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MERCURY IN THE ENVIRONMENT

by

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A CRITICAL ESSAY

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INTRODUCTION

The chances of us being exposed to mercury and its compounds are significant. During the past, farmers, miners, and manufacturers have used millions of pounds of mercury annually. Mercury containing agricultural chemicals are used widely because of their antifungal activity and mercury is used extensively in the manufacturing of many inorganic and organic chemicals, pulp, felt, and electrical appliances. The pollution resulting from these applications eventually finds its way into our food and water supply. The different forms of mercury which get into the environment can be converted to the more dangerous methylmercury by microorganisms.[1] The ingestion of polluted freshwater and saltwater fish is probably the main route by which mercury enters the human body. In heavily polluted water the mercury level in fish can be very high.

Minimata problem was largely molluscs.

Crustacean scavengers are very high, especially crayfish

Mercury due to its extensive market is found throughout the world. Countries such as Japan, Sweden, United States and Canada which employed mercury widely in agriculture and industry have learned of its hazardous effects on their ecosystems. Often when environmental pollutants are being considered, there is not much evidence of their potential or proven detrimental effects on man. But with mercury the case against it is well documented[2] as will be shown.

or due to its geologic distribution & abundance

Units for Expressing Concentrations of Mercury

The different units used for expressing concentrations of mercury in various media are so diverse that confusion sometimes results. To facilitate comparisons, the followng relationship are presented.

Units of weight

1 kilogram (kg) = 1000 grams (g)
1 milligram (mg) = 10^{-3} g
1 microgram (μg) = 10^{-6} g
1 nanogram (ng) = 10^{-9} g
1 picogram (pg) = 10^{-12} g

Units of concentration

A. For foods, body organs, and other solids—weight:weight basis:
   1 part per million (ppm) = 1 mg/kg or 1 μg/g
   1 part per billion (ppb) = 1 μg/kg or 1 ng/g
   1 part per trillion (ppt) = 1 ng/kg or 1 pg/g
B. For water—weight:volume basis:
   1 mg/liter = approximately 1 ppm on weight:weight basis
   1 μg/liter = approximately 1 ppb on weight:weight basis
   1 ng/liter = approximately 0.001 ppb on weight:weight basis
C. For air—weight:volume basis:
   1 μg/m^3 (cubic meter)
   1 ng/m^3

} there are two methods of reporting at the present time: wet wt. or dry wt. basis. Very impt. in comparing figures in the literature.

from: Environmental Research Vol.4 No.1 (pg63)

Mercury in the air is expressed in nanograms of mercury per cubic meter of air, ng/m^3. A cubic meter of air is about 1⅓ cubic yards.

Mercury in the soil or aquatic sediments is ordinarily expressed in nanograms per grams or parts per billion (ng/g or ppb).

Mercury in fish or gamebirds is much larger but still microscopic - "not the right term" Because animals ~~& fish~~ concentrate mercury in their bodies. It is expressed as milligrams of mercury per kilogram of body weight or mg/kg. Mg/kg is the equivalent of parts per million, ppm.

If you have	and you want your answer to be in	multiply by
μg/m^3	ng/m^3	1,000
μg/g	ng/g	1,000
mg/kg	ppm	1*
mg/kg	ng/g	1,000
mg/m^3	ng/m^3	1,000,000
ng/g	mg/kg	0.001
ng/g	ppb	1*
ppb	ppm	0.001
ppb	ng/g	1*
ppm	ppb	1,000
ppm	mg/kg	1*

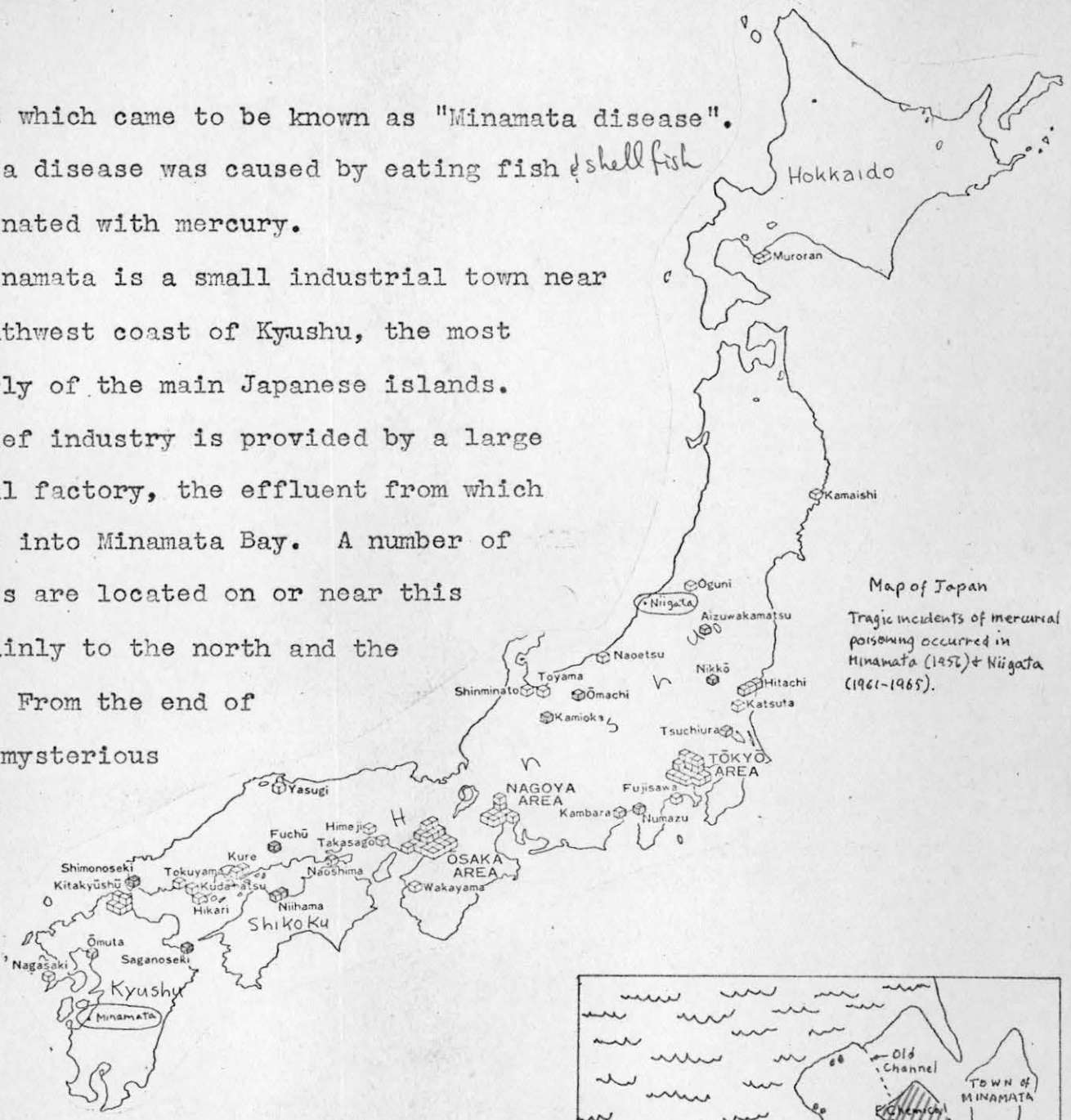
* In other words, they're equal.

from: Montague, Katherine & Peter Mercury 1971 Sierra Club book

JAPAN. If you have read about mercury pollution of our environment, you are probably aware that mercurial poisoning is becoming a world wide problem. In 1953 fishermen and their families around Minamata Bay in Japan were stricken with a mysterious neurological

illness which came to be known as "Minamata disease". Minamata disease was caused by eating fish & shellfish contaminated with mercury.

Minamata is a small industrial town near the southwest coast of Kyushu, the most southerly of the main Japanese islands. The chief industry is provided by a large chemical factory, the effluent from which empties into Minamata Bay. A number of villages are located on or near this bay, mainly to the north and the south. From the end of 1953 a mysterious nervous illness began to affect the villagers near the bay, and by 1956 it had assumed epidemic proportions. The outbreak was investigated by a number of departments of Kumamoto University. During 1956, 15 cases (9 adults and 6 children) were admitted to Kumamoto University hospital. The clinical features included: the



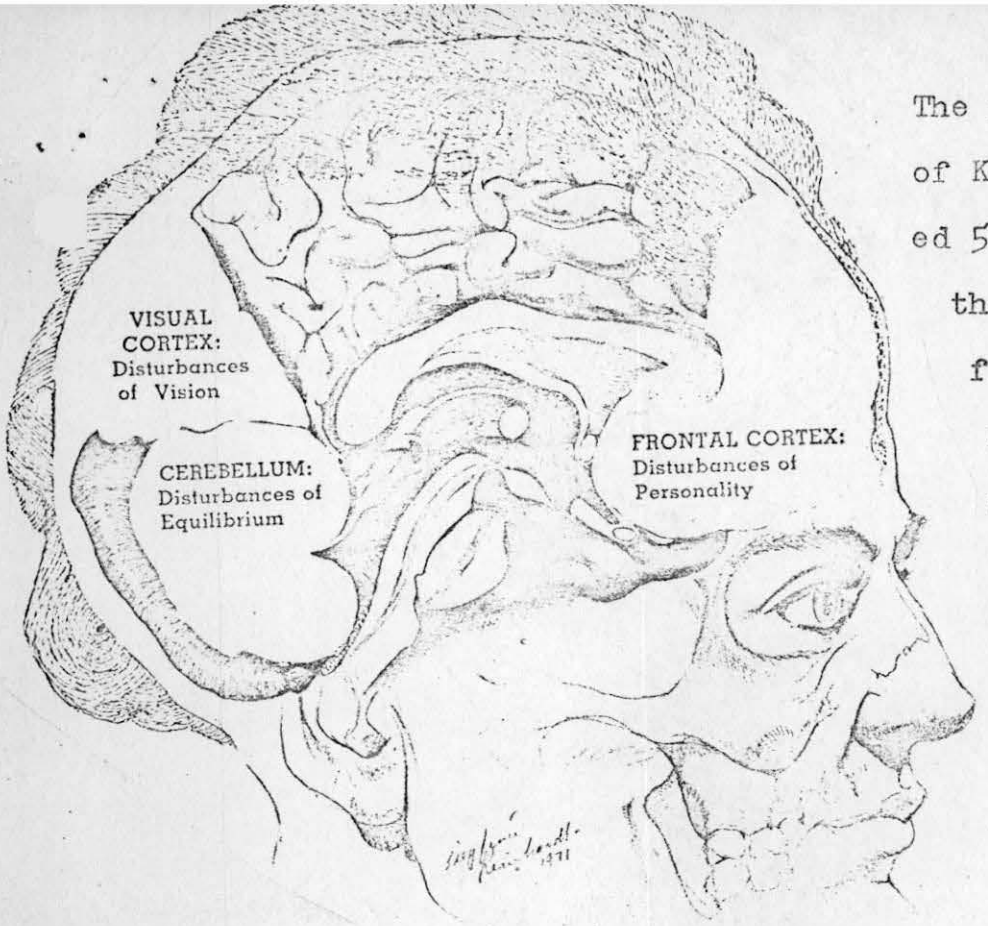
Map of Japan

Tragic incidents of mercurial poisoning occurred in Minamata (1956) & Niigata (1961-1965).

Based on a map published by the public-health department of Kumamoto university to illustrate the distribution of 52 cases of Minamata disease.

onset of acute or subacute illness and usually without fever. In all the adults numbness developed in the extremities & sometimes around the mouth, often accompanied or followed by slurred speech, unsteady gait and increasing disability. Most of the patients complained of deafness & disturbances of vision, associated with constriction of the field of vision. Some cases of dysphagia (impairment of the ability to speak) & increased salivation, insomnia, emotional lability in the form of euphoria or depression was present. The seriously ill-patients were mentally confused; drowsiness and stupor alternated with periods of restlessness & shouting. Four adults showed a mild degree of secondary anemia. The course of the disease fluctuated & its results were variable; the most severly affected died, while others remained incapacitated in varying degree. Improvement in hospital was occasionally followed by relapse on returning home. Because of what? Lower threshold; long ½ life?, Probably the former; increased sensitivity after initial exposure has been reported.

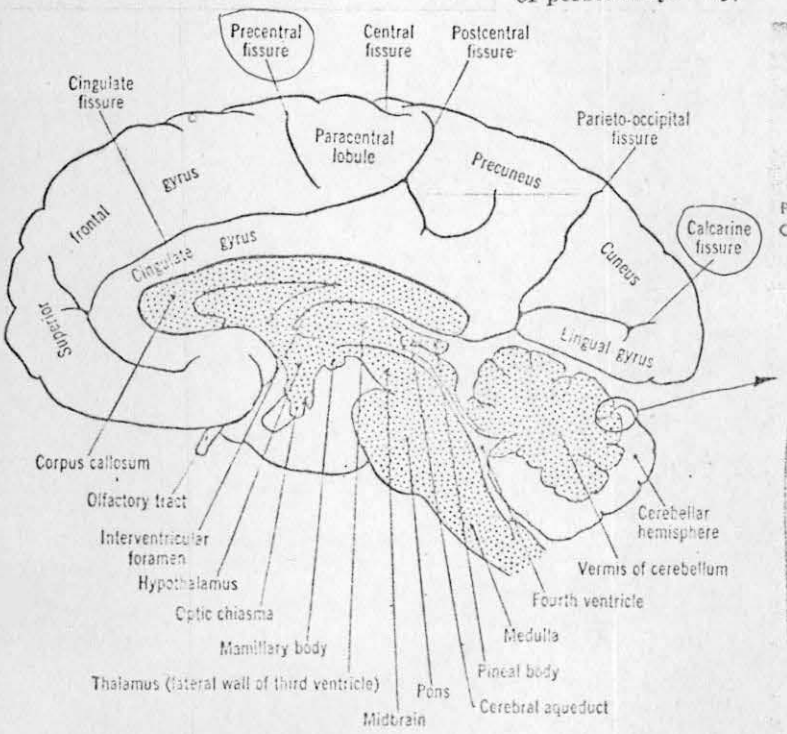
For pathological studies brain & certain internal organs were available from four patients. Areas of necrosis ~~was~~ were found in the intestinal mucous membrane and liver, there was no abnormality of the viscera. The main findings in the central nervous system were: (1) cell degeneration, which was most marked in the granular layer of the cerebellum (see figures next page), while changes of varying degree were apparent in the basal ganglia (the collective ~~grey~~ a matter in the interior of the brain), hypothalamus, midbrain, & cortex; (2) dilatation of the perivascular spaces, with occasional softening, but no true demyelination. (3) Edema & occasional small hemorrhages, and (4) reactive gliosis (proliferation of neuroglial cell in connective tissue). The spinal cord showed minor changes; the anterior-horn cells appeared unaffected.



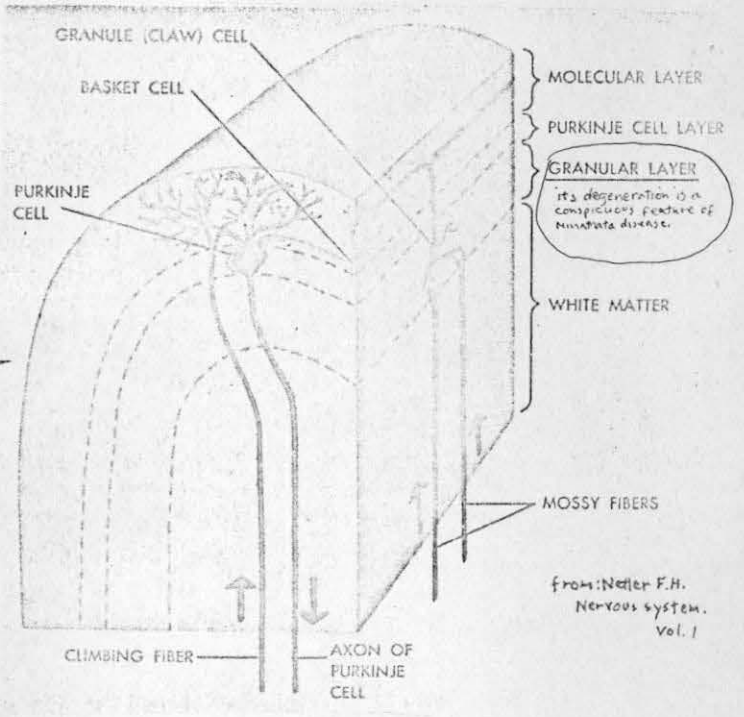
From: Environment Vol 13 No. 4 Pg 13

Methyl mercury is the most toxic and prevalent form of mercury contamination of food. For unknown reasons, it tends to concentrate in specific areas of the brain—principally the cerebellum, which regulates balance, and the calcarine fissure of the visual cortex. Lesser amounts of mercury find their way to other regions, including the frontal lobe where they may cause disturbances of personality. (5)

The public health department of Kumamoto University reported 52 patients affected with the disease, all of whom frequently ate fish from Minamata Bay. There ~~was~~ were approximately 52 cases within a population of 10,000 giving a rate of about 5 per 1000. Of the original 52 patients only 3 were able to return to work within 6 months, 9 improved & 23 were stationary; there were 17 deaths.



Section of Cerebellum



from: Netter F.H. Nervous system. Vol. 1

Figure 12. Sketch of the medial surface of the brain shown in Figure 11. The gyri are directly labeled, while other structures are indicated by leaders. (6) From: Gardner Fund of Neurology

This gave a case mortality of 33%. 8 patients died within 2 months and 4 within a year.

Other data showed that with one exception, namely a barber living on the outskirts of Minamata town who fished in his sparetime, all the cases occurred in the neighborhood of the bay. The 52 patients were distributed among 40 families. In 36 of these families at least 1 member fished in the bay, but in 48 of 68 neighboring families who were unaffected no one fished. 25 of the 40 affected families every day ate fish or shellfish which came from the bay & the remaining 15 families consumed fish from the bay 2 or 3 times a week. By contrast, only 5 of the 68 unaffected families were in the habit of eating fish daily from the bay, & most of them ate less fish per week than the affected families. Survey of the public health department showed that cooked as well as raw fish can cause the disease, which suggests that the toxic substance is thermostable (8,9).

TABLE 5-VII
METHYLMERCURY CONTENT OF PIKE BEFORE AND AFTER BOILING AND FRYING

Fish species	*Preparation*	*Weight of sample, g* *before preparation*	*after preparation*	*Methylmercury content, mg of Hg/ kg of fish muscle* *before preparation*	*after preparation*	*Methylmercury content in prepared fish, recalculated to unprepared, mg/kg*
Pike	boiling	50.0	35.5	0.52	0.76	0.54
Pike	frying	65.6	50.1	0.52	0.71	0.54

TABLE 5-VIII

probably all samples of marine fish are from one or two species

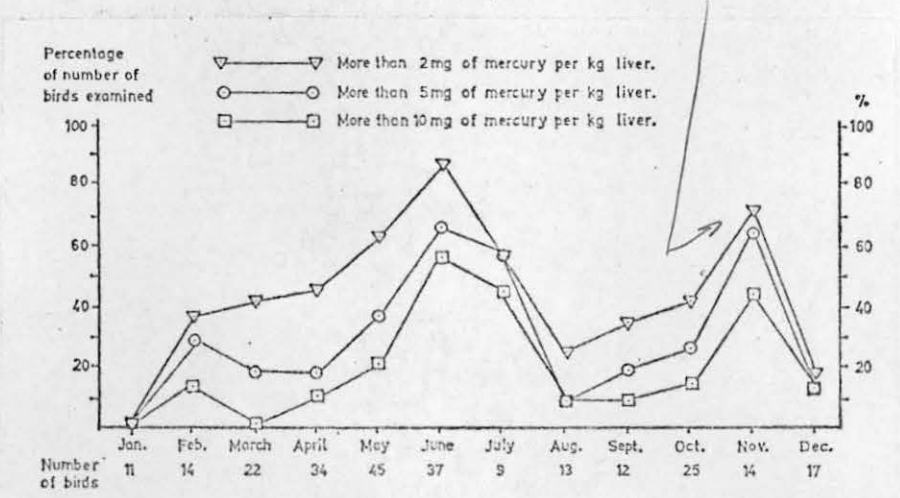
Sample	*Number of Samples With a Methylmercury Content, Calculated as mg of Hg/kg* 0-0.050	0.051-0.200	0.201-1.00	1.01-2.00	2.01-4.00	> 4.00
Marine Fish	29	25	0	0	0	0
Freshwater Fish and Inshore Fish	37	36	857	141	38	10

from: Chemical Fallout : Methylmercury compounds in Animal Foods, Westöö, G pg 88

An interesting note is that the disease also appeared in animals which had eaten fish or shellfish. In the 40 affected families there were 61 cats & 50 died between 1953 & 1956, sometimes in as little as 2 days. Unsteadiness, frequent falls, circling movements, & convulsion were observed; forced running appears to have caused some of them to enter the sea & be drowned. The 68 unaffected families owned 60 cats & of them 24 died. 5 pigs and 1 dog died, also many crows which were in the habit of settling on a floating landing barge where the returning fisherman tied up. The brains of 10 cats were examined, the changes were similar to those observed in the human material, the granular layer of the cerebellum being especially affected.[3] The disease could be readily produced experimently in cats by feeding them for 2 or 4 weeks with fish from Minamata Bay.

Through careful investigation certain facts were established: (1) there exists a close relationship between the eating of fish & the occurrance of the disease, (2) that the fish responsible for the outbreak had been caught in Minamata Bay. When a ban was placed on fishing in the bay, November 1956, no fresh case had been reported. (3) Chemical analysis of silt from the bay suggested that the water was polluted by effluent from the chemical factory. (Similar situation in Niigata catastrophe) (4) Characteristically the disease affects the peripheral nervous system, the cerebellum, hearing & vision, & less frequently the pyramidal tracts. In severe cases there were symptoms of encephalopathy i.e mental confusion, stupor or coma (in fatal cases), convulsion, involuntary movements of various types, insomnia, & intellectual deterioration suggesting progressive brain damage.

At this point it is almost certain that methylmercury caused the Minamata disease.



Similar to Oregon
Winter peak due to winter wheat planting

FIGURE 10-1. Seasonal variation of mercury levels in seedeating birds picked up dead in the field during 1964. After Borg, Wanntorp, Erne and Hanke, 1968.

The most recent data[23a] on the Minamata Bay outbreak showed 121 cases with 46 deaths. Of the 121 cases, 23 were of a cerebral palsy-like disease of infants who had not consumed contaminated fish; however, their mother had done so but were apparently free of symptoms of the disease. Additional information in section on Mercury in the Body, page 48.

There are other cases of mercurial poisoning. A second outbreak of "Minamata disease" occurred in Japan. In 1964, the Agano River in Niigata prefecture was contaminated by mercury in industrial effluent. The result was 47 cases and 6 deaths through 1970. This recurrence of the epidemic was due to the Japanese government resisting to recognize the cause & failure to take measures to prevent similar outbreaks of toxic substances from entering the environment. In 1956 and 1960 outbreaks of mercurial poisoning involving hundreds of persons took place in Iraq, where farmers who had received grain seeds treated with mercurial fungicides ate the seeds instead of planting it. There were similar outbreaks later in West Pakistan (1961) and in Guatemala (1963).[20]

SWEDEN In Sweden, poisoning of gamebirds & other wildlife due to mercury treated seeds began to be noticed in 1960. This poisoning was correlated with: a) unusually high concentration of mercury in dead birds. b) relatively high mercury content of Swedish agricultural products compared with those of other European countries and c) the extensive use of methyl-dicyanodiamide as a fungicide in Swedish agriculture.

In Sweden the mercury problem was first noticed in connection with a study of birds. During the years 1956 to 1963 Borg et al[10] observed that pheasants & several other seed eating species were poisoned, sometimes lethally, during or after the sowing periods in spring. See Fig. 10-1 at side The viscera of the poisoned birds contained large amounts of mercury up to 140 mg/kg in the liver & kidney of pheasants and one-half to one-fourth

the liver level in the muscles. However during the shooting season (October to December) the mercury content had decreased considerably (average value less than 1 mg of Hg/kg of muscle).

Westöö & Nören[11] analyzed five derivatives of mercury compounds in animal foodstuffs by gas chromatography (for more information see references (12, 13, 14) and thin-layer chromatography. The chromatograms showed that the mercury in fish, eggs, meat, & liver (table 5-I) was present mainly as methylmercury compound.

TABLE 5-I
SOME TOTAL MERCURY AND METHYLMERCURY CONTENTS OF SWEDISH FOODS IN 1966

Foods	*Total Mercury mg/kg*	*Methylmercury mg of Hg/kg*	*Methylmercury % of total Hg*
Meat (ox)	0.074	0.068	92
Meat (poultry)	0.023	0.017	74
Liver (pig)	0.130	0.095	73
Liver (pig)	0.096	0.075	78
Egg yolk	0.010	0.005	50
Egg yolk	0.010	0.009	90
Egg white	0.012	0.011	92
Egg White	0.025	0.024	96
Muscle tissue of perch	0.22	0.20	91
Muscle tissue of perch	3.25	2.99	92
Muscle tissue of pike	3.35	3.11	93
Muscle tissue of pike	0.56	0.55	98
Muscle tissue of cod	0.064	0.055	86
Muscle tissue of cod	0.026	0.022	85

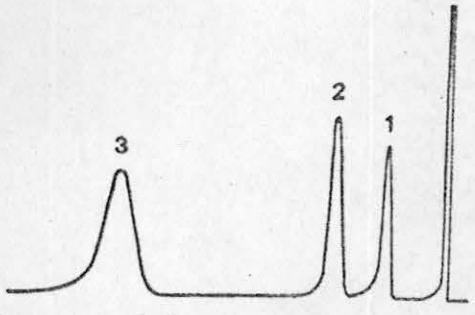


FIGURE 5-1. Gas chromatogram of methylmercury (1), ethylmercury (2) and methoxyethylmercury (3) compounds.

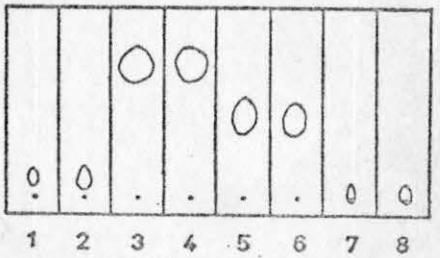


FIGURE 5-2. Thin-layer chromatogram on silica gel of authentic methylmercury chloride (1), iodide (3), bromide (5), and cyanide (7) together with the corresponding compounds prepared from methylmercury extracted from pike (2, 4, 6, 8).

In 1963 Smart & Lloyd[15] and in 1964 Tejning and Vesterberg[16][17] reported a high mercury content (approximately 10 ppm) in eggs from hens fed with seeds containing about 6 or 14 ppm of methylmercury dicyandiamide. This compound was used as a seed disinfectant in Sweden from about 1940 through January 1966 & presently it is not used in U.S. Of more than two hundred eggs bought on the open market in Sweden in 1964 to 1965 all contained less than 0.05 mg of Hg per kg, with an average of 0.029 mg/kg. (Table 5-II)

Ref. 8a Chemical Fallout G. Westöö Methylmercury compounds in Animal Foods pp 77

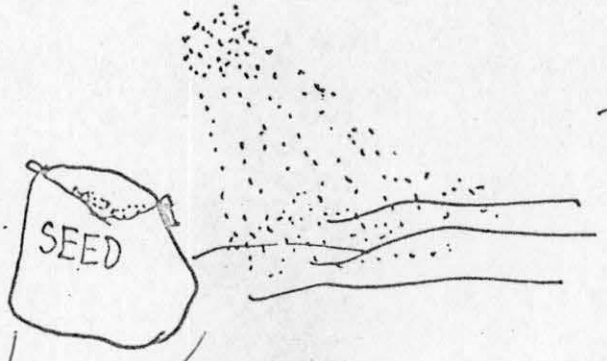
Eggs with mercury levels exceeding 0.1 mg/kg were found on a few small farms in Sweden. On one farm eggs contained up to 1.5 mg of Hg/kg. This possibly shows that some feeding of seed treated with methylmercury compound took place. Eggs from foreign countries were also analyzed. Except for the Norweign eggs, all foreign eggs investigated contained less mercury than Swedish eggs (Table 5-II). In Norway as in Sweden methylmercury dicyandiamide was used as a seed disinfectant, whereas in Denmark methoxyethylmercury compounds were mainly used.

TABLE 5-II
MERCURY CONTENT OF EGGS ON THE OPEN MARKET

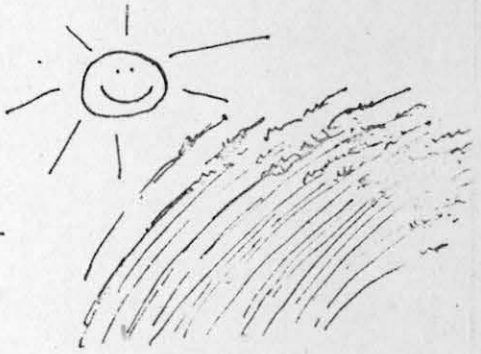
Ref. 8a Chemical Fallout Westöö G. Methylmercury Compounds in Animal Foods (pg81)

Period of Time	*Country*	*Number of Eggs*	*Mercury Content, mg/kg Limits*	*Average*
March 1964-April 1966	Sweden	> 200	0.015-0.043	0.029
1964-1965	Norway	7	0.018-0.022	0.021
1964-1965	Other European Countries	48	0.004-0.013	0.007
April 1967-Sept. 1967	Sweden	> 200	0.005-0.020	0.009

The Mercury Food Chain

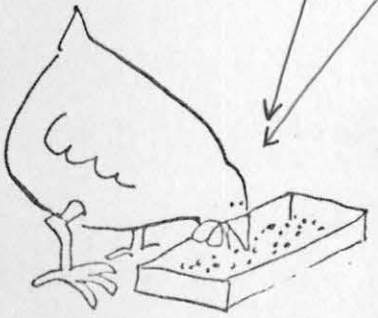


1. Mercury fungicides are used on seed grain.



2. The grain grown from these seeds contains mercury.

Drawings by Melinda Glasgow



3. Chicken feed made from the grain passes the mercury on to the hens.

4. Mercury is concentrated in the hen's eggs.

5. And finally, a human eats mercury in his breakfast eggs.

Ref. Environment Vol. II No. 4 pg 14-15.

From February 1, 1966 treatment of seed with methylmercury compounds was prohibited in Sweden. Instead, the use of methoxyethylmercury compounds was allowed. In October 1965, the disinfection of seed had been strongly restricted. These two amendments, together with mass media propaganda against the use of mercury compounds, caused a decrease in the mercury treatment of seed from about 80% to about 12% (spring sowing 1967). The effect was that the mercury poisoning of seed eating wild animals decreased ceased. no! Furthermore, the mercury content of Swedish eggs decreased from an average of 0.029 mg/kg in 1965 to 0.009 mg/kg in 1967, which is similar to the mercury content of foreign eggs (Table 5-II & fig. 5-6).

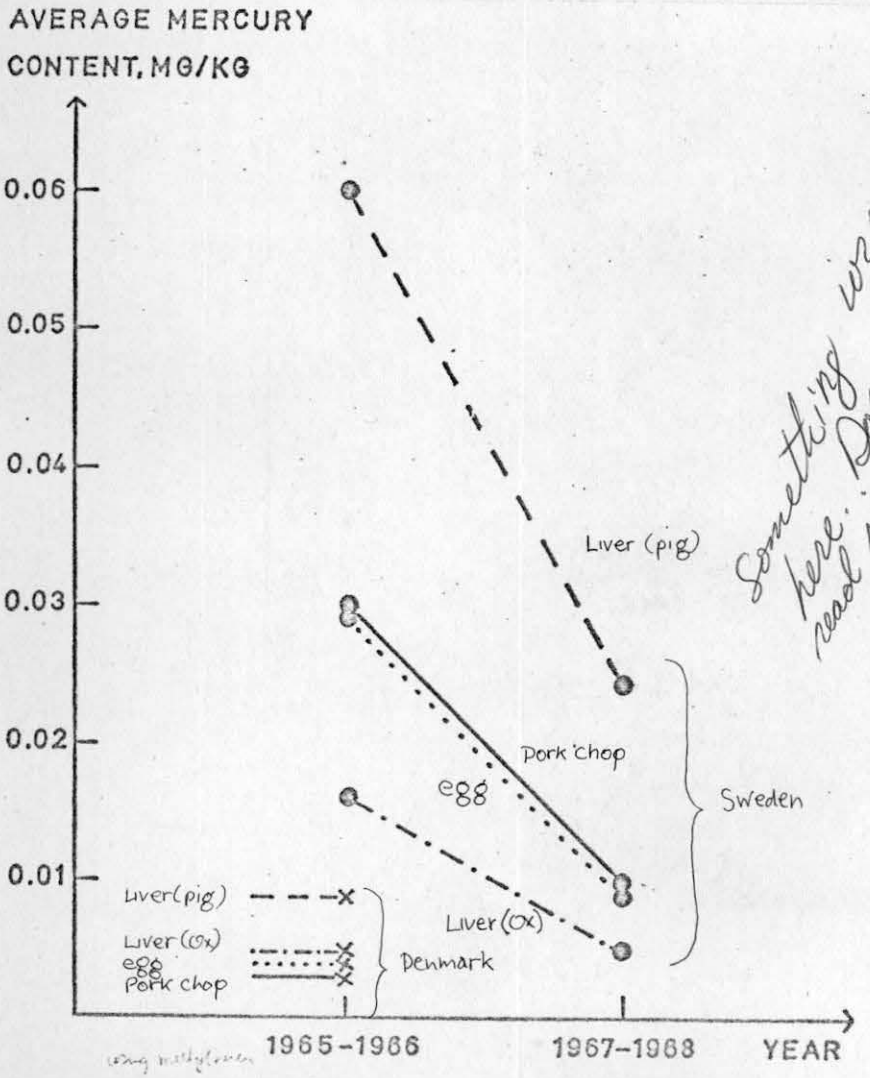


FIGURE 5-6. Decrease of mercury content of animal foods in Sweden, due to changes in seed disinfection.

• Sweden x Denmark
——— Pork chop ..... Egg
– – – – – – Liver (pig) -·-·-·-·- Liver (ox)

This tends to indicate that enough methylmercury compound migrated from the seed to the ripened grain to affect the eggs. That the methylmercury did migrate via this route was verified by a feeding experiment, which also indicated that grains, grown from seed treated with methoxyethylmercury salt, when fed to hens had no effect on the mercury content of the eggs (Table 5-III) pg 14).

Something wrong here. Doesn't read right.

Ref. 8a Chemical Fallout - Westöö. G, Methylmercury Compounds in Animal Foods pg 82.

Considering the high sulfur content of eggs and keeping in mind his first reference to bacteria producing methyl mercury, the mechanism of conversion may be fun to kick around. Concentrations in eggs and hair (very rich in cysteine) appear to be a function of lots of sulfhydral (SH) groups. He should know about hair as a diagnostic tool.

TABLE 5-IV
MERCURY CONTENT OF MEAT AND LIVER

Period of time	*Country*	*Food*	*Number of Samples*	*Mercury content, mg/kg Limits*	*Average*
Sept.-Nov. 1965	Sweden	Pork chop	35	0.016-0.130	0.030
October 1965	Denmark	Pork chop	6	0.002-0.007	0.003
March 1968	Sweden	Pork chop	6	0.006-0.016	0.011
November 1965	Sweden	Liver (pig)	26	0.014-0.183	0.060
October 1965	Denmark	Liver (pig)	6	0.005-0.020	0.009
January 1968	Sweden	Liver (pig)	10	0.011-0.049	0.024
Nov. 1965-April 1966	Sweden	Liver (ox)	23	0.005-0.046	0.016
October 1965	Denmark	Liver (ox)	6	0.003-0.007	0.005
March 1968	Sweden	Liver (ox)	6	0.003-0.008	0.005
Febr. 1965-March 1966	Sweden	Poultry meat	83	0.002-0.058	0.013
March 1965	Sweden	Poultry liver	31	0.016-0.062	0.030
Oct. 1965-April 1966	Sweden	Filet of beef	23	0.002-0.074	0.012
October 1965	Denmark	Filet of beef	6	0.002-0.004	0.003

Ref. 8a Chemical Fallout Westöö G, Methylmercury compounds in Animal Foods (pg 84)

The small amount of methylmercury present may have emanated from other product such as fish meal.

TABLE 5-III

MERCURY CONTENT OF EGGS FROM FEEDING EXPERIMENTS (Ref 8)

Grains Fed	Mercury Content, mg/kg Limits	Average
Grown from methoxyethylmercury-treated seed	0.009-0.011	0.010
Grown from methylmercury-treated seed	0.022-0.029	0.027
Grown from untreated seed	0.008-0.015	0.012

Feeding experiments[8] have shown that some formation of methylmercury from other mercury compounds can take place in hens. Grains were treated with phenylmercury, methoxyethylmercury or inorganic mercury compounds & fed to hens. The mercury content increased in both egg white & yolk. In all the experiments methylmercury was found in the egg white. In the yolk, where the concentration of the mercury was up to five times higher than in the white, only a small percentage of the mercury was methylmercury. When however corn feed was treated with a methylmercury compound, all the mercury in the egg was methylmercury & the concentration in the white was 4 to 5 times higher than in the yolk (?).

Swedish meat & liver (poultry, ox, pig), except pig's liver, contained on the average less than 0.05 mg of Hg/kg even before 1966, but just as in eggs the mercury content was higher than in similar products from Denmark. The substitution in 1966 of methoxyethylmercury for methylmercury as a seed disinfectant resulted also in a lower content of mercury in these meats (Table 5-IV).

Another important problem is the mercury contamination of fish. It is known fish & shellfish accumulate water pollutants. As early as 1934 Stock & Cucel demonstrated that mercury levels in marine fish was 0.03 to 0.11 mg/kg and in fresh water fish 0.03 to 0.18 mg/kg.

TABLE 10-II

HG CONTENT IN ORGANS OF PIKE SPECIMEN

(WEIGHT 3120 g, TIDÖ-LINDÖ, LAKE MÄLAREN, 1/7 1964)

Organ	*Hg ng/g*
Heart muscle	1000
Axial muscle	850
Liver	780
Kidney	640
Ovary	560
Intestine	610
Epidermal finrays	390
Gill	300
Brain	290
Spleen	280
Scales	104

From: Chemical Fallout Johnels, A.G & Westermark. T Mercury contamination of the Environment in Sweden pg 221

TABLE 5-VI

METHYLMERCURY CONTENT OF FISH CAUGHT UPSTREAM AND DOWNSTREAM FROM OUTLETS OF MERCURY COMPOUNDS

Lake, where the fish were caught	*Species of fish*	*Total weight of fish, kg*	*Methylmercury Compounds mg of Hg/kg of fish muscles*	*% of total mercury*
Viren, downstream from paper factory	Perch	0.12	1.91	~100
Viren, downstream from paper factory	Perch	0.12	2.18	99
Viren, downstream from paper factory	Perch	0.19	3.02	86
Viren, downstream from paper factory	Perch	0.41	2.81	91
Viren, downstream from paper factory	Pike	0.59	3.13	95
Viren, downstream from paper factory	Pike	0.91	3.48	92
Öjen, upstream from the same factory	Perch	0.064	0.18	100
Öjen, upstream from the same factory	Perch	0.071	0.20	91
Öjen, upstream from the same factory	Perch	0.10	0.70	93
Öjen, upstream from the same factory	Perch	0.14	0.42	~100
Öjen, upstream from the same factory	Pike	0.40	0.55	98
Övre Hillen, downstream from rectifier factory	Perch	0.015	0.83	94
Övre Hillen, downstream from rectifier factory	Perch	0.017	1.20	92
Övre Hillen, downstream from rectifier factory	Perch	0.21	2.48	86
Övre Hillen, downstream from rectifier factory	Pike	0.40	1.81	95
Övre Hillen, downstream from rectifier factory	Pike-perch	0.37	2.39	94
Övre Hillen, downstream from rectifier factory	Pike-perch	0.41	2.05	95
Övre Hillen, downstream from rectifier factory	Whitefish	0.035	1.40	100
Övre Hillen, downstream from rectifier factory	Whitefish	0.067	1.06	~100
Väsman, upstream from the same factory	Eelpout	0.24	0.35	90
Väsman, upstream from the same factory	Eelpout	0.32	0.50	93
Väsman, upstream from the same factory	Eelpout	0.32	0.70	95
Väsman, upstream from the same factory	Eelpout	0.36	0.37	100
Väsman, upstream from the same factory	Eelpout	0.42	0.53	79

from: Chemical Fallout Westöö G. Methylmercury Compounds in Animal Foods (pg 37)

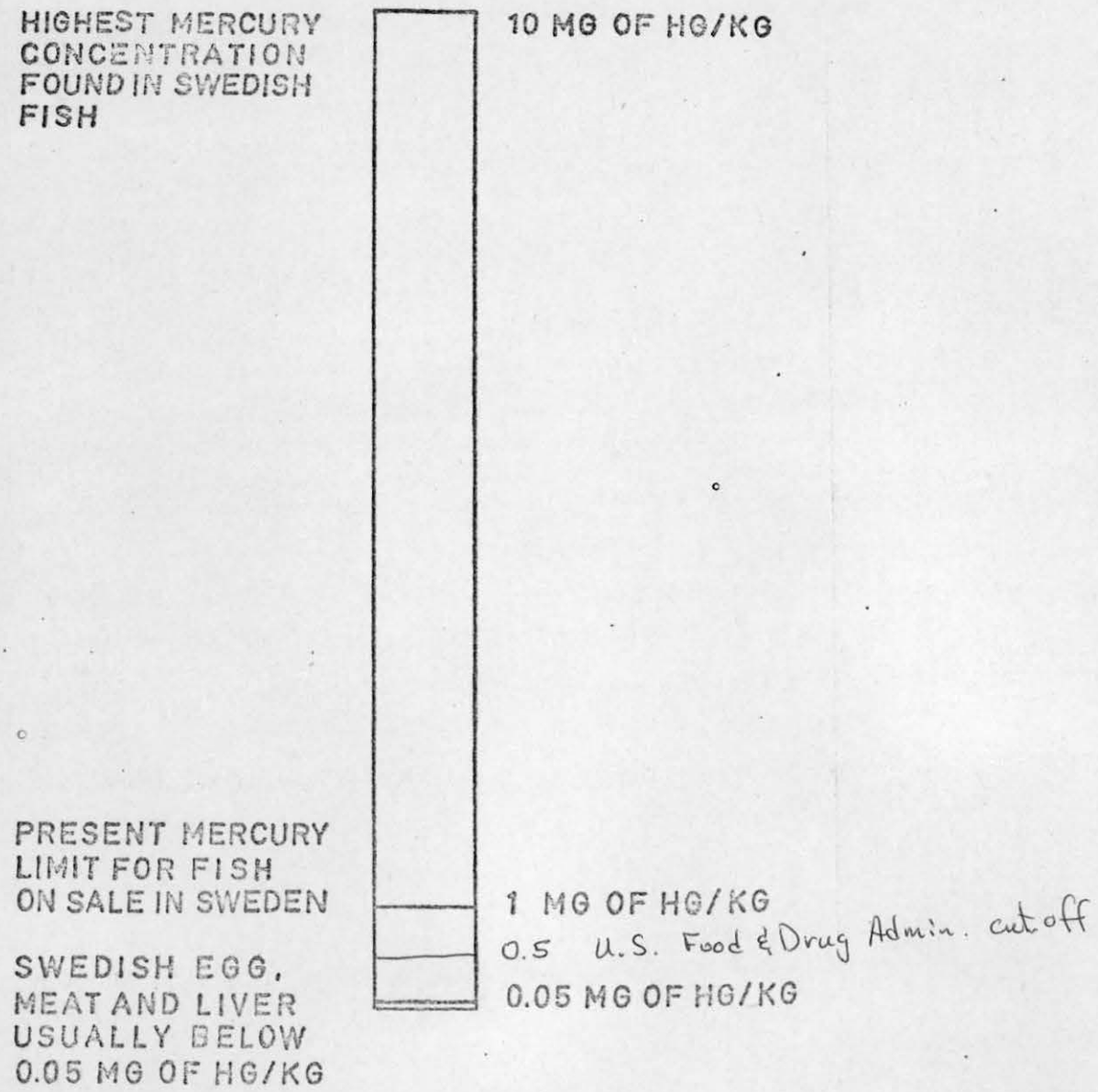


FIGURE 5-7. Methylmercury levels in certain foods in Sweden.

from: Chemical Fallout Westöö G. Methylmercury compounds in Animal Foods (pg 86).

Might kick around the idea of ½ life here. Appears greater input than excretion

Westermark et al[19] in 1965 observed that Swedish fish often contained much more mercury than the fish analyzed by Stock. They also showed that the mercury content of fish increases with the age of the fish.

In Sweden today the mercury level in marine fish caught far from the shore is usually well below 0.1 mg/kg, as is the mercury level in freshwater fish caught in uncontaminated lakes. Marine fish caught near the shore & especially freshwater fish, often contain 0.4 to 1.0, frequently 1 to 5, very infrequently 5 to 10 mg/kg. (fig 5-7). For example in the archipelago of Stockholm, samples of pike, perch & Baltic herring often contain more than 1 mg of Hg/kg. In Vänern, the largest lake in Sweden, the mercury content of pike in several creeks exceeded 1 mg/kg of fish muscles. The high mercury content in fish is usually caused by industrial disposal of mercury into the water or the air. Downstream from chlorine-alkali factories using mercury electrodes, pulp-paper mills which were allowed to use phenylmercury compounds as a fungicide until January 1, 1966, the mercury content of fish is higher than that of fish caught upstream (Table 5-VI)[8]. Today about 4 water areas in Sweden are polluted by mercury to such an extent that sale of fish from these areas are prohibited. Regardless of the nature of the mercury pollutant, only methylmercury has been found in the fish, which indicates that a methylation of mercury compounds takes place.

Should have units everywhere

The following are tables showing mercury in food products.

TABLE III
MERCURY IN FOODS

Food	Country	Nanograms/gram (range)
Haddock[a]	United States	17–23
Herring[a]	Baltic states	26–41
Apples[a]	United Kingdom	20–120
Apples[a]	New Zealand	11–135
Pears[a]	Australia	40–260
Tomatoes[a]	United Kingdom	12–110
Potatoes[a]	United Kingdom	5–32
Wheat[a]	Sweden	8–12
Rice[a]	Japan	227–1000
Rice[a]	United Kingdom (imports)	5–15
Carrots[b]	United States	20
White bread[b]	United States	4–8
Whole milk[b]	United States	3–10
Beer[b]	United States	4

I'd be interested to know how this came about (fungicide?).

[a] Smart, N. A., 1968.
[b] Goldwater, L. J., 1964.

TABLE IV

MERCURY RESIDUES IN GRAIN AND FRUIT UNTREATED AND TREATED WITH PHENYL MERCURY FOLIAR SPRAY[a]

Commodity	Mercury (ppb)	
	Untreated	Treated
Rice	20–100	100–700
Mandarin orange		
Skin	10–50	30–240
Pulp		10–40
Apple		
Skin	10–50	70–310
Pulp	10–50	30–130

[a] Mouyu, S., and Survanai, M., 1965.

TABLE V

METHYLMERCURY IN RELATION TO TOTAL MERCURY IN SOME SWEDISH ANIMAL PRODUCTS[a]

Product	Year	Samples	Average level of methylmercury (ng/g)	% Average level of total mercury
Pork chop	1968	9	11	97
Pig's liver	1966	3	88	73
Pig's liver	1968	15	16	65
Pig's kidney	1968	21	14	41
Pig's brain	1968	6	1	26
Beef filet	1966	1	68	92
Beef liver	1968	10	1	23
Calf's liver	1968	13	3	—
Reindeer saddle	1968–1969	9	8	86
Reindeer liver	1968–1969	27	4	5
Reindeer kidney	1969	10	2	1
Hen's egg, white	1966	6	21	92
Hen's egg, white	1967–1968	24	11	91
Hen's egg, yolk	1966	3	8	91
Hen's egg, yolk	1968	6	1	26
Merganser's egg, white	1969	9	2750	99
Merganser's egg, yolk	1969	9	340	60
Pike and perch	1968–1969	300	(0.04–8400) range	99

[a] Westöö, 1969, Table 15.

TABLE VI

TOTAL MERCURY CONTENT OF CERTAIN SCANDINAVIAN ANIMAL FOOD PRODUCTS[a]

Food product	Total mercury (ng/g wet wt)			
	1964 through 1966		1967 through 1969	
	Range	Average	Range	Average
Sweden				
Pork chop	16–130	30	1–16	8
Pig's liver	14–180	60	3–49	21
Beef filet	2–74	12	1–5	2
Hen's egg	15–43	29	4–23	9
Reindeer	5–23	13	4–17	11
Reindeer liver	9–44	26	17–270	98
Pike	—	—	40–8400	—
Crayfish	—	—	210–500	—
Denmark				
Pork chop	2–7	3	1–8	3
Pig's liver	5–20	9	3–28	9
Beef filet	2–4	3	2–8	5
Hen's egg	—	—	5–70	14

[a] Westöö, G., 1969, Table 13.

	Germany 1934 A	Germany 1938 B	U.S. 1940 C	Japan 1964 D	U.S. 1964 E
MEATS	.001–.067	.005–.02	.0008–.044	.31–.36	.001–.15
FISH	.02–.18	.025–.18	.0016–.014	.035–.54	0–.06
VEGETABLES (FRESH)	.002–.044	.005–.035	0	.03–.06	0–.02
VEGETABLES (CANNED)			.005–.025		.002–.007
MILK (FRESH)	.0006–.004	.0006–.004	.003–.007	.003–.007	.008
BUTTER	.002 (FATS)	.07–.28			.14
CHEESE	.009–.01				.08
GRAINS	.02–.036	.025–.035	.002–.006	.012–.048	.002–.025
FRUITS (FRESH)	.004–.01	.005–.035		.018	.004–.03
EGG WHITE				.08–.125	.01
EGG YOLK				.33–.67	.062
EGG (WHOLE)	.002	.002	0		
BEER	.00007–.0014	.001–.015			.004

CONCENTRATION IN FOODS was reported by Alfred E. Stock in Germany in 1934 (*A*) and 1938 (*B*), O. S. Gibbs in the U.S. in 1940 (*C*), Y. Fujimura in Japan in 1964 (*D*) and the author's group in the U.S. in 1964 (*E*). A listing of "0" means simply a concentration too low to be detected by the method used. The World Health Organization proposed a permissible upper limit of .05 part per million for foods other than fish; the U.S. Food and Drug Administration has set an upper limit of .5 part per million for fish.

From: Scientific American Vol 224 No. 5 Goldwater LJ. Mercury in the Environment (pg 20)

UNITED STATES. In 1969 warning of mercury poisoning arose in North America. In Alamogordo, New Mexico, on December 4, 1969, Ernestine Huckleby, (10)(24a) an 8 year old child went home from school complaining of dizziness & pain. During the following weeks she stumbled & staggered about. She was placed in a hospital in El Paso, Texas, yet her illness remained unidentified. The girl lost control of her voluntary body functions. Two weeks later Ernestine's brother Amos complained of pain

in his neck, and overnight he lost control of his muscles. His vision became tunneled & ~~he could see only straight ahead~~. Ernestine became blind, her speech slurred and muscles were more uncontrollable. Two days after Christmas she drifted into a coma. Ernestine's sister, 22 year old Dorothy Jean began to stagger & blurred vision (bothered where she was going.) needs more or less words. The three Huckleby children were hospitalized; Amos was not only blind but deaf, Dorothy Jean passed out of touch with the world & began raving.

The medical report from the Food Drug Administration laboratory at Atlanta, Georgia, reported the urine of the children showed high levels of methylmercury. Where did the high concentration of mercury come from? Guided by the report that some hogs in the Huckleby farm died of the "blind staggers", the researchers traced the source of mercury to seeds eaten by the hogs that Ernest Huckleby raised & butchered for his family table. The seeds had been coated with a methylmercury compound called Panogen. The meat from the hog contained 27 ppm mercury and the grain seeds 32 ppm of mercury. Lois Huckleby who was pregnant when she ate the pork, gave birth to a blind and retarded child. Many of the symptoms displayed by the Huckleby children are similar to those caused by Minamata disease.

Another warning of mercury pollution came early 1970 when it was discovered (21a)(22) fish caught in Lake St. Clair, which connects Lake Huron with Lake Erie, had levels of mercury as high as 7.09 ppm, which is 1¼ times more than the safety limit fixed by the Food & Drug Administration (FDA). The FDA adopted maximum allowable concentration of mercury in food intended for human consumption at 0.5 ppm in a daily diet. This provides a safety factor of 10. The FDA investigator located two sources of mercury in the area - one a Dow Chemical chlor-alkali factory at Sarnia,

How so? The 0.5 ppm is admitted by FDA to be a fairly arbitrary level.

Ontario; the other Wyandotte Chemical Plant at Wyandotte, Michigan. Canada quietly closed its side of Lake St. Clair to commercial fishing. Later similar action was taken by Michigan. Ohio closed portions of Lake Erie to commercial fishing of walleye, white bass, sheephead, and catfish.

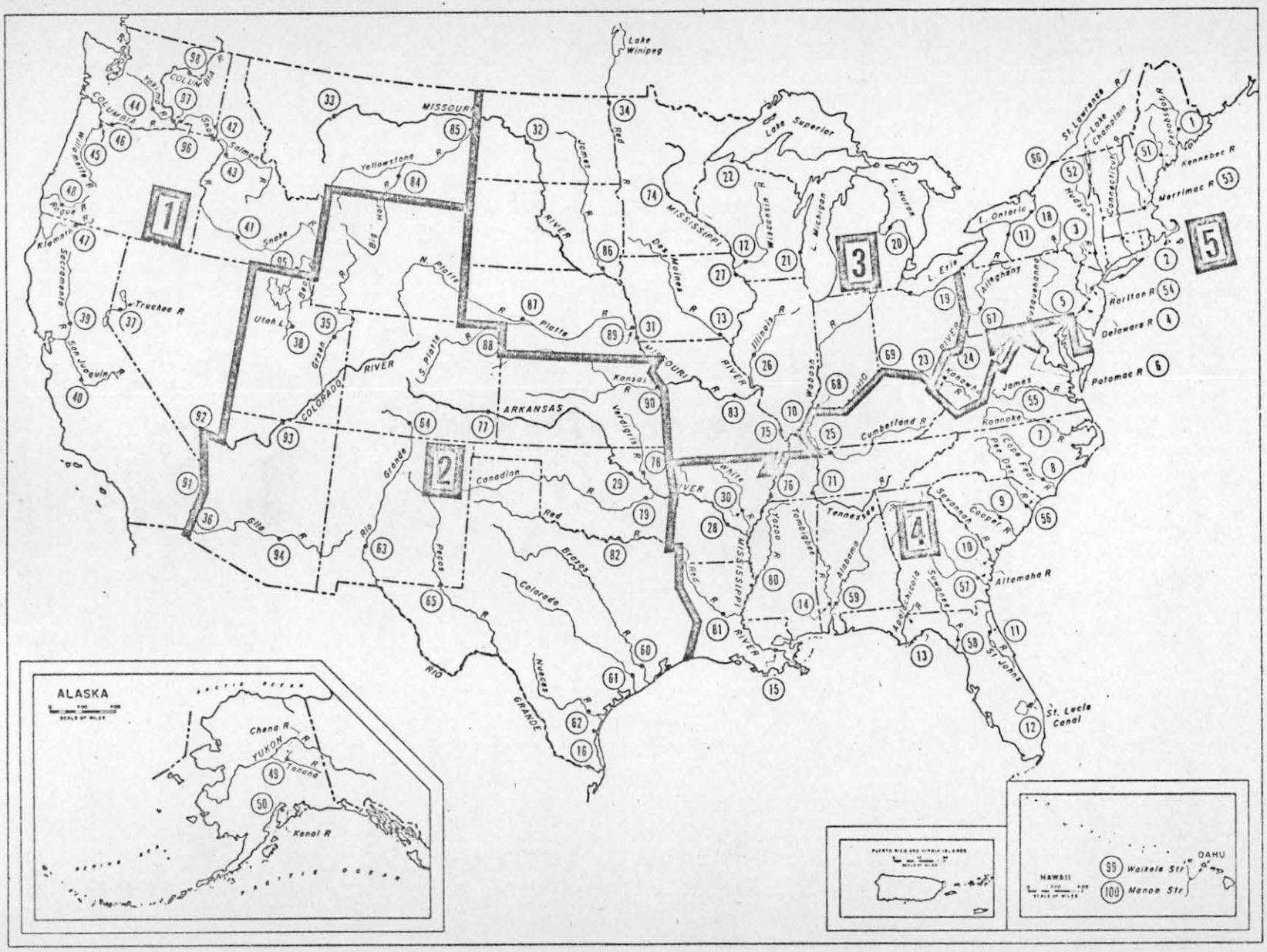
On April 10, 1970 FDA announced inauguration of a country wide study to determine: 1) particular areas of concentrated mercury pollution in U.S. waters 2) actual levels of mercury in sport and commercial fish caught in those waters & 3) mercury in imported fish.

Some data is available. Figure 1 shows the National Pesticide Monitoring regions. Table 5 shows comparison by region of mercury residue in fishes. (see next page)

NATIONAL PESTICIDE MONITORING - FISH

UNITED STATES
DEPARTMENT OF THE INTERIOR

FISH AND WILDLIFE SERVICE
BUREAU OF SPORT FISHERIES AND WILDLIFE



COMPILED IN THE DIVISION OF ENGINEERING
BASE BY U S G S

WASHINGTON, D.C. JUNE, 1970

0 100 200 300 400 500 600
SCALE OF MILES

FIGURE 1

Table 5

Mercury Residues in Fish - Comparison by Regions

Location	Number of Stations	Number of Samples	Mercury Residues - ppm 1/ Number 2/ of Samples	Average	Median	Range	Above 3/ FDA Action Level
Region 1 Pacific 1969	14	39	39	0.25	0.15	.06-1.25	4
Region 1 Pacific 1970	23	84	84	0.26	0.18	.05-1.7	7
Region 2 Southwest 1969	5	15	7	0.08	0.06	<.05-.14	0
Region 3 North Central 1969	9	26	22	0.20	0.13	<.05-.50	0
Region 4 Southeast 1969	12	35	34	0.23	0.14	<.05-1.0	2
Region 5 Northeast 1969	10	30	27	0.23	0.14	<.05-.80	2

1/ Milligrams per kilogram - wet weight, whole fish.

2/ Mercury residues above detectable limit - 0.05 ppm.

3/ Number samples above FDA Action Level.

MERCURY IN THE LITHOSPHERE. Mercury is found everywhere. Both nature & man share the responsibility for mercury production. Mercury is one of the elements that makes up the planet earth and is found in the lithosphere (rock & soil), the hydrosphere, the atmosphere, and the biosphere (in tissues of plants & animals). It is absorbed & held tightly by a variety of materials such as plant fibers & soil. It reacts with a variety of inorganic & organic compounds to form simple & complex molecules ranging from cinnabar (mercuric sulfide, HgS) to metallo-organic complexes which have received recent world wide attention as water pollutants & biological toxins.

Although there are more than a dozen mercury bearing minerals only a few occur abundantly in nature. Cinnabar is the most important & contains 86% mercury by weight; it is usually formed geologically at low temperatures (less than 300° C). It is generally found in mineral veins or fractures in rocks near recent volcanic or hot spring areas.

Mercury content of a broad categories of rocks in the earth's crust range from 10 to 20,000 ppb. Parts per billion is equivalent to 1 pound of mercury per billion pounds of rock. Igneous rock, those formed by melting & cooling, are the basic source of mercury. These rocks average about 100 ppb of mercury. Tables are available showing the amount of mercury in various types of igneous rocks. Table 2 shows mercury content in different types of igneous rock samples from various parts of the world.(154)

TABLE 2.—*Analyses for mercury, in parts per billion, of basalts, gabbros, diabases, andesites, dacites, and liparites*

[Compare with table 6]

Sample	Number of samples analyzed	Range		Average	Reference
		Min	Max		
Basalt BCR-1, Washington	1	4	18	9	Five labs.
Diabase W-1, Virginia	1	94	340	231	Eight labs.
Three basalts, two dolerites, Iceland, Hawaii, and Tasmania.	5	5	21	13	Ehmann and Lovering (1967).
Basalts, oceanic sediments near Iceland	----	180	300	------	Aidin'yan, Ozerova, and Gipp (1963).
Gabbro, Quebec	1	------	------	1	Jovanovic and Reed (1968).
Composite 11 gabbros, Germany	1	------	------	100	Preuss (1940).
Composite 11 gabbros, Germany	1	------	------	80	Stock and Cucuel (1934a).
Gabbros, Yakutia	11	0	50	26	Nekrasov and Timofeeva (1963).
Gabbros, northern Caucasus	13	20	250	100	Afanas'ev and Aidin'yan (1961).
Gabbros	6	<1,100	500	240	Ozerova (1962).
Basalt, Germany	1	------	------	190	Stock and Cucuel (1934a).

From: Geologic survey professional paper 713 Mercury in the Env pg 53

Other tables showing mercury content in igneous & metamorphic rocks are available in Geologic Professional Paper 713.

Most sedimentary rocks have mercury content less than 200 ppb mercury, except for shales, clays, & soils which show considerable variation with average contents of a few hundred parts per billion mercury. Shales rich in organic matter are notably enriched in mercury, suggesting that some of the mercury may be present as organic complexes. The mercury content of soils averages about 100 ppb & varies within limits. Tables 8,9,10,11,12,13, show mercury content in various types of rocks & soils.

TABLE 8.—*Analyses for mercury, in parts per billion, in limestones*

Sample	Number of samples analyzed	Range		Average	Reference
		Min	Max		
	1	------	------	33	Stock and Cucuel (1934a).
Germany	14	28	220	66	Heide and Böhm (1957).
Nineteen Composites, Russian platform	19	10	90	31	Ozerova and Aidin'yan (1966a).
Argillaceous marls, Cauascus, background = 50.	----	10	8,000	------	Abuev, Divakov, and Rad'ko (1965).
Limestones, Crimean highlands	8	100	6,400	2,300	Bulkin (1962).
Marls, Crimean highlands	5	500	5,000	1,500	Do.
Donets Basin	314	<100	10,000	900	Karasik and Goncharov (1963).
Kerch-Taman area, near mud volcanoes	----	2,000	5,000	------	Karasik and Morozov (1966).
Limestones and dolomites, southern Ferghana	22	20	150	75	Nikiforov, Aidin'yan, and Kusevich (1966).
Northeast Yakutia	26	<2	70	18	Nekrasov and Timofeeva (1963).
Kazakhstan	n00	------	------	<20	Fursov, as quoted by Ozerova and Aidin'yan (1966b).
Marble, Viet Nam	1	------	------	500	Aidin'yan, Troitskii, and Balavskaya (1964).

From: Mercury in the Environment - Geologic Survey Professional Paper 713 pg 56,57.

TABLE 9.—*Analyses for mercury, in parts per billion, in sandstones*

Sample	Number of samples analyzed	Range		Average	Reference
		Min	Max		
	2	26	40	33	Stock and Cucuel (1934a).
Composite of 23	1	------	------	100	Preuss (1940).
Sandstones, mudstones, Russian platform	45	0	95	39	Ozerova and Aidin'yan (1966b).
Effusive-sedimentary, Kamchatka	9	------	------	97	Do.
Kazakhstan	n00	------	------	20	Fursov, quoted by Ozerova and Aidin'yan (1966b).
Northeast Yakutia	6	<2	30	12	Nekrasov and Timofeeva (1963).
Sandstones, Crimean highlands	83	100	11,000	5,700	Bulkin (1962).
Conglomerates, Crimean highlands	10	100	7,000	2,300	Do.
Donets Basin	----	<50	1,000	300	Dvornikov and Klitchenko (1964).
Donets Basin	77	<100	7,000	870	Karasik and Goncharov (1963).
Donets Basin, contact with dike	1	------	------	600	Buturlinov and Korchemagin (1968).
Donets Basin, from mercury deposit	----	3,000	10,000	6,000	Bol'shakov (1964).
Sandstones with limestones, southern Ferghana.	----	3,000	10,000	------	Kurmanaliev (1967).
Viet Nam	4	280	1,000	620	Aidin'yan, Troitskii, and Balavskaya (1964).

TABLE 10.—*Analyses for mercury, in parts per billion, in shales and clays*

Sample	Number of samples analyzed	Range		Average	Reference
		Min	Max		
Composite 36 German shales	1	------	------	300	Preuss (1940).
Composite 26 German shales	1	------	------	510	Stock and Cucuel (1934a).
Shales	4	130	250	182	Do.
Marly clays	3	100	320	188	Heide and Bohm (1957).
Clays, Russian platform	58	0	130	35	Ozerova and Aidin'yan (1966b).
Shales, northeast Yakutia	6	15	80	50	Nekrasov and Timofeeva (1963).
Shales, sandstones, southern Ferghana	36	20	150	70	Nikiforov, Aidin'yan and Kusevich (1966).
Shales, Komi A.S.S.R.	26	42	230	------	Zav'yalov and Mal'tseva, quoted by Ozerova and Aidin'yan (1966b).
Argillites, sedimentary-volcanic, Kamchatka	11	------	------	85	Nikiforov, Aidin'yan, and Kusevich (1966).
Bituminous shale, Alaska	2	630	2,800	------	Donnell, Tailleur, and Tourtelot (1967).
Oil shales, Baltic region	10	170	1,500	------	Ozerova and Aidin'yan (1966b).
Oil shales, Povolzhe region	11	200	1,600	440	Do.
Oil shales, Tula region	2	50	100	75	Do.
Silurian shales outside ore region	----	<100	200	------	Ozerova (1962).
Silurian shales within ore region	----	n0	n000	------	Do.
Shales, Crimean highlands	48	<100	19,000	2,300	Bulkin (1962).
Shales, Donets Basin	0	<50	80	50	Dvornikov and Klitchenko (1964).
Shales, Donets Basin, contact with dikes	8	<200	500	350	Buturlinov and Korchemagin (1968).
Shales, Donets Basin	55	<100	8,000	660	Karasik and Goncharov (1963).
Shales, Donets Basin, from mercury deposit	----	1,000	60,000	------	Bol'shakov (1964).
Clays, Kerch Peninsula	----	<100	4,000	800	Morosov (1965).
Clays, Viet Nam	4	100	550	270	Aidin'yan, Troitskii, and Balavskaya (1964).

TABLE 11.—*Analyses for mercury, in parts per billion, in miscellaneous sedimentary rocks*

Sample	Number of samples analyzed	Range		Average	Reference
		Min	Max		
Caucasus, not specified	14	------	------	50	Demidova, quoted by Ozerova and Aidin'yan (1966b).
Gornyi Altai, not specified	9	40	100	------	Shcherban, quoted by Ozerova and Aidin'yan (1966b).
Kerch-Taman area, near mud volcanoes	----	500	2,800	------	Karasik and Morozov (1966).
Kerch-Taman area, away from mud volcanoes	----	400	600	540	Do.
Cambrian, Tyan-Shan	----	70	2,800	------	Shabalin and Solov'eva (1967).
Rock salt, anhydrite, gypsum, Donets Basin	71	<100	4,000	700	Karasik and Goncharov (1963).
Phosphorites	20	20	800	70	Ozerova and Aidin'yan (1966a, 1966b).
Iron-rich laterites, Viet Nam	----	1,000	2,700	------	Do.
Manganese ores, Nikopol	----	------	------	2,800	Do.
Manganese ores, Chiatura	----	360	530	------	Do.
anganese ores, Mangyshlak	----	65	95	------	Do.
auxites	4	120	600	460	Do.

From: Geologic Survey Professional Paper 713 Mercury in the Environment pg 56-57

TABLE 12.—*Analyses for mercury, in parts per billion, in oceanic and lacustrine sediments*

Sample	Number of samples analyzed	Range		Average	Reference
		Min	Max		
Red clay, Atlantic	4	500	1,800	1,000	Aidin'yan, Ozerova, and Gipp (1963).
Red clay, Pacific	2	100	300	200	Do.
Red clay, Black Sea	4	900	2,000	1,200	Do.
Foraminiferal ooze, Atlantic	7	80	300	170	Do.
Foraminiferal ooze, Pacific	1	------	------	50	Do.
Foraminiferal ooze, Indian	2	70	150	110	Do.
Terrigenous ooze, Atlantic	6	80	550	210	Do.
Terrigenous ooze, Indian	1	------	------	70	Do.
Diatomaceous ooze, Pacific	2	60	100	80	Do.
Diatomaceous ooze, Indian	2	------	------	200	Do.
East Pacific	----	[1]1	[1]400	------	Boström and Fisher (1969).
Fjord sediments	2	1,400	2,000	------	Landstrom, Samsahl, and Wenner (1969).
Lacustrine sediments	2	360	810	------	Do.
Manganese nodules, Atlantic	5	<1	810	------	Harriss (1968).
Manganese nodules, Pacific	7	<1	775	------	Do.
Manganese nodules, Indian	4	<1	3	------	Do.
Manganese nodules, Atlantic	----	------	------	2,000	Ozerova and Aidin'yan (1966b).
Manganese nodules, Pacific	----	100	150	------	Do.

[1] On a carbonate-free basis.

TABLE 13.—*Analyses of soils for mercury, in parts per billion*

Sample	Number of samples analyzed	Range		Average	Reference
		Min	Max		
Most soils, California	----	20	40	------	Williston (1968).
Soils, Franciscan Formation, California	----	100	200	------	Do.
Soils, unmineralized areas, California	----	40	60	------	Friedrich and Hawkes (1966).
Unmineralized areas, British Columbia	----	10	50	------	Warren, Delavault, and Barakso (1966).
Near mineralization, British Columbia	----	50	2,500	------	Do.
Very near mineralization, British Columbia	----	250	2,500	------	Do.
Soils, Germany	----	30	290	------	Stock and Cucuel (1934a).
Topsoils, Sweden	273	------	------	60	Anderssen (1967).
Topsoils, Africa	14	------	------	23	Do.
Soils, European U.S.S.R	130	40	5,800	------	Aidin'yan, Troitskii, and Balavskaya (1964).
Soils, Donets Basin	248	<50	10,000	300	Dvornikov (1963).
Soils, Donets Basin	----	100	2,400	1,300	Dvornikov and Petrov (1961).
Soils, Kerch Peninsula	264	<100	3,000	------	Morozov (1965).
Soils, Kerch-Taman area	----	240	1,900	------	Karasik and Morozov (1966).
Soils, Viet Nam	----	20	1,000	300	Aidin'yan, Troitskii, and Balavskaya (1964).

TABLE 16.—*Mercury in coal, in parts per billion*

Sample	Number of samples analyzed	Range		Average	Reference
		Min	Max		
Germany	11	1.2	25	12	Stock and Cucuel (1934a).
Donets Basin, U.S.S.R	------	4,500	70,000	11,100	Karasik and others (1962).
Do	------	140	300,000	46,000	Ozerova (1962).
Do	206	50	10,000	1,100	Dvornikov (1963).
Donets Basin, U.S.S.R. (in lenses within mercury ore body).	------	2,500	6,500	3,700	Bol'shakov (1964).
Donets Basin, U.S.S.R	75	20	20,000	------	Dvornikov (1967a).
Do	------	100	7,000	------	Dvornikov (1965, 1967b).
Do	13	100	300,000	46,000	Dvornikov (1968).

From: Geologic Survey Professional Paper 713 Mercury in the Environment pg 57-59

MERCURY IN THE ATMOSPHERE Mercury is present in the atmosphere, with background values of less than 1 to a few nanograms per cubic meter. However, over metallic ore deposits the contents of mercury is appreciably higher. Volcanic emanations including those of mud volcano type, have high contents of mercury & must contribute a large amount of mercury to the atmosphere. In addition to such "natural pollution" one must assume that mercury is added to the atmosphere by the burning of coal & petroleum & very likely from stack gases of smelters treating copper, lead, & zinc ores. No data are available on the amounts added by "man-made pollution" or on the time of residence in the atmosphere of mercury from "natural" or "man-made" pollution.

Because of mercury's tendency to vaporaize, the atmosphere measured at ground level near mercury ore deposits may contain as much as 20,000 ng/m^3 (nanogram/cubic meter) of mercury in air. One nanogram is one-billionth ($\frac{1}{1\times10^9}$), of a gram. Expressed on a weight basis rather than on a volume basis for comparison with contents of rocks, 20,000 ng/m^3 represents almost 16 pounds of mercury per billion pounds of air. The next highest near-ground levels of atmospheric mercury occurs over precious metal ores (up to 1,500 ng/m^3) & copper ore (20 ng/m^3 [25]).

TABLE 15.—*Mercury in air and in volcanic emanations, in nanograms per cubic meter*

[1 nanogram = 10^{-9} grams]

Sample	Number of samples analyzed	Range		Average	Reference
		Min	Max		
Air					
"Unpolluted air"	2	------	------	8	Stock and Cucuel (1934b).
Over Pacific Ocean, 20 miles offshore	------	0.6	0.7	------	Williston (1968).
California, winter	------	1	25	------	Do.
California, summer	------	1.5	50	------	Do.
Background, Arizona and California	------	1.6	7.2	4.5	McCarthy and others (1969).
Chicago area	22	3	39	9.7	Brar and others (1969).
Kamchatka	10	------	------	190	Aidin'yan and Ozerova (1966).
Moscow and Tula regions (no ore deposits)	------	80	300	------	Do.
Over porphyry copper deposit	------	12	30	18.8	McCarthy and others (1969).
Do	------	18.5	53	28	Do.
Over mercury deposit	------	12	57.5	31.4	Do.
Do	------	58	66	62	Do.
Do	------	200	1,200	------	Karasik and Bol'shakov, quoted by Aidin'yan and Ozerova (1966).

Volcanic				
Air of vent breccias of mud volcanoes	300	700	----	Karasik and Morozov (1966).
Gases of mud volcanoes	700	2,000	----	Do.
Gases, Mendeleev and Sheveluch Volcanoes	300	4,000	----	Aidin'yan and Ozerova (1966).
Gases from hot springs, Kamchatka and Kuriles.	10,000	18,000	----	Do.
Condensates from fumaroles and volcanic emanations, Kamchatka and Kuriles.	[1] .2	[1] 72	----	Do.
Waters from hot springs, Kamchatka and Kuriles.	[1] .5	[1] 4	----	Do.

[1] Parts per billion.

TABLE 28.—*Maximum mercury concentration in air measured at scattered mineralized and nonmineralized areas of the Western United States*

[---, no data available]

Sample location	Maximum Hg concentration (ng/m³)[1,2]	
	Ground surface	400 feet above the ground [3]
Mercury mines		
Ord mine, Mazatzal Mtns., Ariz	20,000 (50)	108 (4)
Silver Cloud mine, Battle Mtn., Nev	2,000 (50)	24 (8)
Dome Rock Mtns., Ariz	128 (6)	57 (20)
Base and precious metal mines		
Cerro Colorado Mtns., Ariz	1,500 (5)	24 (2)
Cortez gold mine, Crescent Valley, Nev	180 (60)	55 (4)
Coeur d'Alene mining district, Wallace, Idaho	68 (40)	----
San Xavier, Ariz	----	25 (3)
Porphyry copper mines		
Silver Bell mine, Arizona	----	53 (3)
Esperanza mine, Arizona	----	32 (3)
Vekol Mtns., Ariz	----	32 (4)
Ajo mine, Arizona	----	30 (3)
Mission mine, Arizona	----	24 (3)
Twin Buttes mine, Arizona	20	22 (3)
Pima mine, Arizona	----	13 (3)
Safford, Ariz	----	7 (2)
Unmineralized areas		
Blythe, Calif	----	9 (20)
Gila Bend, Calif	----	4 (2)
Salton Sea, Calif	----	3.5 (2)
Arivaca, Ariz	----	3 (2)

[1] ng/m³ = nanograms (10^{-9} grams) per cubic meter of air. 1 ng/m³ = 10^{-6} ppb.
[2] Number of measurements shown in parentheses.
[3] Samples taken from single-engine aircraft.

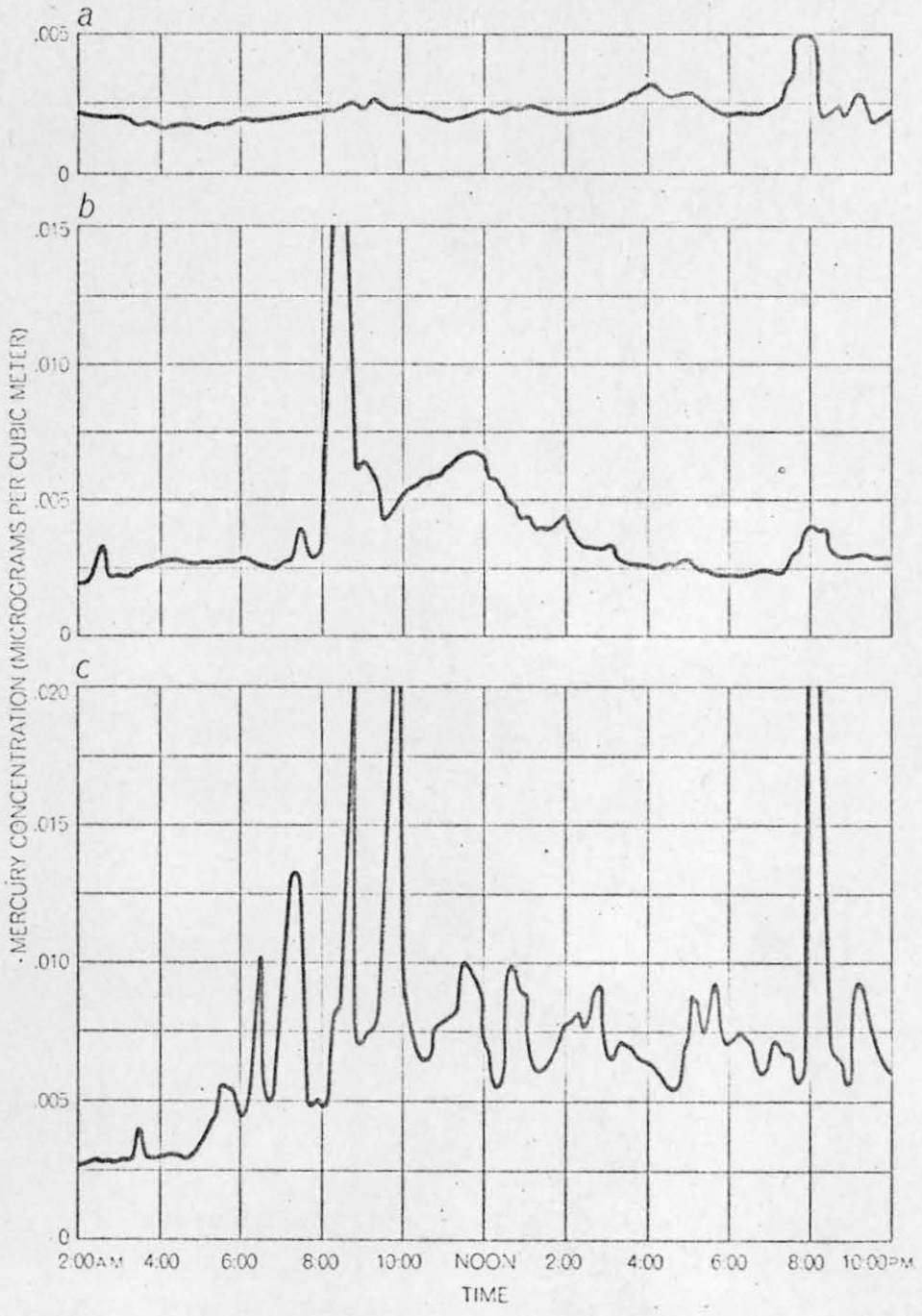
From: Geologic Survey Professional Paper 713 Mercury in the Environment pg 59-67

Natural atmospheric mercury responds to meterological controls & other natural laws. For example the maximum amount of mercury in air is found at about midday with much smaller amounts found in the morning & in the evening. In both cases, the vapor density of mercury, like the density of the atmosphere, is greatest near the surface of the land & diminishes with altitude. For example a concentration

of 20,000 ng/m^3 of mercury at ground level near a mercury mine may diminish to only about 100 ng/m^3 at 400 feet altitude, & a ground-level concentration of 600 ng/m^3 at noon has been observed to drop to only 20 ng/m^3 at 2:00 A.M.(25)

Rain washes mercury from the atmosphere just as it does certain other atmospheric components. Even near mercury ore deposits, tests have shown the mercury content of the atmosphere to be essentially zero immediately after a rainstorm. Such scrubbing accounts for the fact that the mercury content of rainwater averages about 0.2 ppb. Tests in Sweden have shown that mercury carried down by rain adds to each area of land per year about the same amount of mercury one would expect to be added by mercury-bearing seed dressing for fungal control of cereal crop. Mercury from either source is held tightly by the upper 2 inches or so of soil.

A very significant amt.



ATMOSPHERIC MERCURY LEVELS were measured by S. H. Williston at a station south of San Francisco. The concentration averaged about .0002 microgram of mercury per cubic meter of air when the wind blew from the Pacific (*a*) and was somewhat higher when the wind was from the generally nonindustrial southeast (*b*). The average was .008 microgram, with many peaks that went off the record at .02 microgram, when the wind was from the industrial area to the northeast (*c*). The mercury was often associated with dust particles.

from: Scientific American Vol. 224 No 5. (pg 19) Goldwater L.J. Mercury in the Environment.

TABLE I

Concentration and Rate of Output of Mercury from Smokestacks in Illinois and Missouri

Location of Plant	Concentration Ranges (in billionths of a gram per cubic meter)								Estimated Total Output of Mercury Per Year (in pounds)
	less than 50	50-100	100-200	200-500	500-1,000	1,000-2,000	5,000-10,000	more than 10,000	
Power Plants									
Sauget, Ill.	3	4	1						
Wood River, Ill.	2	4							
Portage des Sioux, Mo.	3	6							
Baldwin, Ill.		2							100
Coffeen, Ill.	4	1							800
Kincaid, Ill.	1	3							2,400
Springfield, Ill. 12/9/70				4	5	4	3	4	5,300
Springfield, Ill. 1/14/71		5	4						600
Rockdale, Ill.		1							950
Romeoville, Ill.	No significant detection								
Chicago, Ill. (Calumet Plant)	No significant detection								
Chicago, Ill. (Crawford Plant)	2								450
Chicago, Ill. (Ridgeland Plant)	No significant detection								
Chicago, Ill. (Stateline Plant)	1								500
Chicago, Ill. (Fisk Plant)		3							550
Incinerators									
St. Louis, Mo. (South)				2	3	8	13		4,500
St. Louis, Mo. (North)*				2	5	4	4	1 1	2,300
Chicago, Ill. (Lake Calumet)			1	6	9		1		5,400
Chicago, Ill. Sludge Dryer (Stickney)				1	3	1			570
Industrial									
Monsanto, Sauget, Ill.			2	6	11	2			
American Zinc, Taylor Springs, Ill.	3								
Goldsmith Bros., Chicago, Ill. 12/10/70	2	1	1	2	1				
1/14/71						5	1		
National Lead Co., St. Louis, Mo.	1								
Granite City Steel, Granite City, Ill.	1								
Laclede Steel, Alton, Ill.	1	1							
Shell Oil Co., Wood River, Ill.	13	7	1						
American Oil Co., Wood River, Ill.	2	2							

*One sample from this incinerator drove the measuring instrument to its maximum reading of 50,000 billionths of a gram per cubic meter.

From: Environment Vol 13. No. 4 pg 32

The grey bars mark the ranges of concentration in which mercury was found for each of the plants listed in the left column. The numbers in each bar indicate the number of samples which gave reading in each range of concentrations.

MERCURY IN WATER. Contact of water with soil & rock during storm runoff, percolation into the ground, & movements underground results in the natural distribution of mercury in water. The pattern of such distribution depends on the dispersion of mercury in the earth's crust and other processes. Surface waters, except where influenced by special geological conditions, or recent man-make pollution, generally contain less than 0.1 ppb of mercury. This reflects the relatively low concentration of mercury in rainwater & the relavely tight binding of mercury in organic & inorganic materials over which the water passes in its travel through the environment. In a recent reconnaissance of river waters in 31 states showed (1) 65% of the samples tested had mercury contents below 0.1 ppb, (2) 15% exceeded 1.0 ppb & (3) only 3% were more than 5.0 ppb, the maximum considered safe for drinking water.(21)(25)

Limited sampling of oil-field brines in California showed them to contain from 100 to 200 ppb of mercury. Hot springs in California appear to range from 0.5 to 3.0 ppb; & one measurement was high as 200 ppb of mercury. Vapors issuing from fumaroles & steam condensing from hot springs also have relatively high mercury contents - as much as 600 ppb & 130 ppb, respectively. Fine-grained muds from pots and mud volcanos in Yellowstone National Park yield mercury contents up to 150,000 ppb & measurement as high as 500,000 ppb. have been made on enriched sediments from hot springs & pools in Yellowstone.

Because of mercury's tendency to attach readily on to a variety of earth materials, particule matter suspended in water & bottom sediment of streams are more likely to contain high concentrations of mercury than the water itself, whatever the source may be.

TABLE 14.—*Mercury content of natural waters, in micrograms per liter*

[1 microgram per liter ~1 part per billion mercury]

Sample	Number of samples analyzed	Range		Average	Reference
		Min	Max		
Rivers					
Rhine River	------	--------	--------	0.1	Stock and Cucuel (1934a).
Saale River, Germany	8	0.05	[1] 0.19	.07	Heide and Böhm (1957), and Heide, Lerz, and Böhm (1957).
Elbe River, Germany	1	--------	--------	.09	Do.
Danube River	------	1	2	--------	Aidin'yan and Balavskaya (1963).
Sweden	4	.02	.2	--------	Wikander (1968).
European SSSR	24	.4	2.8	1.1	Aidin'yan (1962).
Armenian SSR	7	1	20	4.2	Aidin'yan (1963).
Armenian SSR	6	1	[2] 2.0	[2] 1.5	Do.
	300	.01	[3] 136	<.1	
Sea water					
	------	--------	--------	0.03	Stock and Cucuel (1934a).
	------	--------	--------	.03	Heide and Böhm (1957).
Atlantic, Indian, Red Sea, Black Sea, etc	14	0.7	2.0	1.1	Aidin'yan (1962).
Atlantic Ocean	9	.4	1.6	1.2	Aidin'yan, Ozerova, and Gipp (1963).
Pacific Ocean, Ramapo Deep	------	.08	.15	.1	Hamaguchi and others (1961).
Do	4	.15	.27	.2	Hosohara (1961).
Minamata Bay, Japan	------	1.6	3.6	--------	Hosohara and others (1961).
Ground water and miscellaneous samples					
Rainwater	------	0.05	0.48	0.2	Stock and Cucuel (1934a).
Spring water, Germany	------	.01	.05	--------	Do.
Surface waters, Northwest Caucasus	7,000	.27	.68	--------	Baev (1968).
Subsurface waters, Northwest Caucasus		.25	1.25	--------	Do.
Springs, Elbrus region	37	<.05	80	≈1	Krainov, Volkov, and Korol'kova (1966).
(No data in abstract on nature of water.)	------	0	140,000	--------	Ishikura and Shibuya (1968).
Ground water, Kerch, U.S.S.R	------	<1	2.5	--------	Morozov (1965).
Ground water, near mud volcanoes, Kerch	------	1	2.5	--------	Karasik and Morozov (1966).
Ground water, Abkhazia, U.S.S.R	------	--------	--------	<.5	Zautashvili (1966).
Mine waters, Abkhazia, U.S.S.R	------	.5	3	--------	Do.
Mineralized waters, Abkhazia, U.S.S.R	------	1	5	--------	Do.
Waters of Permian salt beds, Donets Basin	26	<1	[4] 8.5	--------	Karasik, Goncharov, and Vasilevskaya (1965).
Brines associated with petroleum, Cymric oilfield, California.	------	100	400	--------	Bailey and others (1961).
Brine, geothermal well, Salton Sea, Calif	1	--------	--------	6	Skinner and others (1967).

[1] The value 0.19 (next highest 0.08) is ascribed to waste water from an industrial plant.
[2] Excluding the highest value.
[3] Values above 0.1 ppb were in the drainage area of mercury deposits.
[4] Another sample, a concentrated brine, contained 220 ppb Hg.

from: Geologic Survey Professional Paper 713 Mercury in the Environment pg 58

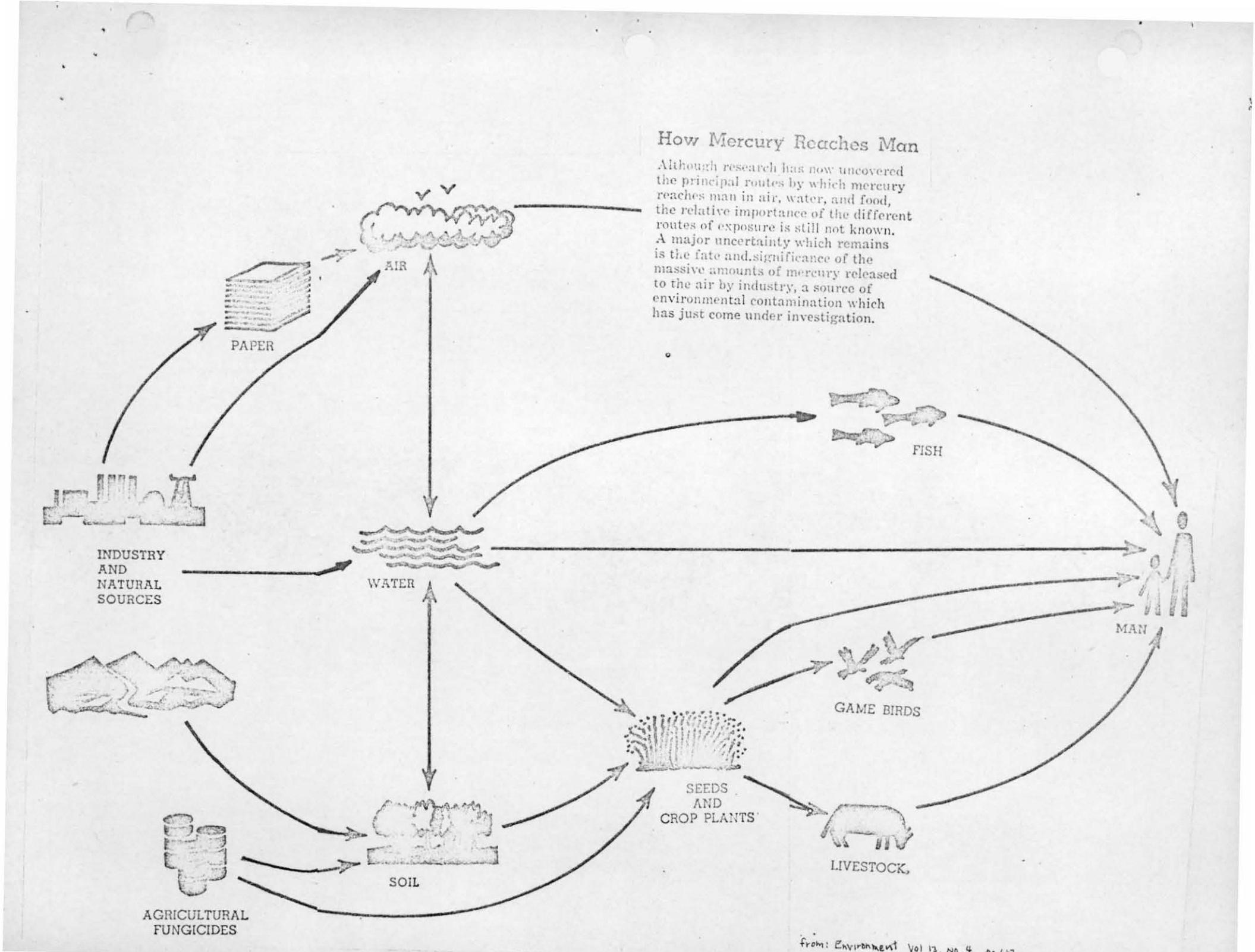
TABLE 22.—*Mercury concentrations in thermal waters from Yellowstone National Park*

[Detection limit, 0.01 part per billion. N.d., not detected. Analyses by M. E. Hinkle]

Sample	Location	Mercury concentration (in ppb)
Ojo Caliente	Midway Basin	0.14
Ear Spring	do	.22
Bonita Spring	do	.07
Chinaman Spring	do	.10
Steady Geyser	Lower Basin	.07
Snort Spring	Porcupine Hills	.10
Beryl Spring	Gibbon Canyon	.18
Little Whirligig Spring	Norris Basin	.07
Cinder Pool	do	.28
Spring, base of Porcelain Terrace	do	.10
Echinus Geyser	do	.11
Cistern Spring	do	.08
Primrose Spring	Sylvan Spring area	.31
Sulfur Pool	do	.27
Green Spring	do	.20
Blue Spring	do	.20
New Highland Terrace	Mammoth Spring	.05

from: Geologic Survey Professional Paper 713 Mercury in the Environment pg 63

The best estimate is that suspended matter may contain from 5 to 25 times as much mercury as the water around it in areas of industrial pollution. Sediments immediately downstream of mercury ore deposits & mercury contaminated industrial discharges may contain from a few hundred to as much as several hundred thousand parts per billion of mercury. The mercury concentration in surface water downstream from a mercury source is likely to be much lower because of dilution, vaporization, precipitation, sorption, & chemical reaction. For example, the mercury concentration in river water near a mercury source was found to decrease from 135 ppb to 0.04 ppb in 30 mile of travel, & sediment in a Wisconsin river near a source of industrial pollution had mercury content of more than 500,000 ppb whereas sediment 20 miles downstream from the source of pollution had a content of only 400 ppb. The tendency of mercury to sink rapidly & combine with sulfide in anaerobic bottom sediments to form cinnabar, which is slightly soluble, appears to be a major scavenging mechanism. Another mechanism which keeps content of dissoved mercury low is the relatively high reactivity of mercury with organic substances & the resulting uptake by living & non-living organic matter. Then lakes & ponds serve as sediment traps & habitats for aquatic organisms & the mercury enters the food chain. The significance of such accumulations of mercury depends upon the solubility of the final mercury form in the particular environment.



from: Environment Vol 13, No. 4 pg 407

Although global and regional transport of mercury is largely unknown, it is possible to construct a partial model of the movement of mercury among the air, soil, and water components of the environment. Such a model is depicted in figure 2. Table VIII illustrates model budget of mercury in the soil as it is related to the atmosphere and runoff.

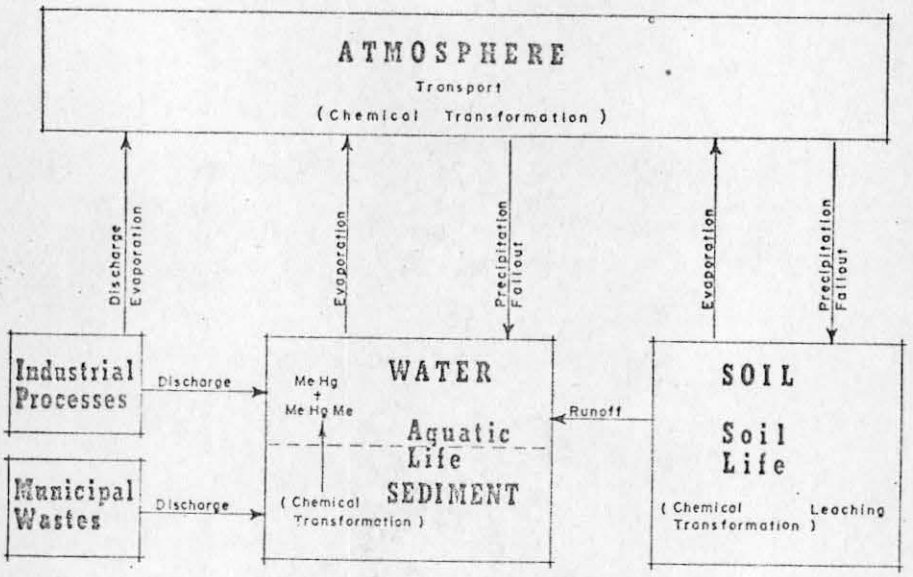


FIG. 2. Mercury cycle in the environment.

From: Environmental Research Thompson J.G. Airborne Mercury pg 52

TABLE VIII
ANNUAL MERCURY BUDGET

Environmental component	Amount of mercury (mg ha)
Soil to depth of 1 m	1,000,000
Precipitation (annual addition to soil)	5,000
Runoff (annual loss from soil)	500
Evaporation (annual loss from soil, addition to atmosphere)	4,500
Atmosphere	2,000[a]

[a] Amount of mercury in entire air column over 1 ha of soil.

From: Environmental Research Thompson J.E. Airborne Mercury pg 51.

TABLE 23.—*Mercury concentrations from analyses of petroleum from the Wilbur Springs area, northern California*

[Detection limit, 0.01 part per billion. Analyses by M. E. Hinkle]

Sample	County	Mercury concentration (in ppb)
Tarry petroleum, Abbott mine	Lake	500,000
Petroleum, Wilbur oil test well	Colusa	1,000

TABLE 24.—*Mercury in selected rivers of the United States, 1970*

[Analyses by M. J. Fishman (U.S. Geological Survey, written commun., 1970)]

Source and location	Time sample collected		Mercury (in ppb)
	Month-day	Hour	
Gold Creek at Juneau, Alaska	6-10	1350	<0.1
Colorado River near Yuma, Ariz	6-18	----	<.1
Welton Mohawk Drain near Yuma, Ariz	6-19	----	<.1
Ouachita River downstream from Camden, Ark	6-18	0900	<.1
St. Francis River at Marked Tree, Ark	6-19	1000	.1
Santa Ana River below Prada Dam near Riverside, Calif	6-29	----	<.1
South Platte River at Henderson, Colo	5-19	1410	.3
Blue River upstream of Dillon Reservoir, Colo	6-22	----	<.1
French Creek near Breckenridge, Colo	6-22	----	<.1
Animas River at Silverton, Colo	6-22	----	.1
Cement Creek at Silverton, Colo	6-22	----	<.1
Red Mountain Creek near Ouray, Colo	6-22	----	17
Red Mountain Creek at Ironton, Colo	6-22	----	<.1
Nuuanu Stream near Honolulu, Hawaii	6-8	0930	.6
Honolii Stream near Papaikou, Hawaii	6-8	1405	<.1
North Fork Kaukonahua near Wahiawa, Hawaii	6-11	1800	.4
Ohio River near Grand Chain, Ill	6-26	1040	.1
Floyd River at Sioux City, Iowa	6-9	1645	.2
Kansas River downstream from Topeka, Kans	5-19	1130	3.5
Mississippi River near Hickman, Ky	6-25	1030	<.1
Merrimack River above Lowell, Mass	6-8	1100	1.2
Wolf Creek near Cedar Lake, Mich	6-7	1100	<.1
Unnamed tributary to Wolf Creek near Edmore, Mich	6-7	1000	.1

(this is a partial list.)

TABLE 25.—*Mercury levels in natural waters outside the United States*

Location	Concentration levels (in ppb)	Reference
Sea water, vicinity of Helgoland	0.03	Stock and Cucuel (1934).
Lamapa Deep	.08-0.15	Hamaguchi and others (1961)
Ramapo Deep (Pacific Ocean, southeast of Honshu, Japan).	.15- .27	Hosohara (1961).
Minamata Bay, Japan	1.6-3.6	Hosohara and others (1961).
Sea waters of U.S.S.R	.7-2	Aidin'yan (1962).
Volga, Don, Araks, and Danube Rivers	1-2	Aidin'yan and Belavskaya (1963)
Rivers of European U.S.S.R	.4-2.8	Aidin'yan (1962).
Armenian rivers and Swan Lake (Armenia)	1-3	Aidin'yan (1963).
Rivers near the mercury deposits of Abkhasia, U.S.S.R.	.5-3.6	Zautashvili (1966).
Natural waters of Germany	.01-.05	Stock and Cucuel (1934).
Saale River, Germany	.035-.145 (avg, .067)	Heide, Lerz, and Böhm (1957).
Uncontaminated river waters of Italy	.01-.05	Dall'Aglio (1968).
Rivers near mercury deposits of Italy	Up to 136	Do.

Tables from: U.S. Geological Survey Professional paper 713 Mercury in the Environment (pg 63, 65)

Before one declares a water body polluted with waste mercury from man's activities, it is necessary to know the natural background level of the metal. It appears that natural mercury contents of unpolluted rivers in areas where mercury deposits are not known are less than 0.1 ppb. Table 24 shows partial data on the natural background level of mercury in selected rivers. The samples representing surface waters in the United States, range in concentration from less than 0.1 to 17 ppb. Of the total, 34 contained less than the detectable concentration (0.1 ppb). Of the remaining, 27 samples ranged from 0.1 to 1.0 ppb and 10 samples ranged from 1.0 to 5.0 ppb. Only 2 samples contained more than 5.0 ppb, the public health service limit for potable water supplies. The fact that many of the samples were taken in areas of suspected mercury contamination would appear to indicate that mercury concentration in surface waters generally do not exceed tolerable limits except in the immediate vicinity of waste outfall.[25]

Table 25 shows that the mercury levels measured in surface waters in other parts of the world generally fall in the same low range of values as found in the United States.

The Public Health Service's limit of mercury in potable water is 5.0 ppb. Generally natural mercury contents of unpolluted rivers in areas where mercury deposits are not known are less than 0.1 ppb. However samples from rivers draining mercury deposits are known to have natural mercury contents exceeding 5 ppb. The mercury concentrations in these water were found to decrease as a function of distance downstream from the mercury deposits. This can be seen in mercury content of aquatic organisms (Tables 10-III, 10-IV, 10-V).

TABLE 10-III
HG LEVELS IN AXIAL MUSCULATURE OF PIKE
(PULP FACTORY, CENTRAL SWEDEN)

Above Dam: Weight, g	Hg ng/g	*Below Dam:* Weight, g	Hg ng/g
1964			
395	160	150	2300
625	260	475	3000
725	330	600	1600
7000	830	1050	1500
1966			
245	340	1000	2400
350	280	1075	2700
475	390	1400	3100
575	620		

TABLE 10-IV
EFFECT OF PAPER MILL ON THE Hg CONTENT IN AQUATIC ORGANISMS
(PAPER MILL LOCATED AT A STREAM IN SOUTHERN SWEDEN, APRIL 1965)

Material	*Locality*	*Hg ng/g*
Tricoptera	15 km above mill	52
Tricoptera	14 km above mill	54
Tricoptera	6 km below mill	10700
Tricoptera	1 km below mill	17000
Tricoptera	5 km below mill	5600
Plecoptera sl. Isoperla	15 km above mill	72
Plecoptera sl. Isoperla	17 km below mill	2400
Asellus aquaticus	1 km above mill	65
Asellus aquaticus	15 km above mill	59
Asellus aquaticus	20 km below mill	1900
Sialis	20 km above mill	52
Sialis	1 km above mill	49
Sialis	1 km below mill	5500
Sialis	6 km below mill	4800
Fontinalis	15 km above mill	76
Fontinalis	below mill	3700
Water lily, piece of caulis	1 km above mill	16
Water lily, piece of rhizome	1 km below mill	520

TABLE 10-V
EFFECT OF PAPER MILL ON THE Hg CONTENT IN AQUATIC ORGANISMS
(THE SAME PAPER MILL AND LOCALITY AS IN TABLE 10-IV—
MATERIAL FROM 1965 AND 1966)

Material *1965*			*Locality*	*Date*	*Hg ng/g*
Hirudinea:					
Helobdella sp.			above dam	24/8	25
Helobdella sp.			below dam	23/8	3100
Helobdella sp.			below dam	19/8	2600
Helobdella sp.			below dam	20/8	2350
Helobdella sp.			below dam	18/8	4400
Insecta, Tricoptera:					
Hydropsyke pellucidula			below dam	18/8	1220
Hydropsyke pellucidula			below dam	20/8	1400
Hydropsyke pellucidula			below dam	23/8	1700
Pike	♂	490 g	8 km above dam	30/9	1200
Pike	♂	575 g	4 km above dam	27/9	1100
Pike	♀	2040 g	4 km above dam	29/9	1680
Pike	♂	580 g	4 km above dam	29/9	1220
Pike	♂	300 g	8 km below dam	30/9	5700
Pike	♂	725 g	8 km below dam	30/9	5650
Pike	♂	910 g	8 km below dam	29/9	3400
Pike	♀	1575 g	8 km below dam	26/9	8000
Atlantic Salmon		4770 g	30 km below dam	autumn	220
Atlantic Salmon		2000 g	30 km below dam	autumn	151
1966					
Pike	♀	1200 g	20 km below dam	Sept	9800
Pike	♀	170 g	20 km below dam	31/5	6300
Pike	juv	120 g	20 km below dam	Sept	5600

from: Chemical Fallout Johnels, AG & Westermark T, Mercury contamination of the Environment in Sweden (pg 230-271)

Mercury containing river, oil field brines, thermal & mineral fluids may be a natural source of pollution of surface & ground waters. The fact that the ocean contains an estimated 50 million tons of mercury suggests that small amounts of the element always have been present in surface waters.

The potential for industrial waste mercury contamination of surface waters can be judged in part from a study of the use pattern of mercury by industry. The world production of mercury in 1968 was 8,000 metric tons. During the period 1930 to 1970 the total mercury mined in the United States was 31,800 metric tons & 39,600 metric tons were imported (total 79,400 metric tons). It is estimated that as much as 25% of this total (17,850 metric tons) may have been leaked to the environment.

Table 26 gives data for mercury consumption by various users in the United States during the calender year 1969. The largest commercial consumption occurred in the manufacture of chlorine and caustic soda, a process thought to introduce appreciable amounts of waste mercury into the environment. For example, Löfroth & Duffy (1969) estimated that 8 chlorine factories in Sweden lose from 25 to 35 metric tons of mercury per year. Mercury losses from such operations have been reported in the U.S. Although considerable effort now is being made to ~~replace~~ prevent their losses of mercury. The second largest consumptive use of mercury is in the manufacturing of electrical apparatus.

TABLE 26.—*Mercury consumption, in kilograms, in the United States for calendar year 1969 and the first quarter of calendar year 1970*

[From "Mineral Industry Surveys," U.S. Bureau of Mines, first quarter, 1970]

Use	1969				First quarter, 1970			
	Primary	Redistilled	Secondary	Total	Primary	Redistilled	Secondary	Total
Agriculture [1]	92,770	-------	-------	92,770	26,462	-------	-------	26,462
Amalgamation	6,693	34	-------	6,728	4,036	104	-------	4,140
Catalysts	77,108	4,968	19,976	102,051	19,941	414	207	20,562
Dental preparations	7,383	49,059	48,886	105,328	242	9,832	6,210	16,284
Electrical apparatus	457,470	132,998	52,958	634,425	106,778	20,458	14,076	141,312
Electrolytic preparation of chlorine and caustic soda	664,574	-------	50,266	714,840	125,752	-------	3,692	129,444
General laboratory use	42,504	19,148	8,763	70,414	12,696	2,036	5,692	20,424
Industrial and control instruments	97,704	120,198	22,942	240,844	16,250	20,252	3,070	39,572
Paint:								
Antifouling	8,418	-------	-------	8,418	1,173	-------	-------	1,173
Mildew proofing	327,267	-------	-------	327,267	87,872	-------	-------	87,872
Paper and pulp manufacture	19,251	-------	-------	19,251	9,280	-------	-------	9,280
Pharmaceuticals	12,420	12,558	-------	24,978	2,346	3,416	621	6,382
Other	290,732	2,794	40,744	334,270	140,036	5,175	1,104	146,314
Total known uses	2,104,293	341,757	244,536	2,690,586	-------	-------	-------	-------
Total uses unknown	4,623	3,691	30,188	38,502	448	1,587	4,520	6,555
Grand total	2,108,916	345,448	274,723	2,729,088	[2] 563,902	[2] 69,690	[2] 41,055	[2] 674,647

[1] Includes fungicides and bactericides for industrial purposes.
[2] The items do not add to the total which has been increased to cover approximate total consumption.

From: US Geological Survey Professional Paper 713 Mercury in the Environment (pg. 65)

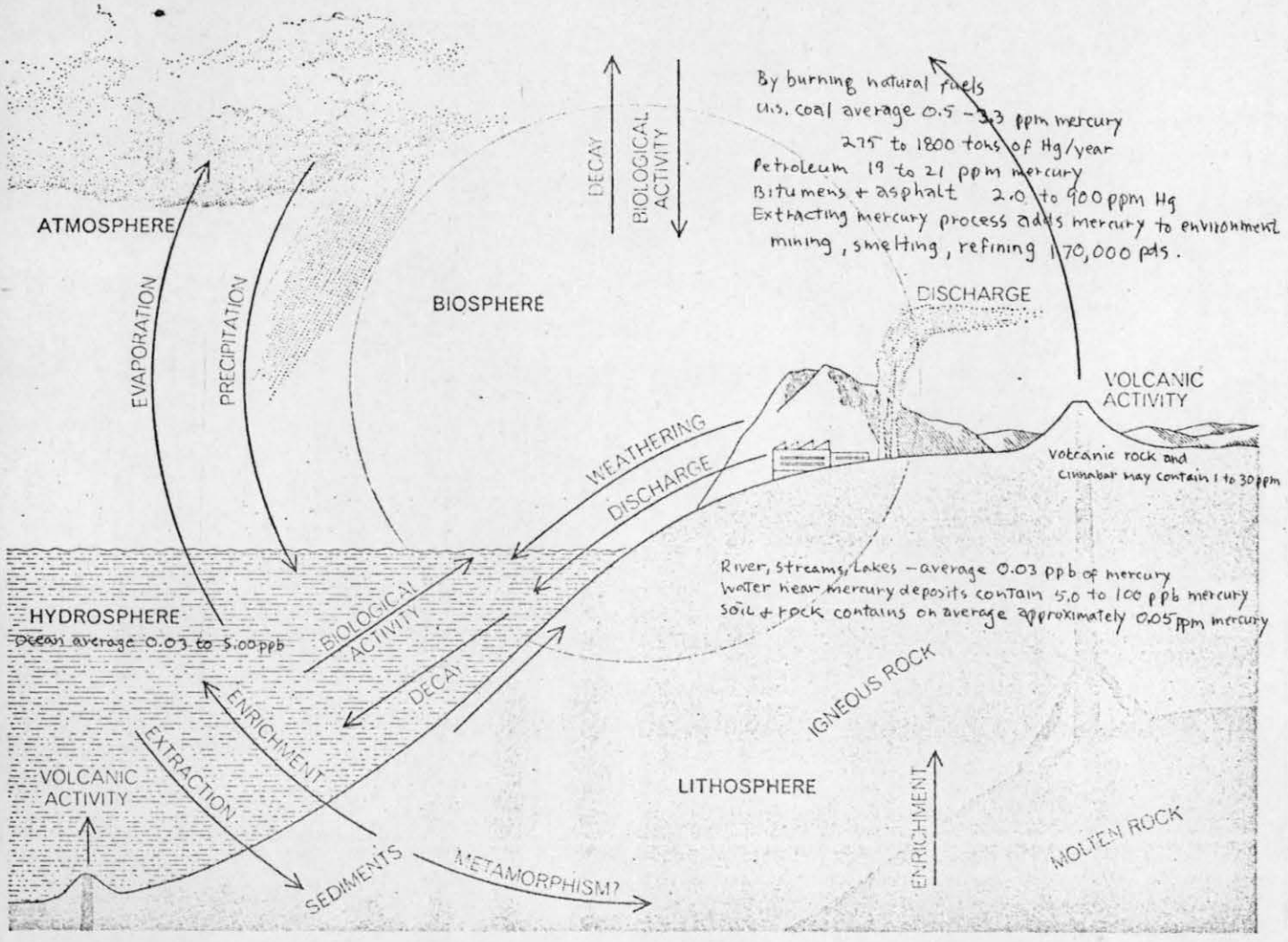
The wide vaiety of uses of mercury by man has resulted in significant mercury pollution of natural water bodies in many parts of the world. If industrial outfalls are not properly scavenged for mercury, or if mercury bearing materials are improperly disposed of, some of the waste inevitably finds its way into surface waters. For example, Anderssen measured mercury concentrations of 6 to 29 ppb (dryweight) in sludge from Swedish sewage-treatment plants. Obviously, care must be exercised in the disposal of such sludge to avoid contaminating water resources.

During the summer of 1970, the U.S. Geological Survey analyzed more than 500 water samples representative of industrial effluents & outfalls where mercury contamination was suspected. Of the more than 500 samples, 28% had less than detectable (0.1 ppb) mercury concentrations; an additional 55% contained between 0.1 & 5 ppb. In other words, 83% of all the samples analyzed had concentrations which were within the range of public health service mercury content allowable for drinking water supplies despite the fact they represented industrial areas. An additional 12% of the samples had mercury contents ranging between 5 & 100 ppb, less than 5% had concentrations greater

than 100 ppb & only two samples of the total had concentrations greater than 10,000 ppb. Sediment samples from the Missouri River basin were also analyzed for mercury content of the 15 samples studied, 11 had mercury contents ranging between 40 & 170 ppb. The remaining 4 had concentrations of 900, 1800, 3000 & 32,000 ppb.

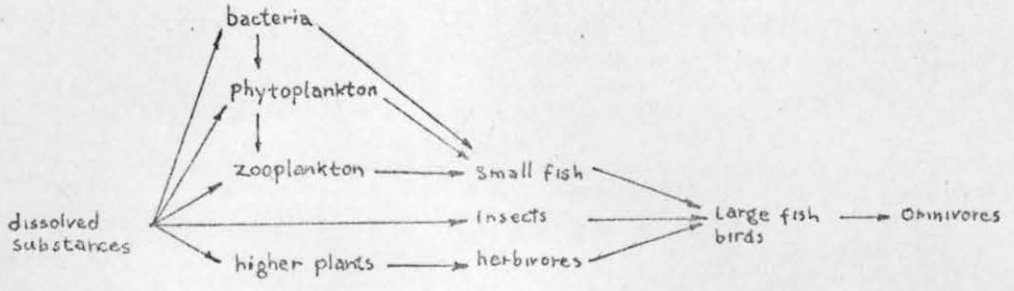
Conclusion. Natural surface waters contain tolerably small concentrations of mercury except in areas draining mercury deposits. Industrial, agricultural, scientific, & medical uses of mercury & mercury compounds, introduce additional mercury into surface waters. Whatever its source, the concentration of mercury compounds, dissolved or suspended, is reduced rapidly by sorption & by complexing reactions with clays, plankton, colloidal proteins, humic materials, & other organic & inorganic colloids. These reactions tend to keep the concentration of dissolved mercury at levels near the normal background levels except at points of actual mercury discharge.

"These reactions" are the danger. "These reactions" represent the introduction of Hg into the food chain. The amt. of Hg still in the water is not of as much concern as how much has been fixed into living tissue or converted to more toxic forms which are not readily soluble.



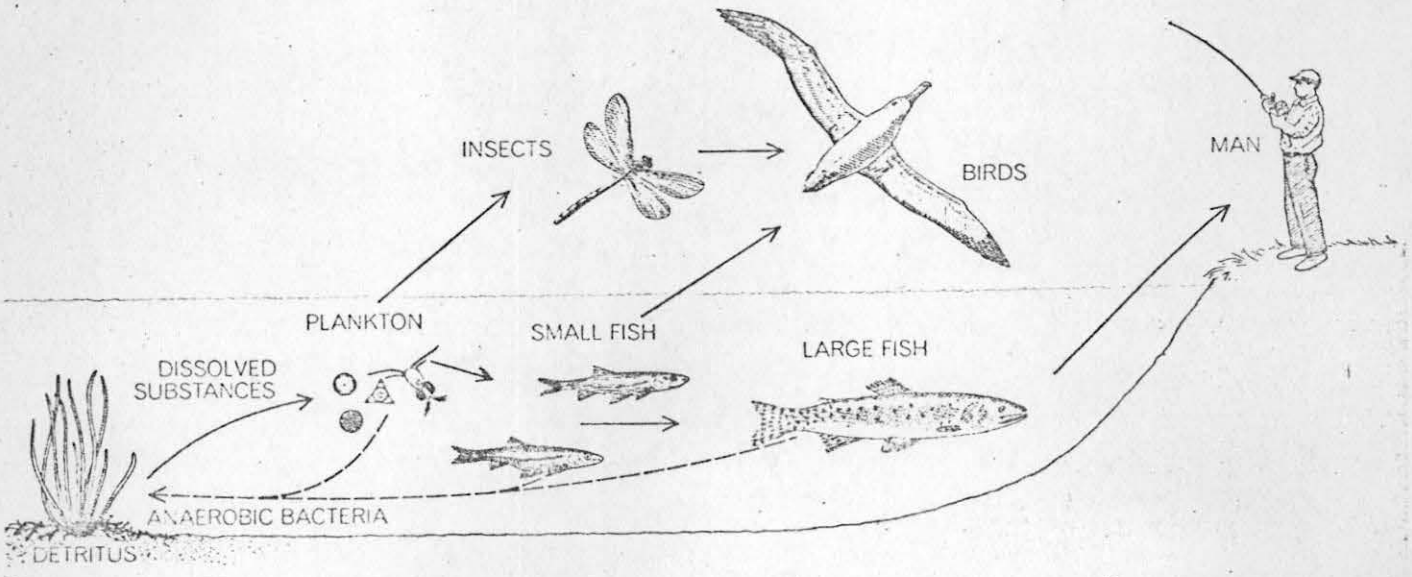
MERCURY CYCLE disperses the metal through the lithosphere, hydrosphere and atmosphere and through the biosphere, which interpenetrates all three. Mercury is present in all spheres in trace amounts, but it tends to be concentrated by biological processes. Man's activities, in particular certain industrial processes, may now present a threat by significantly redistributing the metal.

from: Scientific American Vol 224 No 5 Goldwater L.J. Mercury in the Environment (pg 16)



(modified U.S. Geological Survey).

MERCURY IN THE BIOSPHERE Inorganic chemical in soil & water are the basic substances for living things. In an aquatic environment, such inorganics generally are utilized by low forms of life which in turn serve as steps in the food chain for higher forms of life up the ladder to the vertebrate species, including man. This process is thought to be enhanced through conversion of inorganic mercury by certain anaerobes to methylmercury, a more soluble form.. How was this conversion of mercury accomplished? The study of mercurial conversion goes back to the Minamata incident when people died & suffered severe disability after eating mercury-contaminated fish caught in Minamata Bay. The only source of mercury was from a plastic factory. The factory record indicated discharging only inorganic mercury. Yet chemical analysis of the poisoned fish showed organic methyl mercury. Test of Minamata plastics factory effluent was 1% methylmercury. In Sweden, Prof. Gunnel Westöö 1965) announced that the mercury found in eggs, fish, & some meats was methylmercury. Where was all this methylmercury coming from?



AQUATIC FOOD CHAIN is a primary mechanism by which mercury is concentrated. At each trophic level less mercury is excreted than ingested, so that there is proportionately more mercury in algae than in the water they live in, more still in fish that feed on the algae and so on. Bacteria and the decay chain (*broken arrows*) promote conversion of any mercury present into methyl mercury.

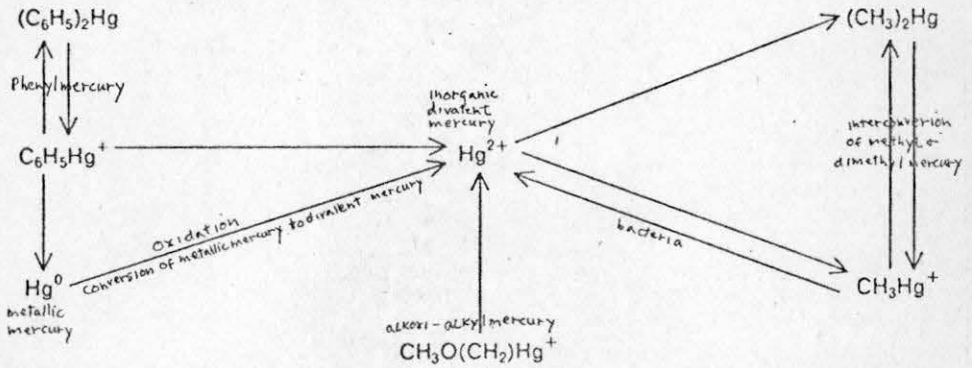
from: Scientific American Vol 224 No 5 Goldwater LJ. Mercury in the Environment (1971)

"Algae ate the bacteria..." ?

They assimilate Hg in bottom sediments & may be able to absorb some Hg cmpds out of water

I think when he says MeHg grew also, he means there is food chain magnification and that individual fish, because of a relatively long ½ life for MeHg, consumed more than they excreted, i.e. MeHg builds up in tissues. It does not "grow".

Westöö concluded small amounts of inorganic mercury could be converted to methylmercury in their livers. Without offering proof Johnels & Olson postulated an opinion that inorganic mercury could be converted into methylmercury by microorganisms in anaerobic ecosystems such as mud in lake bottoms. In 1967, the prediction was confirmed by Jernelöv & Jensen. Wood, Rosen, & Kennedy showed possibity of how certain organisms - Methanobacterium omelanskii were able to digest metallic & inorganic mercury turning it into poisonous methylmercury. Summary of some steps by which inorganic & compounds are converted in nature to methylmercury is shown below.



METHYL MERCURY COMPOUNDS are the most injurious ones. According to Arne Jernelöv of the Swedish Water and Air Pollution Research Laboratory, mercury discharged into water in various forms can be converted by bacteria in detritus and sediments into methyl and dimethyl mercury (*right*). Phenyl mercurials, metallic mercury and methoxyethyl mercury (*left and bottom*) are converted into methyls primarily through ionic mercury.

From: Scientific American Vol. 224 No 5. Goldwater LJ Mercury in the Environment (pg 17)

After the bacteria did their work, a long understood process called organic complexing spread the methylmercury systemically throughout the aquatic environment. Algae ate the bacteria and fish ate the algae. As the fish grew, so did the methylmercury, for the mercury had a half-life in fish of 200 days. That is, half of whatever amount was ingested stayed in the fish's body for 200 days, the remaining half stayed for 200 more days and so on. The poison thus was concentrated thousands of times in the fish.

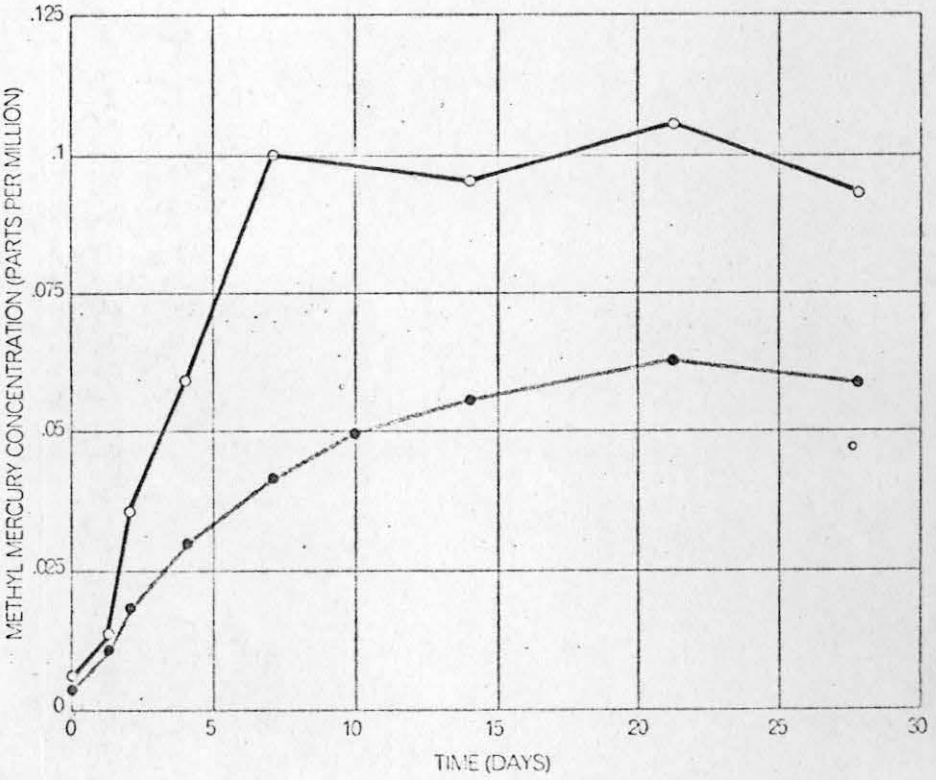
He doesn't seem to understand the continuous process involved in the term half-life

As we discussed at my orals, there is not enough evidence to say that the ~~effidence~~ effects are even primarily neurologic.

Natural excretion rates are maintained. It takes quite a while to "purge" the system free of Hg. →

Men who ate the fish retained half of the mercury for 70 days, and half of the remaining half for 70 more day & etc. There was plenty of time for the poison to reach & attack the brain.

Mercury tends to concentrate in living tissue once it has been assimalated & there is some evidence that the extent of concentration increases with each step up the food chain, from plankton to fish to man. If the supply is cut the organism tends to purge itself of mercury, but the efficiency of recovery varies from organ to organ & organism to organism. One study of fish after 10 days of experience to water with non lethal concentrations of ethylmercury showed mercury concentrations ranging from 4,000 ppb in muscle tissue to 22,800 ppb in the blood; almost complete elimination of mercury occurred within 45 days, except for that in the liver & kidneys. Similar studies have shown concentration factors of 250 to 3,000 ppb in algae, 1000 to 10,000 in ocean fish, & as much as 100,000 in other forms of sea life. Birds which feed on fish combine high intake with high concentration factors to yield extreme body residues. The eagle owl is a prime example with mercury contents as high as 40,000 ppb in its feathers.



CONVERSION of inorganic into methyl mercury in sediment was measured by Sören Jensen and Jernelöv at intervals after the addition of 10 (*gray*) and 100 (*black*) parts per million of inorganic mercury. At lower mercury concentrations methylation may not occur.

From: Scientific American Vol 224 No 5 Goldwater ed Mercury in the Environment (pg 17)

There is evidence also that each step in the food chain has a certain threshold for mercury above which permanent harm to the organism occurs. In some cases, toxicity apparently is catalyzed by synergestic effects of other heavy metals, such as copper, chromium, zinc, & nickel. Critical levels of mercury in lower organisms, such as plankton, generally are thought to be in the range of 5 to 200 ppb. althought some kinds of kelp appear to have tolerances as high as 60,000 ppb. The tolerances of fish ~~is~~ are in the range of 20 to 9000 ppb, depending on the particular species of fish & mercury compound. Human tolerance has not been throughly investigated, but is suspected to be comparatively low.

TABLE 27.—*Lethal concentrations of mercury compounds for various aquatic organisms and man*
[Data summarized from numerous published reports]

Organism	Lethal concen ration (ppb)	Mercury compound
Aquatic organism		
Bacteria:		
Escherichia coli	200	Mercuric chloride.
	200	Mercuric cyanide.
	300	Ethylmercuric bromide.
	300	Phenylmercuric chloride.
	300	Ethylmercuric oxalate.
Phytoplankton:		
Marine mixture	60	Ethyl mercury phosphate.
Scenedesmus	30	Mercuric chloride.
	150	Mercuric cyanide.
Protozoa:		
Microregma	150	Mercuric chloride.
	160	Mercuric cyanide.
Zooplankton:		
Daphnia pulex	5	Phenylmercuric acetate.
Daphnia magna	20	Mercuric cyanide.
	6	Mercuric chloride.
Amphipod:		
Marinogammarus marinus	100	Mercuric chloride.
Isopod:		
Mesospheroma oregonensis	15	Mercuric nitrate.
Flatworm:		
Polycelis nigra	270	Mercuric chloride.
Polychaete:		
Mercierella enigmatica	1,000	Mercuric nitrate.
Mollusca:		
Bivalve larvae	27	Mercuric chloride.
Australorbis glabratus	1,000	Do.
Fish:		
Stickleback	20	Mercuric nitrate.
	4-020	Mercuric chloride.
Guppy	20	Mercuric nitrate.
	20	Mercuric chloride.
Shiner	800	Ethyl mercury phosphate.
Eel	27	Mercuric chloride.
Channel catfish	580	Phenylmercuric acetate.
	1,300	Ethyl mercury phosphate.
Rainbow trout	2,000	Pyridylmercuric acetate.
	9,200	Mercuric chloride.
Salmon	20	Phenylmercuric acetate.
	50	Mercuric acetate.
Man		
Adult, death	[1] 1.0	Mercuric chloride.
Adult, chronic illness	[1] .1	Do.

[1] Gram.

From: U.S. Geological Survey Professional Paper 713 Mercury in the Environment (1966)

MERCURY IN THE BODY The effects of alkylmercury in a seed-treatment plant were described in detail in a report of four cases by Hunter et al (1940)[26]. The clinical features included paresthesias (numbness & tingling) of the extremities, mouth & lips; concentric constrictions of the visual fields which might progress to blindness; loss of hearing; unsteadiness of gait, loss of coordination; reflexes changes; and in more severe cases, loss of ability to speak & progressive intellectual deterioration. The description of one of the patients in the report by Hunter et al provided a critical lead in the recognition of the role of organic mercury in the Minamata Bay catastrophe. This patient died years later of pneumonia. Autopsy reportedly (Hunter & Russell, 1954) revealed the following main pathologic features: (1) cerebellar cortical atrophy, selectively involving the granular-cell of the neocerebellum, & (2) cortical atrophy of the area striata (calcarine fissure, visual cortical area of the occipital lobe).

Diagram on page 5.

Experiments have confirmed the occurrence of mercury in mammary glands & in mother's milk of rats fed mercury compounds. Deshimaru (1969) reported changes in the brains of baby rats nursed by mothers with organic mercury poisoning. Suzuki et al (1967) reported methylmercury is more readliy transferred across the placental barrier than is mercuric chloride or phenyl mercuric acetate (PMA)[84].

Infants can be affected by Minamata disease. In a village near Minamata Bay from 1954 to 1959, 23 of 359 children born were affected with a cerebral palsy-like disease. The disease varied in severity, some children having mild-to- moderate spasticity & ataxia (total or partial inability to coordinate voluntary muscular movements), and others having severe intellectual retardation, seizures, & evidence

of more generalized brain damage. Several features were noteworthy: (1) the affected infant had not eaten contaminated fish or shellfish. (2) The mothers apparently were not affected. (3) The symptons were more varied than cases of Minamata disease in adults.

The infants studied had abnormal levels of mercury in brain, livers, & kidney, in the ratio of about 1:7:8 (approximately that found in the adult disease). They also showed evidence of hypoplasia (a condition of decreased or arrested growth of an organ or tissue of the body) and disarrangement & malformation of nerve cells. The burden of evidence favors methylmercury toxicity during fetal development.

TABLE 12-II
METHYLMERCURY CONCENTRATION IN THE BRAIN AT NEUROLOGICAL SIGNS

Species	*Range* μg/g	*Number of Individuals Based Upon*	*Reference*
Mouse	10–61	10	Saito *et al.* (23)
Rat	49	10	Takeshita *et al.* (27)
Cat	8–18	7	Takeuchi *et al* (28)
Dog	8–50	5	Yoshino *et al.* (34)
Squirrel			
Monkey	12–14	2	Berlin *et al.* (8)
Man	3– 9	2	Lundgren, Swensson (18)
	12	1	Höök *et al.* (17)
	9–24	3	Takeuchi *et al.* (28)
	15–66	2	Okinaka *et al.* (35)
	22–48	1	Tsuda *et al.* (32)

TABLE 12-I
METHYLMERCURY DISTRIBUTION IN MAMMALS

Species	*Brain* μg/g	*Liver* μg/g	*Liver/ Brain*	*Kidney* μg/g	*Kidney/ Brain*	*Blood* μg/g	*Blood/ Brain*	*Number of Animals*	*Reference*
Mouse	28*	72	2.6	64	2.3			8	Saito *et al.* 1961 (23)
	0.49	1.7	3.4	4.2	8.5	0.4	0.82	5	Suzuki *et al.* 1963 (24)
			3.6		14			15	Berlin *et al.* 1965 (6)
Rat	2.7	14	5.2	55	21	44	16	6	Friberg 1959 (13)
	4	16	4	51	13	80	20	6	Gage 1964 (14)
	1.7	7.3	4.3	24	14	21	12	5	Ulfvarson 1962 (33)
	0.19	0.92	4.8	4.6	24	3	16	4	Ulfvarson 1962 (33)
Rabbit	1.5	2.9	2	2.9	2			3	Swensson 1952 (26)
Cat	9	52	5.8	15	1.7			3	Takeuchi 1961 (28)
Dog	33*					12	0.36	3	Yoshino *et al.* 1966 (35)
Squirrel									
Monkey	13*	10	0.77	6	0.46	3.4	0.26	2	Berlin, Nordberg 1968 (8)
Man	5*	20	4	30	6			1	Ahlmark 1948 (2)
	5*	14	2.8	3	0.6	4	0.8	1	Lundgren, Swensson 1948 (18)
	12*	39	3.3	27	2.3			1	Höök *et al.* 1954 (17)
	11*	40	3.6	66	6			10	Takeuchi 1961 (28)
	25*	21	1	51	2			1	Tsuda *et al.* 1963 (32)

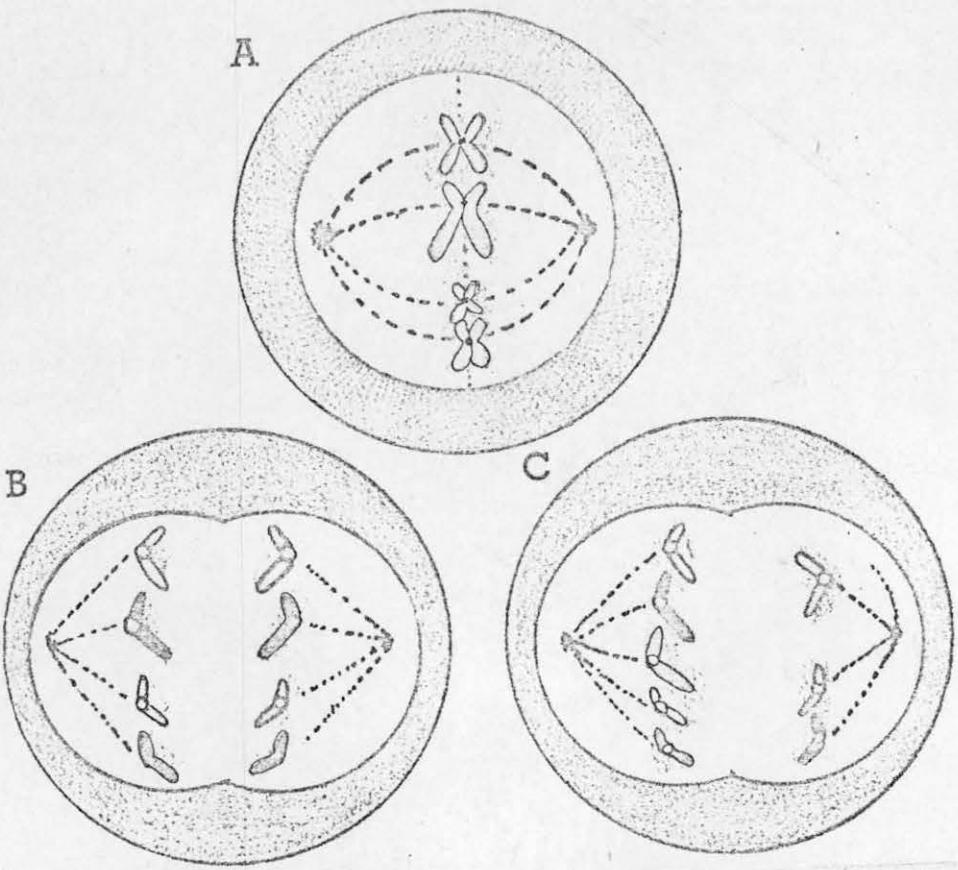
*Toxic signs.

From: Chemical Fallout Berglund, F & Berlin M Risk of methylmercury cumulation in man & mammals & the relation between body Burden of methylmercury & toxic effects (pg 261-263)

There is some available data on distribution & excretion of mercury in man following oral administration of labeled methylmercury (^{203}Hg) to human volunteers. There was rapid uptake of labeled methylmercury by erythrocytes. The main activity was localized in the liver (50%), whereas the head accounted for 10% of the activity. Mercury was excreted principally in the feces, with lesser amount excreted in the urine. Fecal excretion amounted to about 3-4% the first few days & then about 1% per day. Only about 0.1% per day was lost in the urine. Methylmercury was highly concentrated in the hair & epidermis, these tissues have small excretory roles. The biologic half life of methylmercury-203 determined by total body measurement was 70-74 days.[8]

Inorganic mercury salts are less well absorbed than organic mercury salts. For methylmercury available data indicate an intestinal absorption of more than 90% (Berglund & Berlin 1969). Differences in the rate of absorption & metabolism, removal from tissues, affects the amount of mercury entering the brain & fetus.

Experimently, in certain plants & Drosophila,[28] organic compounds of mercury may produce genetic mutations & chromosomal aberrations, but such changes have not been demonstrated in test mammals. However, high levels of methylmercury have produced teratogenic effects in test animals. C-mitosis (colchicine-mitosis, refers to the characteristic appearance of chromosomes which have contracted more than is usual for mitotic metaphase & lie scattered within the nucleus), has been demonstrated in cells of Allium cepa[27] roots exposed to concentrations of alkyl- & phenylmercury compounds at levels as low as 15×10^{-7}M (about 0.05 ppm). Alkoxyl compounds are less active & require levels higher as 30×10^{-7}M (about 0.7ppm) for comparable effects. Although all the organic mercury compounds tested produce C-mitosis, the effects

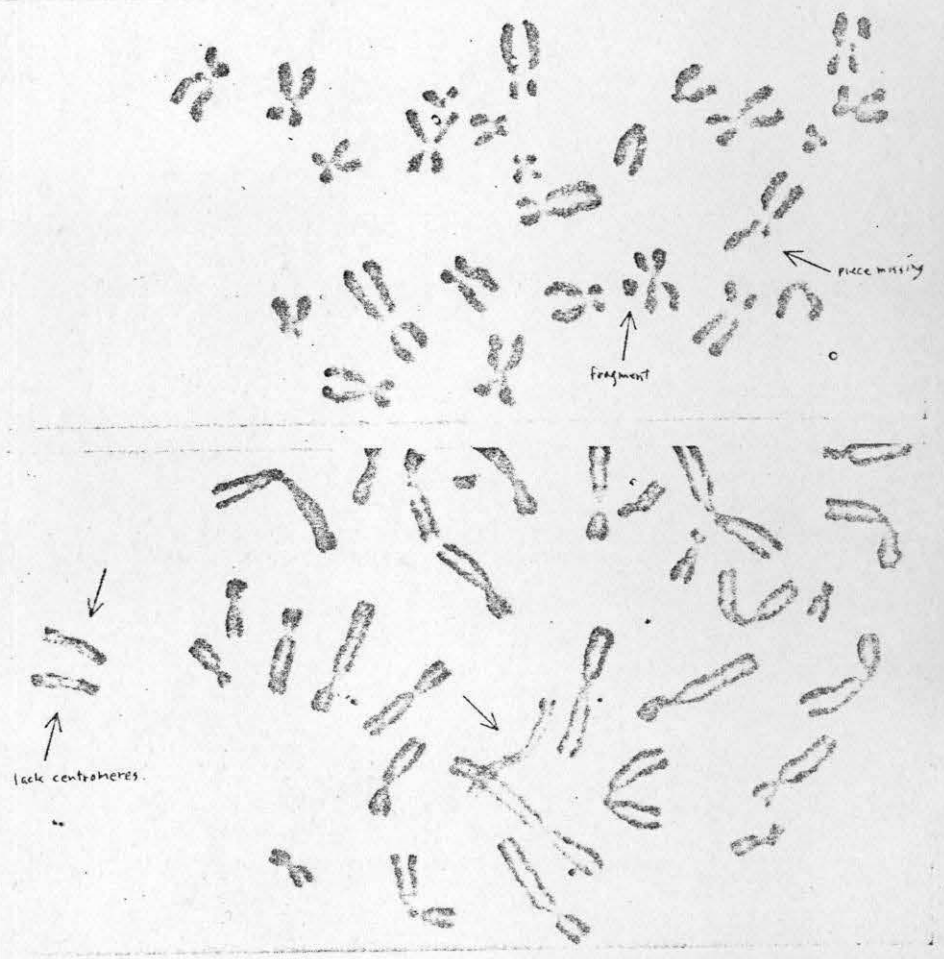


From: Enviroment Vol 13 No. 4 (pg 13)

Methylmercury is the most potent agent known for causing a cellular disturbance called non-disjunction. When a cell divides, delicate structures called spindles, shown as broken lines in the drawing, pull the two sets of the chromosomes to opposite ends of the dividing cell. In A, a normal cell is about to divide; the chromosomes are lined up in pairs along the center. In normal cell division, shown in B, each daughter cell will have a complete set of chromosomes. In non-disjunction, C, the spindles are damaged, and the two cells receive an unequal number of chromosomes. In higher animals this can produce serious birth defects.

are not identical. Phenyl compounds give rise to distinctly more bridges & fragments than do other mercury compounds (Ramel, 1969). Methylmercury & phenylmercury are among the most active C-mitosis agents known, being 200-1000 times more effective than colchicine.

As a result of the C-mitosis action, polyploid (individual or cell with more than two full sets of homologous chromosomes) as well as aneuploid (number of chromosomes is more or less than the normal diploid number) cells occur. The mercurial compounds cause C-mitosis tumors & hook-like growths of the root, perhaps representing incomplete tumorous action. Inorganic mercury is about 200 times less effective than are organic mercury compounds in the production of C-mitosis.



CHROMOSOME DAMAGE is found in persons with high blood levels of mercury after exposure to methyl mercury in fish. Photographs of lymphocytes made by Staffan Skerfving of the Swedish National Institute of Public Health show a broken chromosome and extra fragment (*top*) and three sister-chromatid fragments that lack centromeres (*bottom*).

from: Scientific American Vol 224 No 5 Goldwater LJ Mercury in the Environment (pg 21)

In limited experiments with animals, teratogenic effects have been shown to follow administration of single high-level doses of methylmercury phosphate to pregnant rats on day 10 of pregnancy.

The treatment resulted in reduced body weight of offspring & a 31.6% incidence of cleft palate (Oharazawa, 1968)[23a]

Information on levels of mercury in brain tissue of human beings has been obtained from individuals dying after acute exposure to methylmercury. Values ranging from 3 to 4 μg/g of brain tissue have been reported (Berglund & Berlin, 1969).

Takeuchi (1968) indicated that the neurones through the cerebral & cerebellar cortices may be affected, but that preferentially cells in the calcarine & precentrial regions of the cerebrum & in the granular layer of the cerebellum are involved. The intensity of exposure & the age of the patient play some role in the distribution of lesions.

In Minamata, 3 patients had levels of mercury in the hair of 515, 565, & 763 μg/g, respectively, & 15 members of their families had levels ranging from 15 to 412 μg/g. Blood samples do not appear to have been obtained at the time of intoxication. In the Niigata incident it appears that the lowest blood level at which symptoms were observed were of the order of 0.2 μg/g of blood & more than 200 μg/g of hair. Again we do not know the degree of exposure of the individual between the times of exposure and onset of symptoms. In the Minamata incident it has been calculated that severe intoxication was present at hair levels equivalent to 700 μg/g (Skerfving et al 1970).

In the case of victims of the accidental U.S. poisoning (1969) serum levels rather than whole-blood levels were measured & these were about 3 μg/g, as was the level in one specimen of cerebrospinal fluid from an affected child. Concentrations of mercury in the hair were determined & were as high as 2000 μg/g. Urine levels, considered undependable, were reported as about 0.2 ppm in the 3 cases.

FIGURE 1. Relation of Methyl Mercury Levels in Blood to Physical Hazard

Consumers of Mercury

Individuals who have died from mercury poisoning.

Japanese with observed symptoms of poisoning from fish consumption (Niigata).

Swedish group in which chromosome breakage was observed.

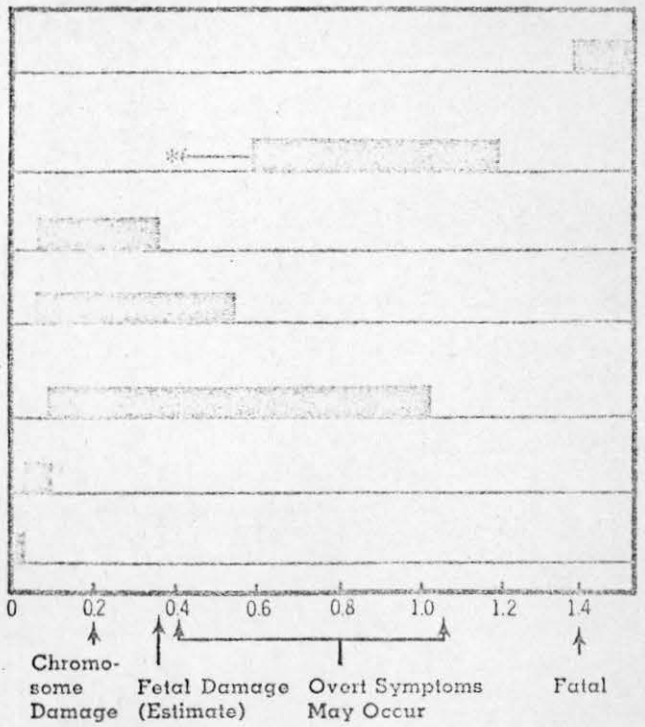
Finnish people who consumed large amounts of fish and had no symptoms.

Swedes in polluted area who consumed large amounts of fish and had no symptoms.

U. S. "Weight Watchers" who consumed large amounts of tuna

Normal consumption — a segment of the Swedish population.

*Isolated case in which low level found.



Sources:

1. Löfroth, Göran, "A Review of Health Hazards and Side Effects Associated with the Emission of Mercury Compounds into Natural Systems," Swedish Natural Science Research Council, Stockholm, Sweden, 2nd Edition, Sept. 1970.

2. Berglund, F. et al., "Methyl Mercury in Fish, A Toxicologic-Epidemiologic Evaluation of Risks," a report preprinted from Nordisk Hygienisk Tidskrift, Supplement 4, Stockholm, Sweden, 1971.

Blood not reliable. Hg content varies w/ time since exposure & exposure level

HISTORY OF MERCURY (30) Mercury & cinnabar (HgS) have been known & used for more than 2300 years. The first recorded mention of mercury was by Aristotle in the 4th century B.C., when it was used in religious ceremonies. Earlier, man is known to have used vermillion (cinnabar) as a decorative & "war paint" (cosmetic) & undoubtedly in religous rites. In the 1st century Dioscorides Pedanius, a Greek physician, and Pliny used mercury as a medicinal ointment. From the 6th century B.C. on the Egyptians frequently mentioned mercury, its uses & preparation, as well as its amalgams with tin & copper. Amalgamation (formation of alloys with mercury) evidently was known to Pliny, who referred to the use of quicksilver in recovering noble metals from the earth & in gilding. Rhazes (852-932) Mesue (925-1015) & Avicenna (980-1037) used mercury ointment & bichloride of mercury in treating itch & various other skin diseases. Paracelsus (1493-1541) introduced the treatment of syphilis with mercury ("one night on Venus one year on Mercury").

Until 1557 when Bartolome De Medina invented the patio process for the recovery of silver by amalgamation, the consumption of mercury was small & chiefly for medicinal & cosmetic purposes. However following the introduction of the patio process, large quantities of mercury were used for amalgamation in Mexico, Peru, & other countries.

The introduction of mercury into scientific research occurred in 1643 with the invention of the barometer by Torricelli, who used mercury to determine the pressure of the atomsphere. In 1720 Fahrenheit invented the mercury thermometer. Prof. Braune of St. Petersburg, Russia, first succeeded in freezing mercury in the winter of 1759-1760 & this event marked the acceptance of mercury as a metal. Joseph Priestley (1733-1804) initiated another important scientific use of

mercury by sealing off water-soluble gases in gas analysis. In 1799 Howard prepared mercury fulminate which, used as a detonator for explosives, has played an important part in peace & war in the history of nations.

Prior to 1850 three great mines dominated the world production of mercury; the Spanish Almadén; the Idria, now in Yugoslavia; & the Santa Barbara in Peru. Since 1850 four districts, the Almadén, Idria, Monte Amiata, & California, have dominated world mercury production.

Almadén, Arabic for "the mine" is in the province of Ciudad Real in Spain, about 150 miles southwest of Madrid. Mercury production began about 700 B.C. under the Phoenicians &/or Carthaginians who were the first to distill mercury on a commercial scale. Since 1500, the first year production for the Almadén mine was recorded, the operation has produced over 7 million flasks of mercury. A flask is 76 pounds of mercury.

The Idria mine, at one time in Austria, later under Italy & now in Yugoslavia, has the world's longest production next to the Almadén. The mine is in the foothills of the Julian Alps, province of Slovenia, along the Idria River. Since 1470 the mine has produced over two & one-half million flasks.

The Santa Barbara mine, department of Huancavelica, Peru, was formally the worlds third largest mine. Production was begun by the Spaniards in 1566 & the mine produced nearly one & one-half million flasks until 1790. Only negligible quantities were produced thereafter.

The Monte Amiata is a district rather than a single mine. It is about 75 miles north of Rome. The first workings were by the Etruscans, but rediscovery was not made until about 1868 when the Siele mine was found & reopened. Totaling the output of the Idria mine

Table 5. World Production of Mercury, 1925–1965, in flasks (76 lb) (8)

	1925	1930	1935	1940	1945	1950	1955	1960	1965[a]
North America									
Canada				2,024[b]					
Mexico	1,123	4,946	6,277	11,653	16,443	3,757	29,881	20,114	18,000
United States	9,053	21,553	17,518	37,777	30,763	4,535	18,955	3,223	18,700
South America									
Bolivia (exports)			250		3				
Chile				100	862	314	526	2,876	200
Peru					209		148	3,034	3,000
Europe									
Czechoslovakia	2,129	2,060	2,004	2,582	435	725	725	725	725
Germany			116	957					
Italy	53,189	56,069	28,191	91,230	25,410	53,346	53,520	55,492	60,000
Spain	37,052	19,221	35,559	52,214	40,694	51,808	36,231	53,369	66,000
U.S.S.R.	287	3,278	8,700	8,700	7,300	11,600	12,300	25,000	35,000
Yugoslavia					8,876	14,649	14,516	14,069	17,000
Asia									
China	95	725	1,313	3,403	1,828	1,450	11,500	23,000	23,000
Japan		121	148	3,394	3,139	1,312	4,990	5,791	4,668
Philippines							635	3,041	3,000
Turkey	98	537	25	500	158		841	1,339	3,000
Africa									
Algeria	55	325		791	326				
Republic of South Africa				42	852				
total[c]	103,000	109,000	100,000	216,000	133,000	143,000	185,000	242,000	275,000

[a] Estimate [b] Total Canadian production 1940–1944, was 54,633 flasks. [c] Production from "other countries" included.

From: Kirk-Othmer Encyclopedia of Chemical Technology Vol 13 pg 225.

when it was Italian, Italy produced about two & one-half million flasks of mercury. It is interesting to note as early 1700 a citizen of the town of Finale in Italy sought an injunction against a factory making mercuric chloride because its fumes were killing people in the town.

Production of mercury in the United States began in California about 1850 & reached a peak of 80,000 flasks annually in 1870. Its early history was closely associated with that of gold & the development of gold mining in California. Production for the period 1850-1957 was 3,100,000 flasks. However, in 1967 U.S. production was low. See tables below on world production of mercury. Lower table on page 64 shows estimated trends of mercury use in U.S.

Table 11.—World production of mercury, by countries

(Flasks)

Country	1964	1965	1966	1967	1968 p
Bolivia (exports)	[1] 32	52	4	r 145	134
Canada	73	20	---	---	e 5,000
Chile	267	r 435	96	184	513
China, mainland e	26,000	26,000	26,000	20,000	20,000
Colombia	3	46	r 89	r 210	285
Czechoslovakia	775	825	875	900	900
Italy	57,001	57,320	53,549	48,066	52,215
Japan	r 4,972	r 4,689	4,846	r 4,617	5,049
Mexico	12,561	19,203	r 22,104	r 14,413	e 13,230
Peru	3,275	3,117	3,166	2,950	3,125
Philippines	2,496	2,384	2,443	2,611	3,506
Rumania	194	191	190	190	e 203
Spain	78,322	74,661	70,054	49,227	57,262
Tunisia	87	174	254	292	e 300
Turkey	2,615	2,755	3,420	r 4,147	4,320
U.S.S.R. e	35,000	40,000	40,000	45,000	45,000
United States	14,142	19,582	22,008	23,784	28,874
Yugoslavia	17,318	16,419	15,896	15,890	e 15,558
Total [2]	r 255,133	r 267,873	r 264,994	r 232,656	255,474

e Estimate. p Preliminary. r Revised. NA Not available.
[1] Purchases by Banco Minero.
[2] Total is of listed figures only.

from: Minerals Yearbook 1968 (pg 699)

PHYSICAL PROPERTIES OF MERCURY Mercury, has an atomic number of 80, atomic weight of 200.61, it is the only metal which is liquid at ordinary temperature. Below its melting point it is a white solid & above its boiling point is a colorless vapor. Its symbol is Hg from the Latin hydragyrum meaning liguid silver. Some features of mercury to which it owes its scientific & industrial importance are as follows: mercury has a uniform volume expansion over its entire liquid range which, in conjunction with its high surface tension is unable to wet & cling to glass, makes it extremely useful for barometers, manometer, & thermometers as well as many other measuring devices. This ability is also enhanced by the liquidity of mercury at room temperature. Mercury also has a propensity to form alloys (amalgams) with almost all other metals except iron & even with iron at high temperatures. The low electrical resistivity of mercury also causes it to be rated as one of the best electrical conductors among the metals. Mercury has a high thermal neutron capture cross section enabling it to absorb neutrons & act as a shield for atomic devices, while its high thermal conductivity also permits it to act as a coolant.

At ordinary temperatures mercury is quite stable & does not react with air, ammonia, carbon dioxide, or oxygen. It combines readily with the halogens & sulfur, but is little affected by hydrochloric acid & is attacked only by concentrated sulfuric acid. Either dilute or concentrated nitric acid dissolves mercury; forming mercurous salts when the mercury is in excess or no heat is used & mercuric salts when excess acid or heat is used. Mercury does react with hydrogen sulfide in the air & should be kept covered.

Mercury ranks about 16th from the bottom of the list of elements in abundance in the earth & comprise less than 30 billionth of the earth's crust. There are only a limited number of mercury minerals & the only one of commercial significance is cinnabar, mercuric sulfide, HgS, from which has come practically all of the world's production of mercury. Small amounts of native mercury are occasionally found associated with cinnabar & metacinnabar, a sulfide in which part of the mercury has been replaced by iron or zinc.

Mercury ore is mined by both surface & underground methods; the latter furnish almost 90% of the United States production. The ore is broken by conventional drilling & blasting, removed by scrapers, mechanical loaders, or by dropping to draw points from where it is trimmed or hoisted to the surface. Open-pit surface mining is accomplished by normal drilling, blasting, & loading. Mercury mining generally presents no special problems other than those due to the erratic distribution of the ore bodies. In a few mines explosive gases & excessive heat require special attention. Operations in the United States mine as much as 300 tons of ore per day at underground mines & 175 tons per day in open-pit workings. The average grade of mercury ore processed in the United States is about 8 lb of metal per ton in underground mines & 3 lb per ton in opencast mines. The underground mines are larger, more expensive operations & must yield more mercury to be economical.

The most common metallurgical process for recovering mercury is that of roasting which is essentially a distillation process. It consists of heating the cinnabar to volatilize the mercury followed by condensation of the vapor. Either mechanical furnaces or retorts are used to roast mercury-bearing materials. The significant differences in the two types of roasting are the furnacing is a continous oper-

ation - the material is heated directly by the gases of combustion & the volume of furnace gas is large, whereas retorting is a batch operation, the material is heated indirectly & the volume of retort gas is small. Except for the type of furnace used, mercury recovery plants are essentially the same. Each plant has facilities for storing, crushing, conveying, & feeding ore; a furnace, a dust collector, a condensing system, a gas fan, a gas tower & stack; a calcine bin; a hoeing machine; bottling equipment; and apparatus for regulating & controlling the pressures & temperatures throughout the plant.

ECONOMICS OF MERCURY[30][31] World economics reserves an odd place for mercury; as a metal it cannot be replaced by any other metal. Mercury has unique properties & these properties have caused prolific development in the uses of mercury, particularly in electrical & electronic instruments & apparatus.

Previous to World War I, mercury was not consistently an industrial commodity; that is, it failed to be affected by market trends & price fluctuations. Two wars, the civil war & the Spanish-American war, failed to alter this pattern. Prior to 1914, mercury was chiefly used for the recovery of gold & silver by the amalgamation process. The oxides had occasional importance as a pigment.

Mercury mining in the United States commenced during the California gold rush & the demand caused output to nearly equal the combined output of the 2 chief rivals, Idria & Almaden. This made the United States the world's largest producer of mercury for some time. For the last few years the United States has been only a minor producer (see Tables II, page 56).

The first violent fluctuation in the price of mercury occurred in 1915. Due to speculation, the price rose to $285 a flask (76 lb) but soon dropped sharply. The price during WW I was fixed by the government at $105 a flask. Considered a high price at the time, it caused an increase in domestic production but not world production. Idria, belonging to Austria, was in enemy territory & Spain encountered shipping difficulties due to a shortage of shipping. The price of mercury followed economic highs & lows during the between-wars period. WW II caused a sustained period of high prices pegged in the United States at $191 a flask. During this time world production reached 275,00 flasks. Mercury from Almadén & Idria was going to the Axis power & the Allies were forced to rely on mercury from the western hemisphere. United States production rose to 52,000 flasks a year. Canada, a non-producer for 40 years, contributed 55,000 flasks & Mexico also contributed heavily. Early in 1944 the U.S. government canceled its purchase contracts. The price of mercury dropped 50% and Canadian production halted. In 1945 use of mercury & price were both high due to development of the "mercury battery"; the Ruben-Mallory cell.

At the end of 1945 accumulated stocks of German & Japanese mercury came on the market, & the price dropped until the Korean War, when a spectacular increase again occurred. The conflict in Vietnam by the end of 1965 has not seemed to have had an effect; however, 1965 saw record prices & uses. Thought probably due to the installation of many new caustic-soda-chlorine plants using the mercury-cell process. By this time electrical & electronic uses were the major consumers of mercury.

In 1968 mercury connsumption rose by nearly 6000 flasks, led by manufacture of electrical apparatus, particularly mercury battery cell, caustic-soda-chlorine plants & mildew proofing compounds. These 3 catergories account for 60% of the total mercury consumed.

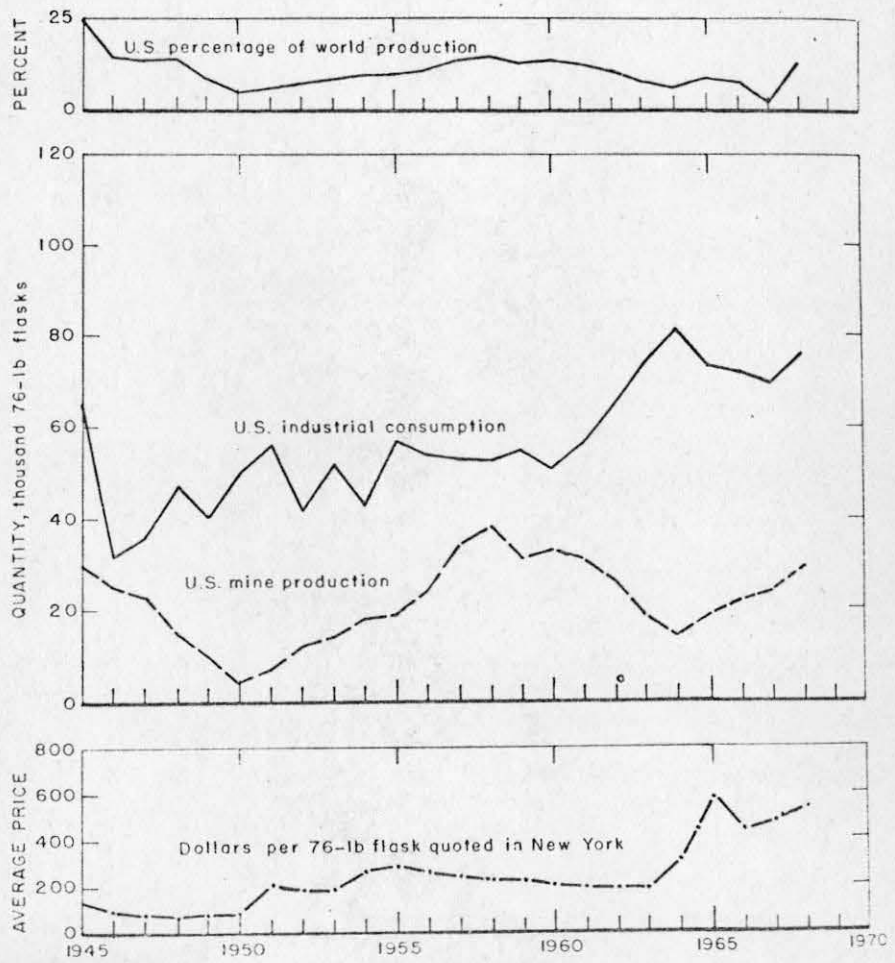


Figure 1. Trends in production, consumption, and price of mercury.

Table 1.—Salient mercury statistics

	1964	1965	1966	1967	1968
United States:					
Producing mines	72	139	130	122	87
Production, flasks	14,142	19,582	22,008	23,784	28,874
Value, thousands	$4,452	$11,176	$9,722	$11,639	$15,464
Exports, flasks	188	7,543	357	2,627	7,496
Reexports, do	196	494	476	475	103
Imports:					
For consumption, do	41,153	16,238	31,364	24,348	23,246
General, do	41,107	17,838	34,757	23,899	23,956
Stocks Dec. 31, do	17,362	20,386	20,076	18,277	21,484
Consumption, do	81,354	73,560	71,569	69,547	75,422
Price: New York, average per flask	$314.79	$570.75	$441.72	$489.36	$535.56
World:					
Production, flasks	255,133	267,873	264,994	232,656	255,474
Price: London, average per flask	$282.25	$607.85	$447.68	$499.36	$546.80

From: Minerals Yearbook 1968 pg 693,896

Table 5.—Mercury consumed in the United States by uses

(Flasks)

Use	1964	1965	1966	1967	1968
Agriculture (includes fungicides and bactericides for industrial purposes)	3,144	3,116	2,374	3,732	3,430
Amalgamation	308	268	248	219	267
Catalysts	656	924	1,932	2,489	1,914
Dental preparations [1]	2,612	1,619	1,334	1,359	2,089
Electrical apparatus [1]	r 14,331	r 16,097	r 16,257	r 14,610	17,484
Electrolytic preparation of chlorine and caustic soda	9,572	8,753	11,541	14,306	17,453
General laboratory use:					
Commercial	1,583	1,119	1,563	1,133	1,246
Government	15,746				
Industrial and control instruments [1]	4,972	4,628	4,097	3,865	3,935
Paint:					
Antifouling	547	255	140	152	392
Mildew proofing	r 5,969	r 8,211	r 8,280	r 7,026	10,174
Paper and pulp manufacture	2,148	619	612	446	417
Pharmaceuticals	r 335	r 418	r 232	r 283	424
Redistilled [2]	11,697	12,131	7,267	7,334	8,252
Other [1] [3]	7,734	15,402	15,632	12,563	7,945
Total	81,354	73,560	71,509	69,517	75,422

r Revised.
[1] Does not include redistilled.
[2] A breakdown of the "redistilled" classification showed averages of 44 percent for instruments, 15 percent for dental preparations, 22 percent for electrical apparatus, and 19 percent for all other uses in 1964–67, compared with 49 percent for instruments, 12 percent for dental preparations, 26 percent for electrical apparatus 9 percent for general laboratory and 4 percent for all other uses in 1968.
[3] Includes mercury used for installation and expansion of chlorine caustic soda plants.

from: Minerals Yearbook (pg 695)

Total World Production of Mercury and Trends in U. S. Use

	1968[a] (tons)	1969[a] (tons)	Estimated 1974–1975[b] (tons)
Total world production	9,836	10,885	—
Trends in uses of mercury in U. S.			
Agricultural use	130	102	101
Amalgamation	10	7	9
Catalyst manufacture	73	112	89
Dental[c]	116	116	144
Electrical equipment	746	710	863
Chlor-alkali plants	663	788	869
Laboratory use[b]	75	78	79
Industrial controls[b]	202	265	351
Paints	401	370	407
Paper and pulp	16	21	9
Pharmaceuticals	16	27	25
Other uses[d]	302	368	226
Not accounted for[e]	12	42	
	2863	3006	3172
Sources and export of mercury in U. S.			
U. S. domestic mines	1097	1090	
Imported	910	1164	
GSA sales to industry[f]	745	117	
GSA transfers to govt. agencies	68	—	
GSA transfers to international redevelopment	91	—	
Redistilled[g]	316	380	
Secondary recovery[h]	402	402	
GSA stock	86	539	
Exported	289	19	

NOTE: These values do not include any mercury held by General Services Administration or Atomic Energy Commission.

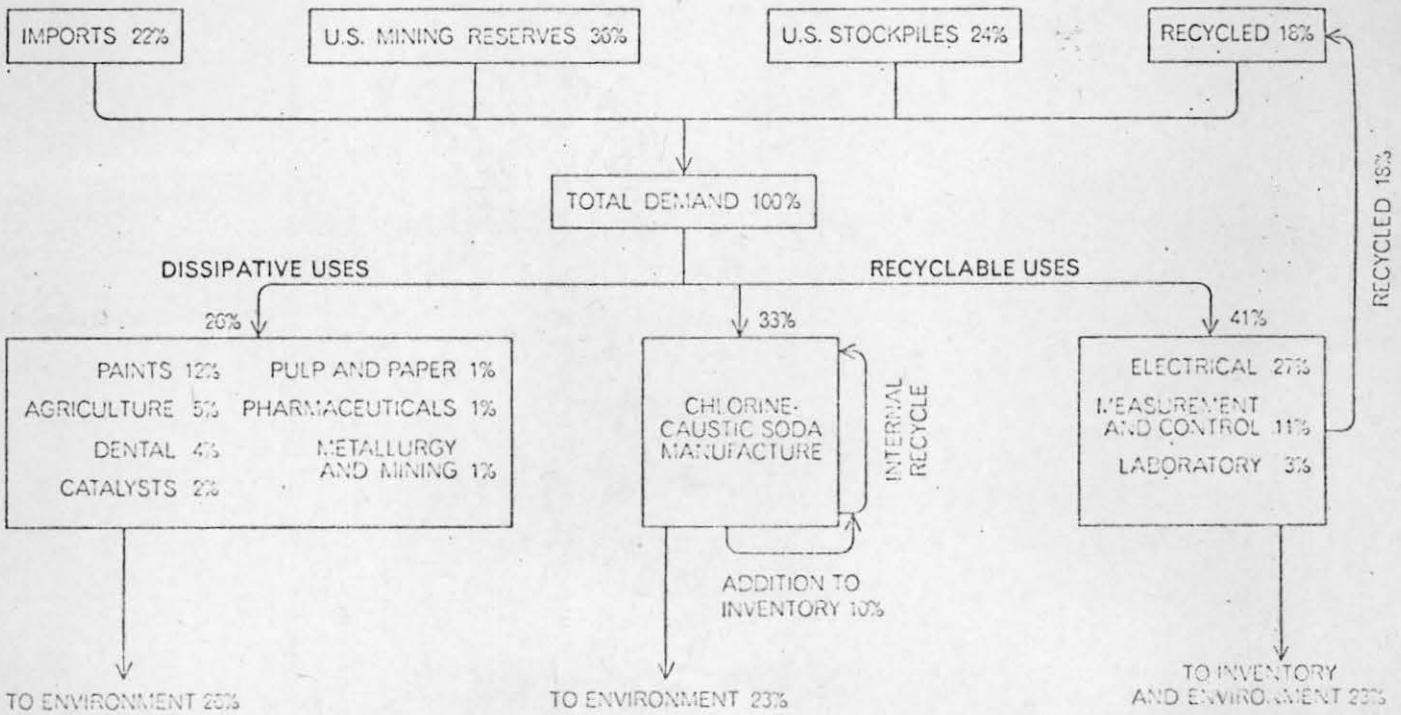
[a] U.S.D.I. Bureau of Mines, USGS 1968 + 1969 (Mercury).
[b] Trends in Usage of Mercury, National Materials Advisory Board, National Research Council, Washington, D. C.
[c] Includes redistilled mercury.
[d] Includes purchases for expansion and new chlor-alkali plants.
[e] Mercury, chiefly from secondary recovery—uses not specified.
[f] General Services Administration.
[g] This mercury is from other sources and is given additional purification.
[h] This mercury is recovered from battery scrap, dental amalgams and other reprocessed sources.

From: Environmental Research Vol 4 No.1 (pg 62)

USES OF MERCURY [30][31][33] It has been estimated that the total number of mercury uses must be close to 3,000. Detailed data concerning specific applications are difficult to compile. Complicating the situation is the fact that consumption of mercury has increased steadily through the years. And certain uses have withered away & new uses have taken their place.

Agricultural uses include the manufacture of germicides for treating & storing seeds, for weed control, & for fungicidal fruit sprays. This category also includes the phenylmercury compounds used in fungicides & bactericides to preserve textiles & in other industrial uses, and as slimicides in the pulp & paper industry.

With the exception of iron almost all other metals can be amalgamated (alloyed) with mercury. Many mercury compounds, especially the chloride, oxide, sulfate, acetate, & phosphate, are good catalysts for many chemical reactions. Mercury is used in electrical apparatus, in mercury lamps, in mercury batteries. It is used as medicine; in barometer, thermometer, casting process, etc. The figure below shows the uses and flow of mercury.



MERCURY FLOW through the U.S. is shown for 1968. The chart is based on one prepared by Robin A. Wallace, William Fulkerson, Wilbur D. Shults and William S. Lyon of the Oak Ridge National Laboratory. Major use of mercury has been as a cathode in the electrolytic preparation of chlorine and caustic soda. In this process a large inventory of mercury is continuously recycled, but in 1968 23 percent of total mercury demand still went to make up what was wasted. Another 10 percent went for start-up of new plants. Since then legislation and lawsuits have required manufacturers to increase recycling sharply, reducing emissions to the environment.

From: Scientific American Vol 224 No 5 Goldwater LJ. Mercury in the Environment (page)

CONCLUSIONS

1. Generally, the current mercury problem can be divided into 2 broad parts: one relates to the toxicity of mercury pesticides & the other to the accumulation in biosystems of alkylated mercury from a variety of sources.

2. Mercurial pollutants from pesticides, chlorine & alkali production, agriculture, & slime control from paper mills have toxic affect on wildlife, domestic animals, & human beings.

3. Methylmercury is concentrated in fish & shellfish, partly through contamination of their food & partly through its presence in the water.

4. Methlymercury is far more toxic to the brain on a chronic basis than is inorganic mercury. The relative ease with which methylmercury passes the "blood-brain barrier" accounts for the severe neurological manifestations & even death, which may follow the accumulation of small amounts of this compound. The slow rate of elimination of methylmercury, which has been demonstrated in both fish & man, potentiates this effect. In contrast to inorganic mercury which passes the placenta poorly, methylmercury is concentrated in fetal red blood cells to values about 30% higher than in maternal red blood cells.

5. The syndrome of methylmercury poisoning in man through the consumption of contaminated fish & shellfish has now come to be known as "Minamata disease". The clinical symptoms of the disease includes progressive blindness, deafness, incoordination & intellectual deterioration.

6. It was found that inorganic mercury can be converted by microbial systems in the bottom muds of contaminated waters to methylmercury. Thus the mercury contamination in the bottom sediment constitutes a a depot which through the methylating process represents a potential continuing source of methylmercury.

7. The FDA guide line of 0.5 ppm mercury in fish for human consumption appears for the present a safe basis for the protection of public health.

8. The exposure of the general population to methylmercury appears to be chiefly through fish & possibly other foods & not directly through water or air.

9. The works of Irukayama (1968), Takeuchi (1968,1970) & others, have established the etiologic role of methylmercury in Minamata disease.

RECOMMENDATION FOR STUDY

1. It is essential to under take population studies (1) to determine the body burden of mercury ie the level of mercury in the tissues, to the ingestion of mercury, particularly from fish. (2) To develope & to apply more sensitive diagnostic technique to identifiy possible mercury toxicity. (3) To under take medical studies of exposed populations which demonstrate no obvious ill effects. (4) To assess the potential effects from prenatal & postnatal exposures to mercury. (5) To dtermine the body burden of mercury at differential occupational patterns of exposure. (6) To assess the possible synergistic interaction of mercury other potentially hazardous residues.

2. All sources of mercury contamination should be either maximally reduces or eliminated. Thus (1) the use of all alkylmercury pesticides should be terminated & all other mercurial pesticides should be severely restricted to usage on a basis of demonstrated need only. Safe substitutes should be sought for those remaining in use.

(2) Safeguards should be developed for the manufacture, packaging, distribution, & field use of seed treated with organic mercurials & for the disposal of unused treated seed & containers. (3) All industrial users of mercury, particularly those operating chlorine & alkali production plants & those using mercury catalysts, should be required to reduce their discharge of mercury into the environment. (4) Other sources of mercury contamination or exposure, for exampe, discarded electrical equipment, chemicals, paints, cosmetics, pharmaceuticals, sewages & fossil fuels, must be identified & brought under control. Because all forms of mercury have the potential to be converted to the highly toxic form of methylmercury.

3. Need better understanding of the movement of mercury from natural & man-made sources in waterways, & the role of microbial flora, water pH, sunlight in the transformation of mercury in water.

4. We need to find means to interrupt the methylation or decontamination of existing deposits of mercury.

5. To increase the interplay of world-wide talents & responsibilities in the control of mercurial pollution. There is need to review meticulously other toxicants in the environment such as other heavy metals for possible dangers.

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As a biologist, I would have expected the author to have given more information on biosphere - Hg relationships.