EXECUTIVE SUMMARY

TOXICOLOGICAL INVESTIGATION OF FINE PARTICLE EMISSIONS FROM OIL-FIRED POWER PLANTS

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Laboratory and field studies have been performed of the physical, chemical, and selected biological properties of smoke-stack oil fly ash collected aerodynamically from a commercial 485 MWe oil-burning steam-cycle utility electrical power plant located in Southern California. Samples were collected with a specially designed sampler system over a 21 day period of continuous operation at about 80% power level (400 MWe) to provide representative samples. The special fly ash sampler was designed to aerodynamically separate the fly ash particles into coarse (non-respirable) and fine (respirable) fractions for these studies. This separation was achieved with a cyclone separator with cut size of about 5 μm aerodynamic diameter. The fly ash collection was conducted at 140°C, the stack gas temperature, to avoid condensed sulfuric acid. Low ash, low sulfur Indonesian crude oil, typical of the type used by power companies in California, was burned throughout the sampling period.

There were several reasons for interest in the physical, chemical, and biological properties of oil fly ash released from power plants. Oil-burning power plants are used to produce the majority of electricity generated in California and they usually release to the atmosphere most of the respirable fly ash produced during the oil combustion. The quantities of fly ash released are significant. Hence, these power plants represent an important source of fly ash particles as well as pollutant gases. The potential health impact for people breathing the resultant aerosol in California requires evaluation of the biological properties associated with the physico-chemical characteristics of the respirable oil fly ash particles.

This project, therefore, involved determination of the physical properties of the fly ash particles, measurement of the chemical constituents, and studies of the effects of these particles on mammalian cells, namely pulmonary alveolar macrophages, the frontier cells of the lung that respond to inhaled particles. In addition, the potential carcinogenicity of these particles was considered by subjecting suitable extracts of chemical components to a bacterial test (Ames analysis) of cellular mutagenesis, an indicator of potential carcinogenicity.

The oil burned at the chosen power plant had a fuel ash concentration of 0.005%. For operation at 400 MWe, involving the combustion of 217,000 lbs of oil per hour, the effluent stream of about one million cubic feet of gas per minute had a fly ash concentration of 2.5 mg/m^3. This figure does not include condensable sulfuric acid that also forms part of the released aerosol upon mixing with ambient air at the exit of the smoke stack. Of this fly ash, 64% was in the fine (respirable) fraction (less than 10 μm in aerodynamic diameter).

The coarse particles consisted of some pitted cinder-like particles, some iron rust-like particles and metallic sulfates, and the fine particles consisted primarily of relatively soluble metallic sulfates and appeared to have structures typical of mixed salt crystals (see Figure). About half the mass of the particles was identified as associated with the sulfate anion. The principal metals present in the fine ash were nickel (10.3%), sodium (3.7%), iron (3.8%), vanadium (2.7%) and calcium (1.2%). Also present were important quantities of manganese, zinc, cobalt, magnesium, aluminum, and potassium. About 85% of the fine ash was water soluble and about 65% of the coarse ash was water soluble, indicating high potential biological availability of the trace metals present upon inhalation deposition.

The organic analyses showed organic compounds to be only a minor component of these fly ash particles. Elaborate procedures were used to avoid organic contamination in handling or collection and to insure that the observed organic, chemical properties were representative of the combustion process. Gas chromatographic traces were made of the organic species, but background organic constituents on the Teflon filters used for collection obscured the organic analysis and limited its usefulness, because of the inherently low concentration of organic constituents in the ash.

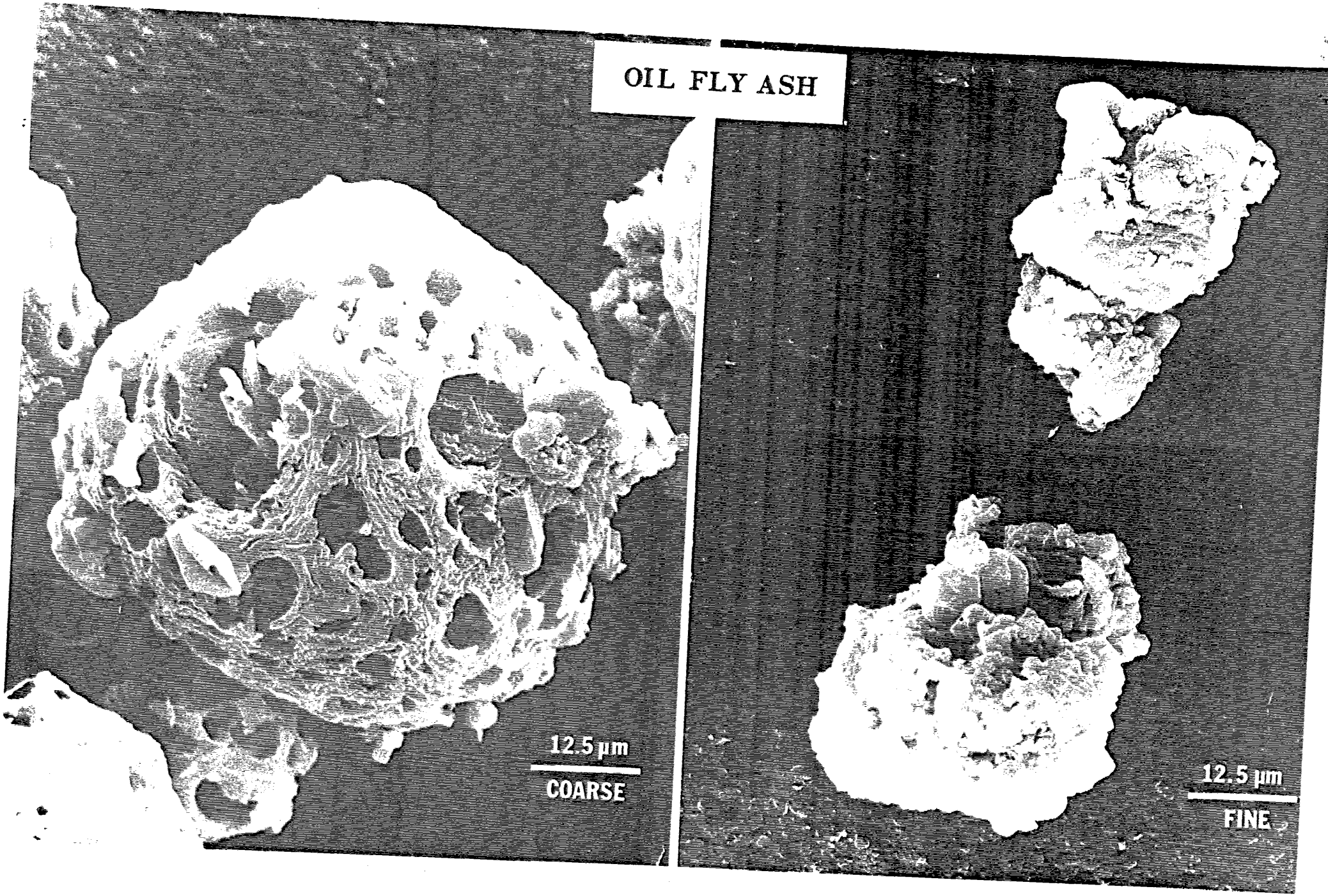
Biological studies of the mutagenesis of these oil fly ash particles showed that there was some slight mutagenic activity in the ash (as assessed in the Ames bacterial mutagenesis assays) and considerable toxicity to the bacterial cells. These studies were performed using five tester strains, TA 100, TA 98, TA 1535, TA 1538, and TA 1537, with and without microsome activation. Extracts were prepared with an azeotropic benzene/methanol mixture and with horse serum. Except in the case of two tests with benzene/methanol extracts of 4.83 mg and 0.483 mg of fine oil ash per colony culture plate with

TA 100, none of the samples showed statistically significant levels of mutagenic activity ($P < 0.1$) although some slight dose-response trends were suggested by the data. However, the cellular toxicity demonstrated by the oil fly ash may have obscured some of the inherent mutagenic activity that may have been present.

Three sets of cellular toxicity studies with New Zealand white rabbit pulmonary alveolar macrphage were conducted that demonstrated a clear toxicity dose response relationship with increasing fly ash exposure for the fine particles. Both fine fly ash particles and the dissolvable soluble components were separately observed to be highly toxic to the cells with the equivalent of 156.7 μg of ash per ml causing cell lysis and reduced phagocytic function as observed in test sphere phagocytosis challenge tests. Exposure to 512.7 μg/ml concentration of fine ash caused cell death. Comparison with similar effects caused by vanadium implicated the vanadium portion of the fly ash to the observed cellular toxicity.

These studies show that oil fly ash is highly biologically active, is relatively toxic to cells, and may contain some mutagenic constituents. Most of the ash released from the power plant was in the respirable fine fraction. Since the fine (respirable) ash particles consisted primarily of metallic sulfates, including the biologically important trace metals vanadium, nickel, manganese, cobalt, and magnesium, and were 85% soluble in water, relatively high solubility in lung fluids upon inhalation deposition is to be expected. Oil fly ash thus provides a major contrast to coal fly ash which primarily consists of relatively inert insoluble fused aluminosilicate spheres with extremely low concentrations of trace metals. Future work should consider the magnitude of oil fly ash releases and estimates of health impact.

FIGURE CAPTION - Scanning electron micrographs of both the coarse oil fly ash (volume median diameter 22 μm) and aggregated fine (respirable) oil fly ash (volume median diameter of unaggregated particles 3 μm) aerodynamically size separated during collection from the smoke stack breeching of a 485 MWe oil burning power plant in Southern California.


OIL FLY ASH
12.5 µm
COARSE
12.5 µm
FINE