ECOTOXICOLOGY AND ENVIRONMENTAL SAFETY 7, 3–8 (1983)

Ecotoxicology of Cadmium: General Overview[1]

FRIEDHELM KORTE

Institut fur Okologische Chemie, Gesellschaft für Strahlen- und Umweltforschung, mbH, D-8042 Neuherberg, Post Oberschleissheim, West Germany

Received August, 1981

It has been over 17 years since the relationship between cadmium contamination and Itai-Itai disease was first published by the agriculturalist Yoshioka, who had found, 20 years ago, environmental pollution along the Jinzu River caused by waste water from a lead and zinc mine located upstream.

Itai-Itai had already been documented in 1955 by Kono *et al.* It was recognized shortly after World War II. The disease, occurring mainly in women, has as major symptoms pains in the extremities, difficulty in walking, bone fractures, and a fish-bone-like spine. There are also some changes in enzyme activities.

Even earlier, in the beginning of the century in the Toyama Prefecture, a disease with symptoms similar to Itai-Itai, namely, osteomalacia, had been described. Since the 1950's there have been many investigations to differentiate between the two diseases.

Itai-Itai occurs in the area of the Jinzu River basin covering about 70 km^2 with a population of 24,000. Originally the number of patients thought to have Itai-Itai was 55, the majority of them over the age of 50. However, more than 200 people actually had the disease.

Since the time between exposure and the appearance of Itai-Itai was about 20 years, it was of interest to become acquainted with the living conditions of the people in the area at the beginning of the century. Some of these conditions were described by Hayashi in 1906,

> *Residences*: The houses are built on stepped terraces and are dark even in daytime because of the surrounding trees. These houses have thatched roofs and low lintels. Three sides of the house are completely closed even in summer and light comes only through the sliding paper doors on the south side. The residents do not use tatami ("thick straw mat") on the floor but sit on mushiro ("thin straw carpets"). Sleeping rooms are usually located to the rear of the house and no light enters, even in the daytime. The patient lies in this sleeping room almost all the time. In winter, since a mushiro screen is set in front of the doors to protect the house from snow, lighting and ventilation conditions are even worse. In this area, which has much precipitation and short durations of sunshine, the houses are located at the foot of a cliff and both the land and the houses are very damp.
>
> *Food*: The staple food is rice, with barley next in importance. However, in hilly areas where the arable land is not only small in area but also infertile and the average temperature is low, the harvest of rice and barley is not sufficient. Accordingly, sweet potatoes and potatoes are eaten as supplementary foods. In addition to sweet potatoes and potatoes, beans and vegetables are also used in the diet as supplementary foods. Much fish is eaten in the areas along the coast and the

[1] Paper presented at the International Symposium, "Ecotoxicology of Cadmium," May 6–8, 1981, Neuherberg, Federal Republic of Germany.

0147-6513/83/010003-06$03.00/0

adjacent lowlands, but in the remote villages on highlands, fish is very rarely served, because of poor transportation and the low standard of living.

Water: In the lowlands, the people use well water (these wells are very shallow) and in the highlands, well water or spring water is used.

In 1965, the Japanese Ministry of Health and Welfare began investigations on the environmental pollution caused by cadmium. Supported by the Public Health Association, a study group performed extensive epidemiological studies on the association between environmental pollution by cadmium and Itai-Itai disease in the area located along the Jinzu River. The Ministry, on the basis of these investigations, made an official announcement in 1968 concerning the etiological relationship between environmental factors, including cadmium, and Itai-Itai disease. It stated that Itai-Itai disease was caused by the following process: Renal tubular impairment was first caused by cadmium poisoning, followed by the development of osteomalacia, which resulted in Itai-Itai disease. Inductive factors included pregnancy, lactation, changes in internal secretion, aging, and nutritional deficiencies such as inadequate calcium.

The Japan Environment Agency, published an administrative report in 1972 which included a summary of all the investigations conducted. The report entitled, "Control of Environmental Pollution by Cadmium," includes the following important statements:

> The first reports by official government agencies concerning the number of patients were made in 1961 when the Yatsuo and Toyama health departments announced the results of the investigations. Among the reports the Yatsuo local health department indicated the statistical prevalence of the disease by hamlet over the period 1954–60. Toyama Prefecture, in 1967, with the cooperation of the Committee on Countermeasures for Special Diseases in Toyama Prefecture, the Committee on Itai-Itai Disease Research supported by the Ministry of Health and Welfare, and the Research Group on Itai-Itai Disease supported by the Ministry of Education, performed mass health examinations, all using the same diagnostic criteria, with the following results:
>
> The number of patients approved by the prefecture for treatment was 73 as of March 31, 1968, and 150 persons required follow-up observation. Those who needed treatment were all born between 1883 and 1920, with a peak between the years 1896 and 1908. The estimated prevalence of the disease showed a peak about 1946–7, with a generally high prevalence over a period of 25 years from 1935 to 1960. . . .
>
> The development of clinical symptoms of chronic cadmium poisoning according to the literature takes about 10–20 years. In light of this fact, it is assumed that the inhabitants of the Itai-Itai disease area had the chance to intake high amounts of cadmium 10–20 years before the outbreak of Itai-Itai disease was supposed to have occurred in 1920.

In 1968, the patients suffering from Itai-Itai disease went to court in a suit against the company whose mine was located on the Jinzu River. In 1972, the courts decided in favor of the patients, each of whom was awarded approximately \$66,000 (U.S.), plus free lifetime medical treatment for the disease.

Since 1968, a great number of administrative investigations have been carried out. As a result, more than 10 areas in Japan were found to be polluted by cadmium. In most of these areas the soil contained high cadmium levels as a result of irrigation by river water which was contaminated by mines located in the vicinity. Because of these high levels of cadmium in soil, rice grown in these fields contained more than 0.3 ppm cadmium. This level was sometimes found in rice in nonpolluted areas. Thus, the concentration of 0.3 ppm was established as the highest "normal" level in Japan by the Environment Agency. However, a study on cadmium concentrations in rice throughout Japan, published in 1975, showed as high as 0.88 ppm cadmium, with an average of 0.1 ppm, in about 2700 samples from nonpolluted areas.

Up to the present time, no additional outbreaks of Itai-Itai disease or osteomalacia have occurred in areas polluted by cadmium other than those designated by the Ministry of Health and Welfare.

This historical review, taken mostly from the book by Tsuchya, is meant to describe what is known from the past. There are two additional things to learn from the Japanese experience which should be considered. Despite all the research efforts a number of scientists from Japan still question whether it was actually cadmium that was the primary factor causing the Itai-Itai disease. Political pressure may have played an important role and influenced those scientists who made these controversial statements. It is obvious that there is no simple correlation between soil or rice cadmium levels and the development of Itai-Itai disease, since large amounts of cadmium in soil and rice in areas other than the one where Itai-Itai was prevalent did *not* lead to any known cases of the disease. Thus, controversial opinions on the etiology of Itai-Itai disease and the effects of cadmium in rice on the kidney still exist. Nevertheless the a.d.i. value for cadmium in Japan is four times the WHO value. The discrepancy between strong restrictions with respect to soil for rice cultivation with a limit of 5 ppm, and a high a.d.i. value can easily be explained by the special experience and situation in Japan; it reflects generally the uncertainties prevailing on the effect of cadmium in the environment. After all is said and done, rice is still one of the staple foods of Japan.

Thus, cadmium is truely one of the critical environmental chemicals, because it enters into many biological and chemical processes.

Based on the current international concern, the Commission of the European Communities asked its "Scientific Advisory Committee" in April, 1980 to examine the toxicity and ecotoxicity of chemical compounds and to review the available data on cadmium. The major task was to determine whether cadmium presents a problem at the community level and whether action should be taken to reduce exposure. The Ecotoxicology Section of the Committee had mainly to assess the sources of exposure and current levels of intake, to identify transfer pathways and evaluate these quantitatively, to evaluate the current impact on the environment and different ecosystems, and to examine the potential impact based on the trends regarding the use of cadmium over the next 10 to 20 years. Table 1 presents some of the topics evaluated by the committee. These topics will be discussed in later papers in order to provide available new perceptions which might be included in the final report.

A few ecotoxicological points need to be mentioned at this junction. As a common element, cadmium naturally occurs everywhere in the environment. Table 2 shows the background levels in the environment. This natural background represents a basic problem, since the levels vary—for nine orders of magnitude in the samples given in Table 2—and since we have no control over them. This problem, however, is true of any natural chemical.

The sources of cadmium in the environment are uncertain despite available statistical data. Table 3 shows an estimate of a few intentional uses of cadmium. However, the discharge into the environment as waste, for example, by industries which are not using cadmium (mineral oil, iron, and steel production) are more difficult to assess. We can assume that we know, even quantitatively, the major uses of cadmium, within 10%. The release of cadmium from these uses into the environment can be fairly well estimated. The types of release for which we need additional data to arrive at a more correct balance are those not resulting from cadmium use itself.

TABLE 1

TOPICS OF CONCERN

Industrial production	The terrestrial environment
Consumption use pattern	Soil
Pigments	Occurrence and fate
Plating	Immissions from industry
Batteries	Immissions with phosphate fertilizers
Stabilizers	Immissions with sewage sludge
Alloys	Leaching and accumulation
Other Uses	Biota
Balance and trend studies	Plants
The atmosphere	Animals
Natural emissions	Balance and pathway studies
Anthropogenic emissions	Human exposure
Concentrations in air and dust deposition	Food and drink
The Aquatic environment	Daily intake
Freshwater	Absorption via inhalation
Occurrence and fate	Absorption via gastrointestinal tract
Effect on organisms	Total absorption
Accumulation in organisms	Population studies
Proposed quality criteria	Possible future trends
Seawater	
Occurrence and fate	
Effect on marine organisms and accumulation	
Accumulation in marine birds and mammals	
Balance and pathway studies	

There are three major sources of cadmium in the air, but their evaluation would require much more detailed reliable data. There is one special phenomenon to be learned in terms of source and pathway of cadmium in the environment. There are emissions from the intentional production and from the application and use of the

TABLE 2

BACKGROUND LEVELS IN THE ENVIRONMENT[a]

Compartment	Concentration range	log concentration (ppm)[a]
Air	0.1–5 ng/m^3	−7.0 to −5.3
Freshwater	0.05–0.2 μg/liter	−4.3 to −3.7
Seawater		
Coastal	up to 0.05 μg/liter	up to −4.3
Open sea	0.01–0.1 μg/liter	−5.0 to −4.0
River and lake sediments	up to 5 mg/kg	up to +0.7
Marine sediments	0.03–1 mg/kg	−1.5 to ±0.0
Soil	0.01–1 mg/kg	−2.0 to +0.7
Soil, volcanic origin	up to 4.5 mg/kg	up to +0.7
Igneous rock	0.001–0.6 mg/kg	−3.0 to −0.2
Phosphatic rock	up to 100 mg/kg	up to +2.0

[a] The orders of magnitude are approximately 1 ppm = 1 mg/kg soil or rock, 1 mg/liter water, or 1 mg/m^3 air.

TABLE 3

CADMIUM CONSUMPTION AND USE: ESTIMATION FOR EEC (AVERAGE DATA FOR THE PERIOD 1976–1978)

Total balance	
Production	4000 t/a
Import	2000 t/a
Consumption	6000 t/a
Estimated share	
Pigments	30%
Stabilizers	15%
Batteries	10%
Electroplating	10%
Alloys	10%
Surface treatment	25%
Estimate of use in plastics	
Pigments	1500 t/a
Stabilizers	600 t/a

element cadmium. According to the present state of knowledge, however, cadmium differs from other industrial chemicals in that this is not the major anthropogenic source of cadmium in the environment. There are major releases of cadmium, which have nothing to do with any application of this element, result from burning fossil fuels, smelting ores, etc. This means that there is a problem with a heavy metal cadmium, which results predominantly from zinc, iron, and steel production and phosphate–rock–fertilizer application. Thus, there are difficulties in elucidating transport phenomena considering the different point and aerial sources.

There is much data available on the occurrence of cadmium in a large variety of environmental samples, and some knowledge of the fate and accumulation in aquatic ecosystems. We are looking forward to new data which will accumulate to complement existing information. It should be emphasized that problems still exist with cadmium in terrestrial ecosystems. As opposed to other ions, cadmium does not move within the soil which therefore favors its accumulation in soil. The transfer factors from soil to plants and to animals are insufficiently known. For rice culture, where many analyses have been done, a certain cadmium concentration in soil results in about one-tenth of this concentration in raw rice. Since basic knowledge on terrestrial ecosystem interactions is still insufficient, this transfer problem, however, pertains not only to cadmium, but to other ions as well.

In aquatic and terrestrial organisms, there is evidence that present concentrations do not result in severe species or populations effects. Concentrations of one to two orders of magnitude higher than the present ones have been shown to be biologically effective in certain species, but these data are not yet sufficient for generalizations and estimation of an ecological "no-effect" level.

In light of these considerations, the conclusions of the Ecotoxicology Section can be summarized as follows:

1. Cadmium is a hazardous substance. Obviously, it is of no use to biological systems. At certain concentrations it causes damage to humans and other living organisms.

2. In general, levels of air-borne cadmium as well as cadmium levels in soil and water in the EEC have not yet reached dangerous concentrations. However, certain problem situations are increasingly being identified.

3. Inputs of cadmium into the environment may be expected to increase in the future if the present uses and emissions are continued.

4. At the EEC level, several estimates of emissions and potential pathways of cadmium have been attempted. They are lacking in accuracy due to insufficient information on many of the individual sources of cadmium pollution, as well as uncertain basic statistical data. Therefore, it is not yet possible to establish reliable inventories and mass balance for man-made cadmium pollution.

5. In the long term, a continued input of cadmium into the general environment may result in hazardous levels, particularly in soils, with the resulting consequences.

6. Attempts must be made to reduce the uses and inputs into the environment. On a short-term basis, it is possible to substitute for cadmium in stabilizers, PVC, and pigments.

We are looking forward to new data and arguments for updating and amending the status report.

REFERENCES

1. YOSHIOKA, K. (1964). *Yamaguchi Med. J.* **13**, 146.
2. KONO, M., et al. (1956). *J. Clin. Nutr.* **9**, 1.
3. HAYASHI, H. (1906). *Index. Japan. Med. J.* **4**, 805.
4. Japan Environment Agency (1972). *Control of Environmental Pollution by Cadmium.* Environmental Health Division, Planning and Coordination Bureau.
5. TSUCHIYA, K. (1978). *Cadmium Studies in Japan, A Review.* Kodansha Ltd Tokyo, Elsevier/North-Holland Biomedical Press, Amsterdam/New York/Oxford.