANT SIX SPIKES			0			
PLANT THREE SPIKES			0			

ELEMENT: 19 MAGNESIUM
DET. LIMIT: <0.01

ERA 8301 (1:100) IN 100 PC SEA			0			
ERA 8301 (1:100) IN 10 PC SLA			0			
ERA 8301 (1:10) IN 10 PC SLA			0			
OTHERS IN 100 PC SEA	498	498	3	95.1	5.9	6.2
PLANT ONE SPIKES	23.9	23.9	2	80.3	19	23.7
PLANT SIX SPIKES			0			
PLANT THREE SPIKES			0			

ELEMENT: 20 MANGANESE
DET. LIMIT: <0.01

ERA 8301 (1:100) IN 100 PC SEA	0.26	0.26	8	82.7	14.1	17
ERA 8301 (1:100) IN 10 PC SEA	0.26	0.26	9	104	8.18	7.87
ERA 8301 (1:10) IN 10 PC SLA	2.6	2.6	2	79.6	2.69	3.38
OTHERS IN 100 PC SLA			0			
PLANT ONE SPIKES	0.1	0.1	1	100	0	0
PLANT SIX SPIKES			0			
PLANT THREE SPIKES	0.52	0.52	1	113	0	0

ELEMENT: 21 MOLYBDENUM DET. LIMIT: <0.2 <0.4 Type of Sample	Conc.(ppm)		# Samples	% Recov.	S.D.	% RSD
ERA 8301 (1:100) IN 100 PC SEA			0			
ERA 8301 (1:100) IN 10 PC SEA			0			
ERA 8301 (1:10) IN 10 PC SEA	1.9	1.9	2	92.1	11.2	12.2
ERA 8301 (1:10) IN 100 PC SEA			0			
OTHERS			0			
PLANT ONE SPIKES			0			
PLANT SIX SPIKES	0.38	0.38	1	105	0	0
PLANT THREE SPIKES						

ELEMENT: 22 SODIUM DET. LIMIT: <1						
ERA 8301 (1:100) IN 100 PC SEA			0			
ERA 8301 (1:100) IN 10 PC SEA			0			
ERA 8301 (1:10) IN 10 PC SEA			0			
ERA 8301 (1:10) IN 100 PC SEA	24.1	80.3	2	104	5.94	5.71
OTHERS			0			
PLANT ONE SPIKES						
PLANT SIX SPIKES						
PLANT THREE SPIKES						

ELEMENT: 23 NICKEL DET. LIMIT: <0.05						
ERA 8301 (1:100) IN 100 PC SEA	0.13	0.13	8	94.3	16.4	17.4
ERA 8301 (1:100) IN 10 PC SEA	0.13	0.13	9	109	31.7	29.1
ERA 8301 (1:10) IN 10 PC SEA	1.3	1.3	2	83.5	7.07	8.47
ERA 8301 (1:10) IN 100 PC SEA			0			
OTHERS	0.27	0.27	2	87.1	13.1	15
PLANT ONE SPIKES			0			
PLANT SIX SPIKES	0.26	0.26	1	92.3	0	0
PLANT THREE SPIKES						

ELEMENT: 24 PHOSPHORUS DET. LIMIT: <0.5 <1			
ERA 8301 (1:100) IN 100 PC SEA			0
ERA 8301 (1:100) IN 10 PC SEA			0
ERA 8301 (1:10) IN 10 PC SEA			0
ERA 8301 (1:10) IN 100 PC SEA			0
OTHERS			0
PLANT ONE SPIKES			
PLANT SIX SPIKES			
PLANT THREE SPIKES			

ELEMENT: 25 LEAD
DET. LIMIT: <0.05 <0.1

Type of Sample	Conc. (ppm)		# Samples	% Recov.	S.D.	% RSD
ERA 8301 (1:100) IN 100 PC SEA	0.115	0.115	8	65.2	32.7	50.2
ERA 8301 (1:100) IN 10 PC SEA	0.115	0.115	9	57.9	30.6	52.8
OTHERS IN 10 PC SEA	1.15	1.15	1	43.5	0	0
PLANT ONE SPIKES IN 100 PC SEA			0			
PLANT SIX SPIKES	0.21	0.21	2	23.8	0	0
PLANT THREE SPIKES	0.23	0.23	0			
			1	21.7	0	0

ELEMENT: 26 SILICON
DET. LIMIT: <0.05 <0.1

ERA 8301 (1:100) IN 100 PC SEA			0			
ERA 8301 (1:100) IN 10 PC SEA			0			
OTHERS IN 10 PC SEA			0			
PLANT ONE SPIKES IN 100 PC SEA	2	2	3			
PLANT SIX SPIKES			0	3.83	2.31	60.3
PLANT THREE SPIKES			0			
			0			

ELEMENT: 27 STRONTIUM
DET. LIMIT: <0.001

ERA 8301 (1:100) IN 100 PC SEA			0			
ERA 8301 (1:100) IN 10 PC SEA			0			
OTHERS IN 10 PC SEA			0			
PLANT ONE SPIKES IN 100 PC SEA			0			
PLANT SIX SPIKES	0.12	0.12	2			
PLANT THREE SPIKES			0	81.3	1.77	2.18

ELEMENT: 28 THORIUM DET. LIMIT: <0.01 <0.1 Type of Sample	Conc. (ppm)		# Samples	% Rec	s.	% RSD
ERA 8301 (1:100) IN 100 PC SLA		0				
ERA 8301 (1:100) IN 10 PC SLA		0				
ERA 8301 (1:10) IN 10 PC SLA		0				
OTHERS IN 100 PC SLA		0				
PLANT ONE SPIKES		0				
PLANT SIX SPIKES		0				
PLANT THREE SPIKES		0				

ELEMENT: 29 TITANIUM DET. LIMIT: <0.005 <0.01						
ERA 8301 (1:100) IN 100 PC SLA	0.1	0.1	8	73.5	11.3	15.4
ERA 8301 (1:100) IN 10 PC SLA	0.1	0.1	9	91	15.3	16.8
ERA 8301 (1:10) IN 10 PC SLA	1	1	2	80.4	6.36	7.91
OTHERS IN 100 PC SLA			0			
PLANT ONE SPIKES	0.054	0.054	2	97.9	5.34	5.88
PLANT SIX SPIKES			0			
PLANT THREE SPIKES	0.2	0.2	1	100	0	0

ELEMENT: 30 VANADIUM DET. LIMIT: <0.005 <0.01						
ERA 8301 (1:100) IN 100 PC SLA	0.12	0.12	8	84.2	13.5	16
ERA 8301 (1:100) IN 10 PC SLA	0.12	0.12	9	101	9.71	9.61
ERA 8301 (1:10) IN 10 PC SLA	1.2	1.2	2	90.3	6.08	6.73
OTHERS IN 100 PC SLA			0			
PLANT ONE SPIKES	0.135	0.135	1	86.7	0	0
PLANT SIX SPIKES	0.026	0.026	2	38.5	10.9	28.3
PLANT THREE SPIKES	0.24	0.24	1	101	0	0

ELEMENT: 31 ZINC DET. LIMIT: <0.05						
ERA 8301 (1:100) IN 100 PC SLA	0.345	0.345	8	81.6	34.2	41.9
ERA 8301 (1:100) IN 10 PC SLA	0.345	0.345	9	109	7.31	6.71
ERA 8301 (1:10) IN 10 PC SLA	3.45	3.45	2	82.7	9.83	11.9
OTHERS IN 100 PC SLA			0			
PLANT ONE SPIKES	0.3	0.3	2	91.7	2.35	2.56
PLANT SIX SPIKES			0			
PLANT THREE SPIKES	0.69	0.69	1	94.2	0	0

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

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3. RECIPIENT'S ACCESSION NO.	
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15. SUPPLEMENTARY NOTES AEERL project officer is Julian W. Jones, Mail Drop 61, 919/541-2489. (*)Haley and Aldrich, Inc., Cambridge, MA 02142. (**)Geologic Associates, Inc., Knoxville, TN 37922. Volumes I and II are the basic report.

16. ABSTRACT

The six-volume report summarizes results of a 3-year study of current coal ash and flue gas desulfurization (FGD) waste disposal practices at coal-fired electric generating plants. The study involved characterization of wastes, environmental data gathering, evaluation of environmental effects, and engineering/cost evaluations of disposal practices at six sites around the country. Study results provide technical background data and information for EPA, state and local permitting officials, and the utility industry for implementing environmentally sound disposal practices. Study data suggest that no environmental effects have occurred at any of the six sites; i.e., data from wells downgradient of the disposal sites indicate that waste leachate has resulted in concentrations of chemicals less than the EPA primary drinking water standards. A generic environmental evaluation--based on a matrix of four waste types, three disposal methods, and five environmental settings--shows that, on balance, technology exists for environmentally sound disposal of coal ash and FGD wastes for ponding, interim ponding/landfilling, and landfilling. For some combinations of waste types, disposal methods, and environmental settings, mitigation methods must be taken to avoid adverse environmental effects. Costs of waste disposal operations are highly system and site specific.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution Waste Disposal Wastes Coal Combustion Electric Power Plants Ashes Flue Gases Desulfurization Cost Engineering	Pollution Control Stationary Sources	13B 21B 14G 07A, 07D 21D 14A 10B

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