UPTAKE OF MERCURY BY FISH IN
NATURAL AND ARTIFICIAL SYSTEMS

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## Introduction and Historical

The accumulation of mercury in food chains was dramatically brought to the world's attention in 1953 when the people of Minamata Bay, Japan, began showing symptoms of acute mercury poisoning[1]. It was found that the fish and shellfish of the Bay contained high levels of methyl mercury. The only source of mercury entering the Bay was from an industrial plant that released 20 ppb of inorganic mercury in its wastewater. It was found that the inorganic mercury was rapidly converted into organic mercury, usually as methyl mercury which is a highly toxic compound[2]:

$$Hg^{2+} + \xrightarrow{Org.} {}^{+}HgCH_3$$

The various forms of mercury present are shown in Table 1. The mercury was then taken up by the fish and shellfish which in turn were eaten by the people of the Bay causing death and disability.

Table 1

Common Organic and Inorganic
Forms of Mercury

| Inorganic | | Organic | |
|---|---|---|---|
| $Hg^{2+}$ | ionic | $CH_3Hg^{+}$ | monomethyl mercury |
| $Hg^{o}$ | metallic | $CH_3HgCH_3$ | dimethyl mercury |
| $Hg_2^{+}$ | ionic |  - $Hg^{+}$ | phenyl mercury |

The second major incident of mercury accumulation in the food chain occurred in Sweden when a large portion of the bird population died of mercury poisoning[3]. It was found that the seed-eating birds were ingesting

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seed treated with methyl- and phenyl mercury. The fish-eating birds were eating fish contaminated by mercury leached from treated seeds used on agricultural lands.

These incidences showed that a small concentration of mercury in the water can be concentrated in the food chain to the point where the higher carnivores could contain a lethal concentration of mercury.

Since New Mexico has a limited water supply, a mercury contamination problem could possibly exist on a local or state level. A small amount of mercury contamination could remove a large percentage of water from use. New Mexico at this time has a relatively mercury-free environment. The few man-made sources of mercury such as smelters and coal-burning power plants may be too scattered and too small to cause any major mercury problems. Other industrial sources do not exist, and agricultural practices have not caused any documented contaminations in New Mexico's waters.

Studies of mercury in natural waters throughout the State are now in progress at the State Bureau of Mines. The preliminary results show that the levels of mercury are relatively low (Table II)[4]. Concentration of mercury by fish from natural waters was studied at the Bosque del Apache National Wildlife Refuge south of Socorro, New Mexico. These results can be compared with data obtained from laboratory experiments of uptake by goldfish from low-level mercury concentration.

Table II

Mercury Concentrations in Natural Waters in New Mexico

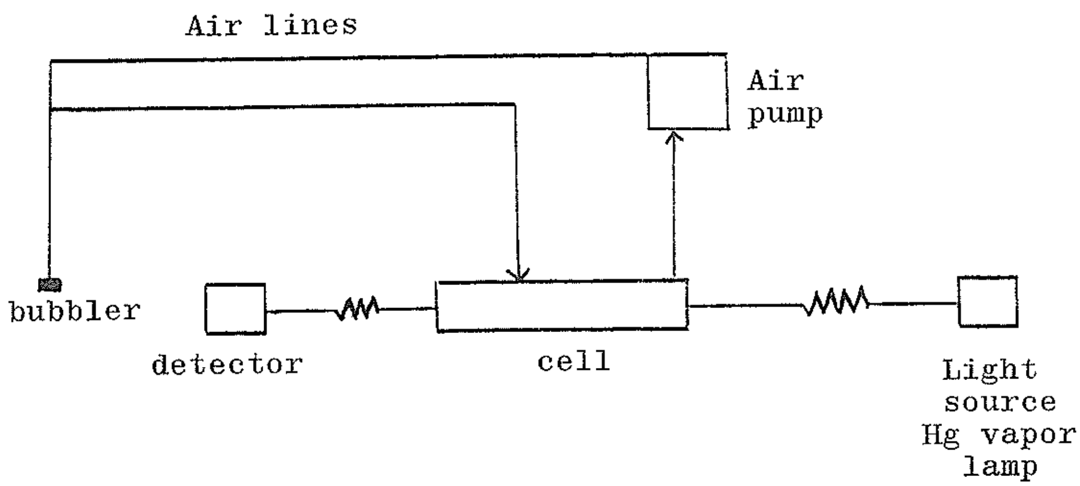
| Location | ppb mercury µg/l |
|---|---|
| Copper Canyon - Magdalena Mts. | 5.0 |
| Water Canyon - Magdalena Mts. | N.D. |
| Rio Salado above Riley | N.D. |
| Morgan Lake | 3.0 |
| Navajo Bridge | 0.2 |
| San Juan River - at Hogback | 0.14 |
| San Juan River - Bloomfield | 1.1 |
| Murphy Lake | 2.0 |
| Rio Pueblo | 2.0 |
| Carrizozo Creek | N.D. |
| Cimmaron River | 2.5 |
| Red River | 0.5 |
| Clayton Lake | 2.4 |
| Ute Lake | 3.0 |
| Road Canyon Well ground water | 0.3 |

Experimental

Only in the last few years have mercury concentrations in the parts per billion (ppb) range been quantitatively detectable. This is due to the development of the flameless atomic absorption method of analysis[5]. Figure I is a schematic of the analysis. When mercury is tied up in a compound or in tissue, a problem exists in breaking down the binding agent without losing the mercury. The improvements in techniques have allowed analyses of mercury where previous studies had shown none.

Figure I

Mercury Analyzer




The laboratory experiments were conducted in 38 liter tanks equipped with aerators and heaters. Goldfish (Carassius auratus) were used as the experimental fish. A mercury concentration in the tanks of 5 ppb was used to contaminate the water. This concentration was chosen since it: 1) closely represented natural waters; 2) did not kill the fish during the experiment; and 3) was in a reasonable analysis range. No previous mercury uptake studies have been reported at these low-level mercury concentrations. The fish were sampled periodically and analyzed for total mercury and the distribution of mercury in selected organs.

Results and Discussion

Mercury in Bosque del Apache Refuge Waters

Mercury analyses of the water at the Bosque Refuge showed low-level mercury concentrations (Table III). It is assumed that this mercury originated from natural sources or possibly from agricultural practice since much of the Refuge water originates from ground water. The water was sampled at eight points representing water entering the Refuge, leaving the Refuge, in ponds, and water flowing past the Refuge.

Table III

Mercury in Ground Waters

Bosque Del Apache Refuge

| Sample Station Number* | Inorganic Mercury-ppb | Organic Mercury-ppb |
|---|---|---|
| 1 | 2.9 | 0.2 |
| 2 | 1.8 | 0.1 |
| 3 | 1.8 | 0.5 |
| 4 | 1.6 | 1.7 |
| 5 | 2.4 | 1.7 |
| 6 | 2.2 | 1.4 |
| 7 | 3.8 | 0.5 |
| 9 | 1.7 | 1.1 |

*Station #'s 1, 3, 7, 9 - Agricultural Drains

Station # 2 - Bureau of Reclamation Channel

Station # 5 - Permanent Marsh

Station # 6 - Fishing Pond

Station # 4 - Waterfowl Pond

Fish were taken from the surface water station #6 and analyzed for mercury (Table IV). Both bottom-feeding and carnivorous fish were sampled.

Table IV

Total Mercury in Fish in a Natural System

| Type | weight-g | μg of mercury | ppm |
|---|---|---|---|
| Catfish Channel | 47.6112 | 5.21 | 0.11 |
| Bullhead | 69.7093 | 13.10 | 0.19 |
| Carp | 201.6721 | 86.72 | 0.43 |
| Bass | 233.271 | 103.42 | 0.47 |
| Trout | 45.30 | 0.47 | 0.01 |

Individual major organs of two of the fish were analyzed for mercury to determine the distribution of mercury in the fish (Table V).

Table V

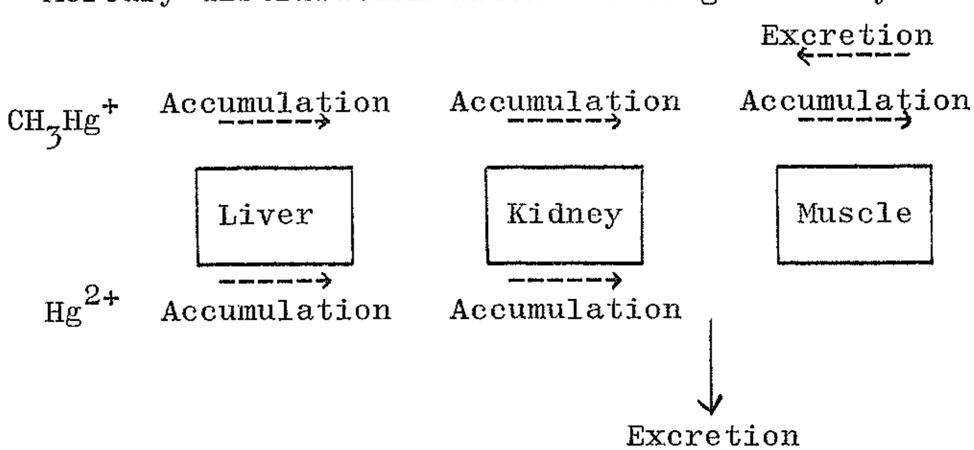
Mercury Content of Selected Tissue of Channel and Bullhead Catfish

| | weight-g | μg of mercury | ppm |
|---|---|---|---|
| **Channel Catfish** | | | |
| Liver | 1.0938 | 0.34 | 0.31 |
| Kidney | 0.1808 | 0.39 | 2.16 |
| Muscle | 2.8607 | 0.20 | 0.07 |
| **Bullhead Catfish** | | | |
| Liver | 2.307 | 0.25 | 0.11 |
| Kidney | 0.687 | 0.68 | 0.99 |
| Muscle | 2.741 | 0.38 | 0.14 |

The analysis of the organs showed that the highest concentrations of mercury were in the kidney and liver, and the lowest concentration was in the muscle. The fish were in an environment where inorganic and organic mercury were both present. A proposed pathway for the distribution of mercury in the organs[6] seems to be supported by the data (Figure II). This pathway shows that mercury--both inorganic and organic--is passed through the liver to the kidney where inorganic mercury is concentrated and excreted. Organic mercury is also excreted but a small percentage is passed on to the muscle tissue. This results in the highest concentrations in the kidney and the lowest in the muscle.

Figure II

Mercury distribution after entering the body



Total uptake of mercury is higher in the carnivores than in the bottom-feeding fish. This implies that mercury is concentrated with each step of the food chain. The rainbow trout analysis shown in Table IV was a planted fish from a hatchery and may represent a baseline concentration of mercury before the fish could accumulate mercury from natural waters. However, this conclusion cannot be supported since water analysis data from the trout's origin are not available. The low level may be due to the use of artificial food in the trout-rearing process.

## Mercury Uptake by Fish Under Controlled Conditions

In order to study the uptake of mercury by fish on a controlled basis, laboratory experiments were performed on goldfish (Carassius auratus) placed in aquariums spiked with mercury.

The organs studied showed the same uptake as organs of fish in natural waters (Table VI). The kidney showed the highest uptake, the liver showed the next highest concentration, and the muscle showed the lowest concentration. The change in mercury content of the organs with time is shown in Figure III.

Table VI

Mercury content of selected tissue of Experimental Fish

| Hours | Mercury content by tissue (ppm) | | |
|---|---|---|---|
| | Liver | Kidney | Muscle |
| 0 | 0.68 | 4.15 | 0.31 |
| 72 | 2.07 | 6.50 | 0.81 |
| 144 | 5.85 | 12.24 | 1.09 |
| 216 | 0.65 | 4.81 | 0.60 |
| 264 | 1.49 | 9.00 | 0.95 |
| 288 | 2.51 | 4.20 | 1.00 |
| 360 | 3.72 | 9.39 | 0.77 |
| 442 | 3.70 | 8.80 | 0.66 |
| 514 | 9.09 | 12.67 | 1.36 |
| 562 | 10.21 | 12.41 | 1.35 |

The total uptake showed an initial rapid uptake followed by a leveling off which remained approximately the same for the duration of the experiment (Table VII). The goldfish showed the greatest increase when the concentration of organic mercury was highest, indicating that organic mercury is more available for uptake by fish (Figure IV).

FIGURE III

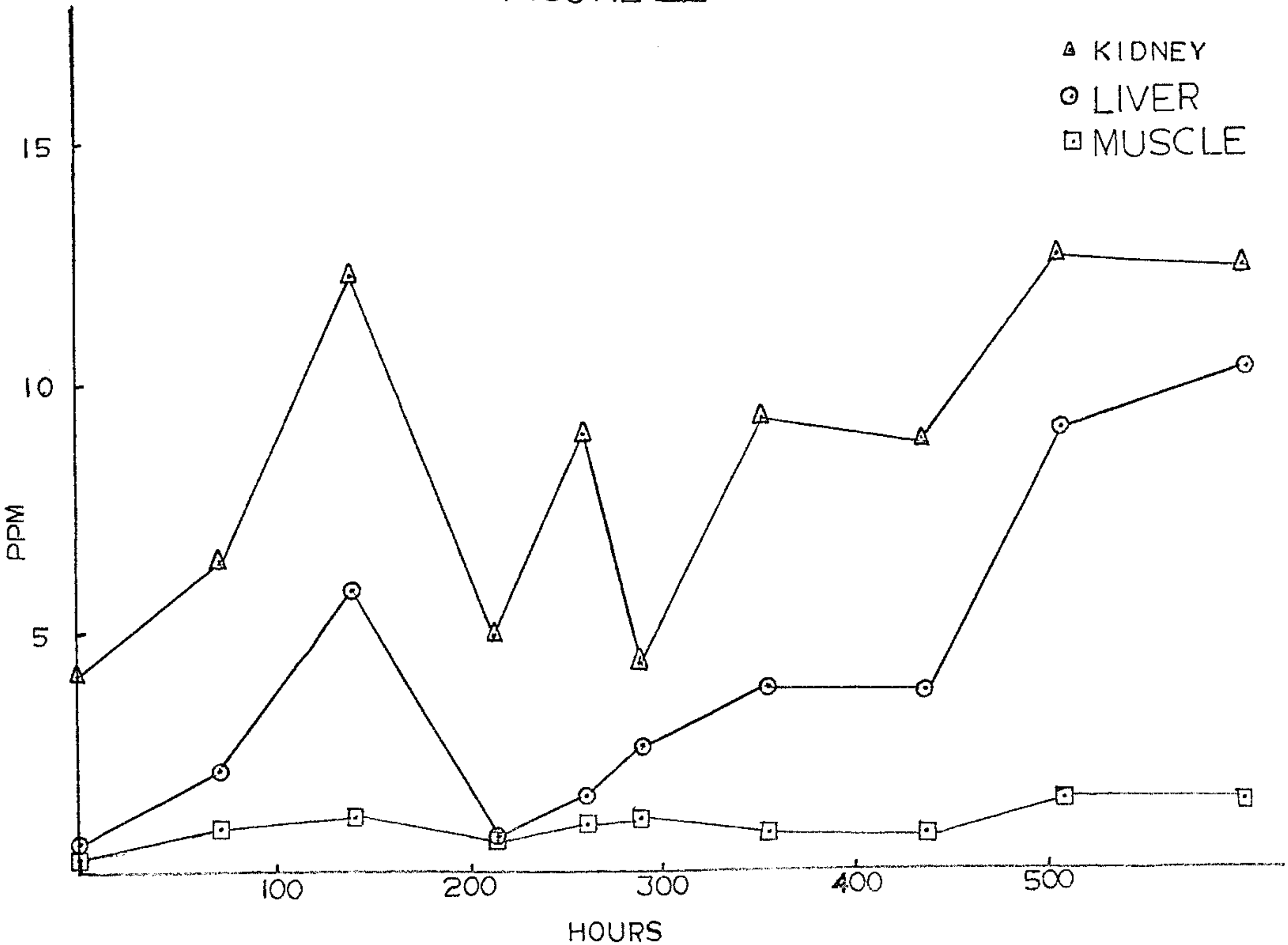


Table VII

Total Mercury Content in Experimental Fish

| Hours | Hg content (ppm) |
|---|---|
| 0 | 0.12 |
| 72 | 0.30 |
| 144 | 0.97 |
| 216 | 0.71 |
| 264 | 1.20 |
| 288 | 0.44 |
| 360 | 0.63 |
| 442 | 0.58 |
| 514 | 1.20 |
| 562 | 1.19 |

## Conclusions

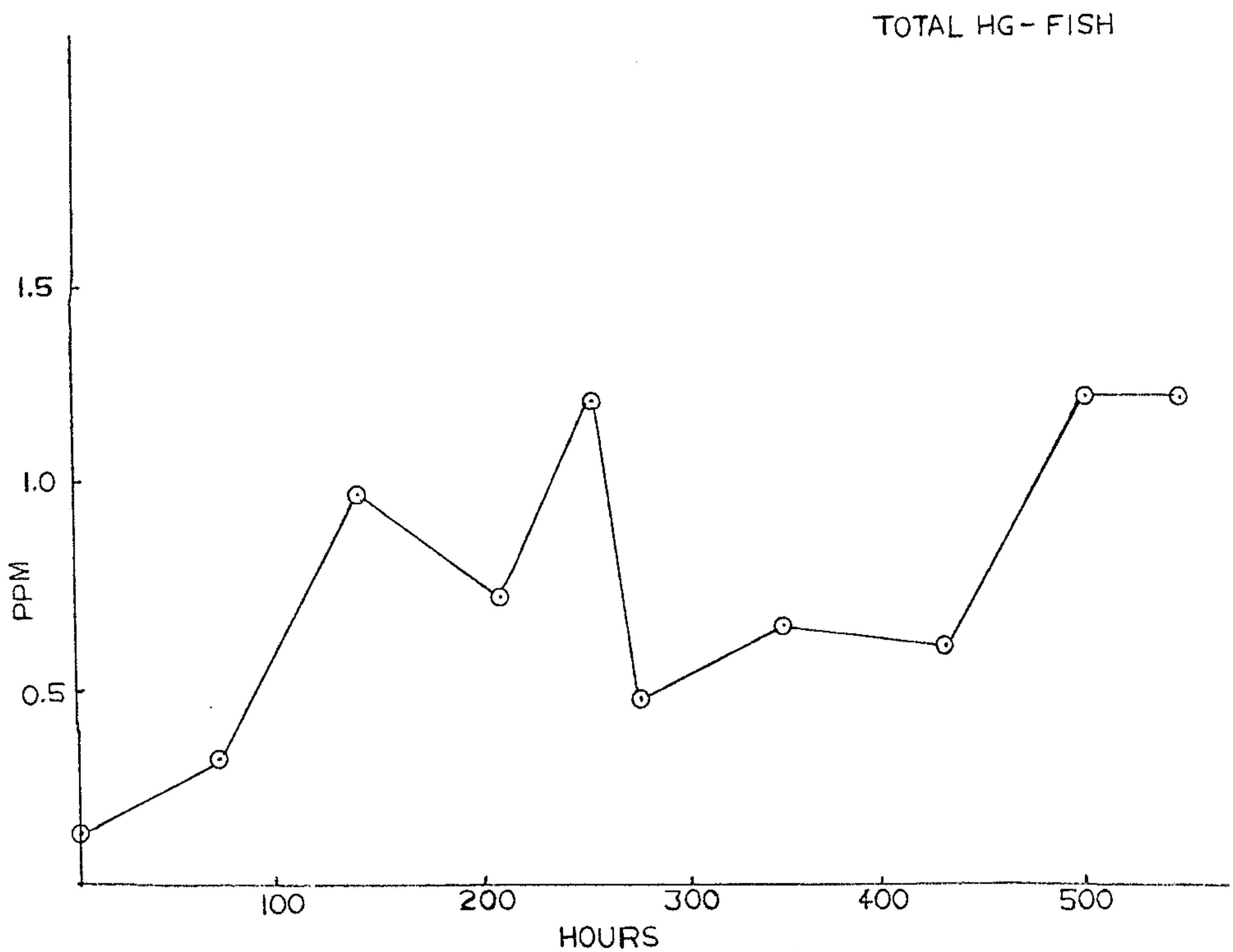
Fish have the ability to uptake and concentrate mercury from water with low-level contamination. This concentrating effect can be as high as one thousand times the water concentration. At low-levels of mercury in the water, the fish concentrations reach an equilibrium level which seems to be maintained. However, even at the low mercury concentration levels of the water in the laboratory experiment, the goldfish rapidly reached mercury accumulations which are considered dangerous by the Food and Drug Administration[7].

In the natural environment, both organic and inorganic forms of mercury are available. The mercury cycles between forms which continuously make organic mercury available for fish uptake. Not all the mercury in the water may be available for uptake since fish in the natural waters studied do not attain the mercury levels of fish in the controlled water. Some of the mercury may be tied up in sediments and suspended matter not utilized by the fish. These competing mercury "sinks" may make the mercury less available.

At this time New Mexico has no major mercury problems, but as the State grows and industry moves in, problems could arise. Due to the limited water supply, it would not require much mercury to create a problem.

More studies are needed to find ways of keeping mercury from reaching dangerous levels in aquatic environments. The only practical way known at this time is stopping the mercury and its source. As shown by this study, even a very small amount of mercury could potentially be harmful.

FIGURE IV



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