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Cadmium and Lead Accumulation by Goldfish Exposed to Aqueous Refuse Incinerator Fly Ash Leachate

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The increased use of incineration with modern emission control devices for reducing the mass of municipal solid waste is resulting in ever greater quantities of ash to be disposed. Heavy metals present in the original refuse are concentrated in the ash and landfill disposal of it has prompted public concern of possible contamination of groundwater through leaching. Several investigators have reported the presence of heavy metals such as lead and cadmium in aqueous leachates of refuse incinerator ashes in laboratory studies (Di Casa et al. 1982; Austin and Newland 1985; Wadge and Hutton 1987; Sawell et al. 1988).

It was of interest to determine the effect of such leachates on fish. In the work reported here, goldfish were exposed to aqueous leachates of municipal refuse incinerator ash. Visual observations of fish behavior, heavy metal analysis and histologic examination of tissues were then carried out.

MATERIALS AND METHODS

Fifteen kg of fly ash was obtained from a municipal refuse incinerator. The material was air-dried and mixed by tumbling. Pertinent data on the composition of the ash is given in Table 1. Six goldfish (Carassius auratus), approximately 6 cm in length, were placed in an aerated glass tank containing 20 liters of well water (electrical conductivity 280 micromhos/cu cm; temperature 20°C). A filter holder containing no adsorbent was attached to one side of the tank. Thirty gm of the ash was placed in a cellulose extraction thimble (43 x 123 mm) and, after moistening the cellulose, the open end was folded and stapled shut. The thimble containing the ash was placed in the filter holder and the water in the tank was continuously circulated through the filter containing the thimble of ash using a small air-driven pump. In this way, the water passed through the cellulose, leached the ash and carried soluble materials back into the tank containing the fish. The fish were thus exposed for 12 days. Fish exposed for 12 days in a similar tank containing water circulated through a

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cellulose thimble without ash were used as controls. At the end of this period, the fish were removed and analyzed for cadmium and lead and examined histologically. The metals were determined in individual fish by freeze drying the fish, wet ashing the tissue with nitric and perchloric acids and analyzed by conventional stripping voltammetry (Gajan and Larry 1972). Water was sampled from the ash-exposed and control tanks at the end of the exposure period and analyzed for cadmium and lead by the latter procedure. Histologic examination was performed by sectioning paraffin-embedded tissues at 6 μm intervals, staining tissues with hematoxylin and eosin, followed by light microscopy.

Table 1. Data pertinent to ash composition.

Analyte	Magnitude
pH	7.3
Organic matter, %	1.7
Soluble salts, %	7.0
Cadmium, ppm	185
Lead, ppm	5334

RESULTS AND DISCUSSION

The concentrations of cadmium and lead in the water and goldfish are given in Table 2. The cadmium and lead content of ash-exposed fish were significantly higher ($p < 0.05$) than the control fish. The fish showed no external symptoms of toxicity such as impaired or disoriented swimming ability or accumulation of gill mucus, which is a well known early indicator of heavy-metal exposure in fish (Carpenter 1927, 1930). Mild necrosis of the margins of all fins except the adipose fin was evident grossly in all fish exposed to fly ash leachate. This lesion was absent in control fish. Histologic examination of fish tissues revealed no abnormalities except for mild localized necrosis of epithelium on the margins of fins of ash-exposed fish. The lethal concentration of cadmium in distilled water for goldfish has been reported to be 0.0165 ppm (Ellis 1937). The lethal concentration of lead in water for goldfish has been reported to be in the range of 10 to 17 ppm (Doudoroff and Katz 1953; Jones 1957). However, the presence of other ions in solution, as in the case of the refuse ash leachates, may alter the toxicity of heavy metals to fish through antagonistic or synergistic effects (Doudoroff and Katz 1953).

The data indicate that fish in water exposed to refuse ash leachates can accumulate heavy metals such as cadmium and lead. The concentrations of cadmium and lead in the refuse fly ash used in this study (Table 1) are not atypical of those reported by others (Lisk 1988). Based on the increase in the concentrations of these metals in the water during the 12 days of leaching the ash, 33.12% of the total cadmium in the ash was solubilized whereas only 0.26% of the total lead was dissolved. Assuming that

Table 2. Cadmium and lead in goldfish and water.

Sample	Parts per million[a]	
	Cadmium	Lead
Ash-exposed fish	3.75 ± 0.80^{xb}	1.55 ± 0.21^{x}
Control fish	0.28 ± 0.08^{y}	0.33 ± 0.01^{y}
Ash-exposed water	0.0936	0.0234
Control water	0.0017	0.0023

[a]Average ± standard error.
[b]Dissimilar letter superscripts indicate significant differences ($p < 0.05$) between respective treatment means.

all of the soluble salts in the ash (7.0%) were dissolved during the exposure period, the electrolyte content of the water would have increased by 105 ppm. The pH of the water containing the fish rose from an initial value of 7.2 to a final value of 7.5 during the 12 days of leaching through the ash.

Elements in refuse fly ash or coal fly ash may be present in a number of associations. Using specific extractants which favored removal of metals in specific forms, Wadge and Hutton (1987) showed that cadmium and lead in refuse fly ash were mainly associated with the exchangeable fraction, whereas in coal fly ash they were mostly present in mineral lattices. They found that these metals are typically much higher and more water-soluble in refuse fly ash than coal fly ash. The higher the pH of newly produced refuse ash the lower will be the dissolution of metals such as cadmium and lead by aqueous leachates (Vogg 1987). Therefore, if refuse ash is exclusively disposed in landfills the leachate will typically contain lower concentrations of such metals since the leachate is more apt to remain alkaline. Conversely, if refuse ash is co-disposed with unburned municipal solid waste, the leachates tend to become acidic and will remove higher concentrations of heavy metals (Francis and White 1987). Alkaline amendments to refuse incinerator ash have been reported to be effective in rendering heavy metals insoluble (Riemann 1987; Behel et al. 1986). Also, the immobilization of toxicants in waste materials by their incorporation in cement prior to disposal or use has been reported (Tay and Yip 1989; Shieh and Roethel 1989).

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