RETENTION AND DISTRIBUTION OF INORGANIC MERCURY (^{197}Hg, ^{203}Hg) IN THE HUMAN BODY AFTER SINGLE INHALATION

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ABSTRACT- Inorganic mercury (^{197}Hg,^{203}Hg) was inhaled by two workers during decontamination procedures in a hot cell. The retention and distribution of the mercury in the body were studied with a whole-body counter. The biological half-lives in the whole body were about 33 days, which was shorter than those reported for organic mercuries. The biological half-lives in the upper abdomen were about 50 days.

Scanning along the body axis and counting at several different points above the upper abdomen revealed that the mercury deposited mainly in the kidneys and in the liver. The activities of the mercury-203 in the kidneys and in the liver were determined using the counting efficiencies obtained from a REMAB phantom. The total activities in the kidneys 10 days after inhalation were almost equal to those in the liver. The high concentration in the kidneys, about 5 times as high as that in the liver, suggested that the kidneys were the critical organ for the inhalation of inorganic mercury.

INTRODUCTION

A solution of radioactive mercury-197 (2 ml, 100 mCi, $Hg(NO_3)_2$) was spilled in a hot cell and the decontamination was carried out by four workers with full face masks and protection clothes. At first, it was thought that no inhalation of the radioactive mercury-197 had occurred in the human subjects. However, to make sure of it, the subjects were monitored with a whole-body counter on the 10th day after the decontamination procedures. It was found that two out of the four subjects were contaminated with radioactive ^{197}Hg and ^{203}Hg. Therefore, to assess the radiation doses of the radioactive mercuries to the critical organ, the distribution in the body and the effective half-lives of the radioactive mercuries were studied with the whole-body counter.

METHOD

Subject, contaminant and whole-body counter

The age, height and weight of the contaminated workers are given in Table 1 . Their body builds were not so different from that of a typical Japanese. The whole-body counter used in this study consisted of a NaI(Tl) crystal of 8 inch ϕ x 4 inch and a 400 channel pulse height analyser. The monitoring room was shielded with 200 mm Fe + 3 mm Pb.[1] The measurements of the radioactivities within the body were carried out by three different geometries, i.e., 1) by standard chair geometry, 2) by placing the detector above the upper abdomen of the human subject who lay on a bed in a supine position (see Fig. 1) or in a prone position and fixing the distance from the detector surface to the bed as 22.5 cm and 3) by scanning along the body axis. In the case of scanning, the detector was provided with a collimator having a 5 cm slit, and the distance from the detector to the bed was kept as 42.5 cm.

Determination of counting efficiencies for ^{203}Hg in the kidneys and liver

Table 1. Age, height and weight of the contaminated workers

Subject	Age	Height (cm)	Weight (kg)
A	29	160	53
B	32	169	50

The counting efficiencies for ^{203}Hg were obtained using a REMAB phantom (Alderson Research Lab. U.S.A.). The volume of the right kidney of the phantom was 90 ml and that of the left was 110 ml and the total volume was 200 ml. The volume of the liver of the phantom was 1300 ml. The average weight of the kidneys of adults of Japanese is 270 g and that of the liver, 1440 g.[2] Therefore, there were some discrepancies in the organ sizes between the phantom and a typical Japanese.

The vessels for the kidneys and liver of the phantom were filled with a standard solution of ^{203}Hg. The solution of ^{203}Hg was prepared as follows. Mercury-203 was dissolved in a solution containing $HgCl_2$(2 mg) + $KClO_3$(7 mg) per ml of 3N HCl. The activity of ^{203}Hg in the solution was 15.84 μCi/ml. One ml of this solution was divided into two kidney vessels in proportion to their volumes (i.e., right, 0.45 ml, left, 0.55 ml). The radioactive solution was diluted until 200 ml for both the vessels with a diluting solution containing NaCl(10 mg) + $HgCl_2$(2 mg) per ml of 0.5N HCl. The vessel for the liver also was filled with the same radioactive solution and diluting solution as those for the kidneys.

On the condition that the NaI(Tl) detector was placed above the central part of the upper abdomen and the distance from the detector to the bed was fixed as 22.5 cm, the counting efficiencies for the ^{203}Hg in the kidneys and liver were determined in the supine and prone positions. They were as follows.

$\eta(k)_s$ = 0.013 (cpm/dpm) for ^{203}Hg in the kidneys in the supine position,
$\eta(k)_p$ = 0.065 (cpm/dpm) for ^{203}Hg in the kidneys in the prone position,
$\eta(l)_s$ = 0.054 (cpm/dpm) for ^{203}Hg in the liver in the supine position,
$\eta(l)_p$ = 0.012 (cpm/dpm) for ^{203}Hg in the liver in the prone position.

RESULTS

Determination of effective half-life of mercury in the whole body

Since it was difficult to determine the counting efficiencies for the radioactive mercuries in the whole body, the radioactivities in μCi in the whole body were not determined. Only net counting rates in the energy ranges of 77 ± 43 keV (for ^{197}Hg) and 279 ± 59 keV (for ^{203}Hg) were measured by standard chair method from the 10th to 36th day after inhalation. To obtain the net counting rates, the contribution of the ^{40}K and ^{137}Cs in the body to the energy ranges of ^{197}Hg and ^{203}Hg was subtracted. Also, the contribution of ^{203}Hg to the counting rate in the energy range of ^{197}Hg was subtracted. The contribution was estimated to be 0.81 (for subject A) and 0.83 (for subject B) times the counting rates in the photopeak of ^{203}Hg. These values were obtained after 29th day postinhalation when the ^{197}Hg had decayed sufficiently.

The net counting rates of the ^{197}Hg and ^{203}Hg in the whole body as determined by standard chair geometry are plotted against time in Fig.2. The effective half-lives were obtained by the least square method. The effective and biological half-lives of ^{203}Hg are listed in Table 2.

Distribution of radioactive mercury in the body

The distribution of radioactive mercuries in the body was estimated by scanning along the central body axis with the detector provided with the collimator. The energy range used in this scanning was from 34 to 338 keV to include the energies of ^{197}Hg and ^{203}Hg. The result of scanning on the 10th day after inhalation for subject A is illustrated by a solid line in Fig.3. It was found that the radioactive mercuries deposited mainly in the upper abdomen, but somewhat in the chest, in the lower abdomen and in the other parts of the body. On

Table 2. Effective and biological half-lives of ^{203}Hg in the body

Subject	Effective half-life in whole body (day)	Effective half-life in upper abdomen (day)	Biological half-life in whole body (day)	Biological half-life in upper abdomen (day)
A	19	23	32	45
B	20	24	35	49

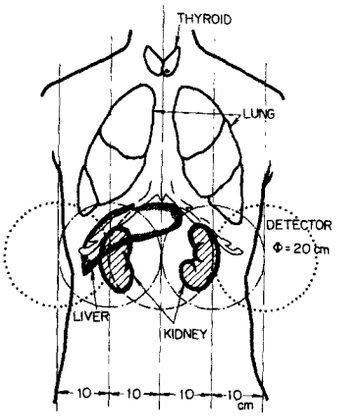

Fig.1. Relative position of detector and the kidneys and liver.

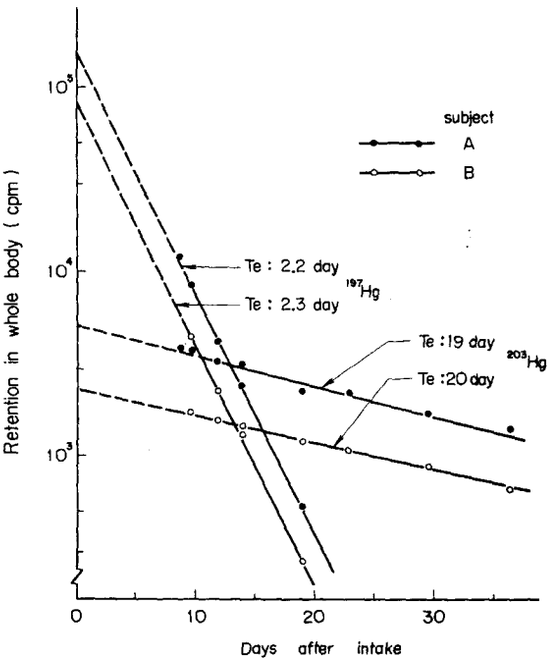

Fig.2. Retention of ^{197}Hg and ^{203}Hg in th whole body after single intake. (Te : eff tive half-life)

the assumption that the counting efficiencies were the same for any points al the body axis, it was calculated that about 60 per cent of the mercuries in t total body deposited in the upper abdomen. To know the organ in which the rad active mercuries in the upper abdomen mainly deposited, the position of the detector (without collimator) was moved above the upper abdomen from the righ to the left perpendicularly to the body axis at 10 cm intervals in the supine position (see Fig.1). The counting rates at each position decreased in the fo lowing order; center 10 cm right > 10 cm left > 20 cm right > 20 cm left. This result supported that the mercuries deposited mainly in the kidneys and liver.

Determination of effective half-life of mercury in the upper abdomen

The human subjects lay on the bed in a supine position and the distance between the NaI(Tl) detector and the bed was fixed as 22.5 cm as usual. The tector was placed above the center of the upper abdomen (see Fig.1). On thes conditions, the mercuries deposited in the upper abdomen would be detected w out much error, because the mercuries in the other parts of the body were re tively small in quantity as shown in the above paragraph for distribution.

Here, again, the net counting rates of the ^{197}Hg and ^{203}Hg were obtaine the same procedures that taken for the mercuries in the whole body. And, the

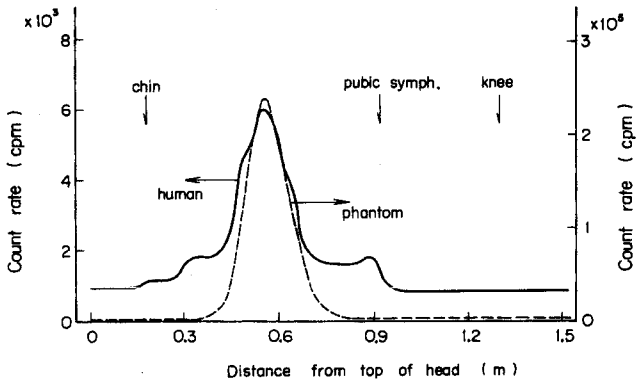

Fig.3. Profile curves from human subject and phantom.

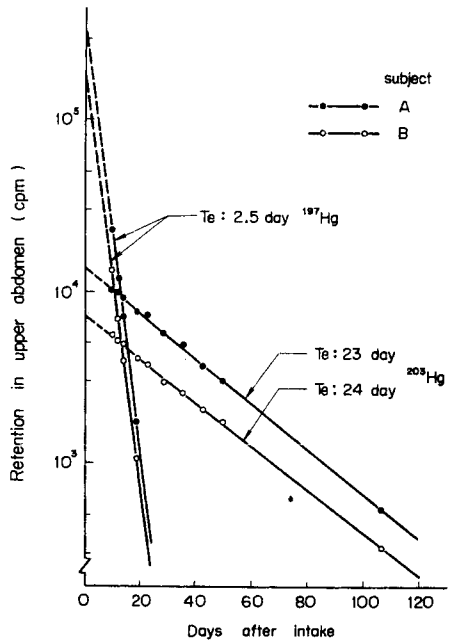

Fig.4. Retention of ^{197}Hg and ^{203}Hg in the upper abdomen.

contribution of the ^{203}Hg to the counting rates in the energy range of ^{197}Hg were 0.72 (for subject A) and 0.68 (for subject B) times the counting rates in the ^{203}Hg photopeak.

The change with time of the net counting rates of the ^{197}Hg and ^{203}Hg in the upper abdomen is shown in Fig.4. The effective and biological half-lives of ^{203}Hg are listed in Table 2, showing that the half-lives in the upper abdomen were longer than those in the whole body.

Determination of the radioactivities of ^{203}Hg in the kidneys and liver

It was possible to determine the radioactivities of ^{203}Hg in the kidneys and in the liver from the measurements of the human subject lying on the bed in the prone and supine positions.

If no mercury is involved in the body except for the kidneys and liver, the counting rates in the prone position, P(cpm), and those in the supine position, S(cpm), are given by the following formulas,

$$P = C\,E\{\eta(k)_p\,K + \eta(1)_p\,L\}$$
$$S = C\,E\{\eta(k)_s\,K + \eta(1)_s\,L\}$$

where C : $2.22\ 10^6$ (dpm/μCi),

E : 0.83, emittion rate of γ-rays of 279 keV per disintegration of ^{203}Hg,

K : organ burden in μCi of ^{203}Hg in the kidneys, and

L : organ burden in μCi of ^{203}Hg in the liver.

As described already, on the condition that the distance from the detector to the bed was fixed as 22.5 cm,

$\eta(k)_p$ and $\eta(k)_s$: 0.065 and 0.013 (cpm/dpm), respectively, and

$\eta(1)_p$ and $\eta(1)_s$: 0.012 and 0.054 (cpm/dpm), respectively.

From the above formulas,

$$L\ (\mu Ci) = \frac{1}{CE}(19.6\,S - 4.08\,P)$$

$$K\ (\mu Ci) = \frac{S}{0.0135\,CE} - 3.96\,L\ .$$

Therefore, it was possible to evaluate the activities in the kidneys and in the liver from the counting rates in the prone and supine positions. The activities in these organs on the 10th day and 50th day after inhalation were calculated

from the counting rates on those days. The results are given in Table 3. The table shows that on the 10th day the ratio of the activities in the kidneys to those in the liver was about 1 : 1 in both the subjects. If the subjects had the kidneys of 270 g and the liver of 1440 g like a typical Japanese, the concentration of ^{203}Hg in the kidneys must be about 5 times as high as that in the liver on that date, suggesting that the kidneys were the critical organ for the inhalation of inorganic mercuries.

Table 3. Radioactivity of ^{203}Hg in the kidneys and liver on the 10th and 50th day after inhalation

Subject	Organ	Activity (μCi) on day		Ratio of activities (kidney/liver) on day	
		10th	50th	10th	50th
A	kidney	0.079	0.028	0.97	1.17
	liver	0.082	0.024		
B	kidney	0.045	0.018	1.00	1.34
	liver	0.045	0.013		

DISCUSSION

Biological half-life

Table 4 summarizes the effective and biological half-lives of ^{203}Hg reported by several workers for the whole body. [3-7] These data suggest that the biological half-lives of inorganic mercuries are shorter than those of organic ones, and the retention function of mercury should be expressed by three components.

Table 4. Comparison of effective and biological half-lives in the whole body. (Figures in parentheses show biological half-lives)

Chemical form of Hg	Route of entry	Effective and biological half-life: fast component (day)	intermediate component (day)	slow component (day)	Author
inorganic	inhalation	-	-	20, 19 (35) (32)	this study
inorganic	oral	-	-	22 (42±3)	Rahola et al.
^{203}Hg-methyl mercury	oral	-	-	29 (76±3)	Rahola et al.
^{203}Hg-neohydrin	oral	-	-	30 (84)	Johnson et al.
^{203}Hg-neohydrin	oral	0.22 (0.22)	7 (8.2)	-	Greenlaw et al.
monomethyl ^{203}Hg nitrate	oral	-	-	28, 27 (71) (66)	Falk et al.
			8.2 (10)		ICRP[7]

The present study showed that the mercuries in the upper abdomen have longer half-lives than those in the whole body. This is consistent with the finding by Falk et al. that the monomethyl-^{203}Hg nitrate deposited in the liver region dereased more slowly than those in the other regions of the body.

Distribution

Falk et al. have studied the distribution of the monomethyl-^{203}Hg nitrate

in the body by scanning along the body axis. Their profile curves of the net counts are very similar to ours (Fig.3) as a whole. Their conclusion was that the mercury mainly accumulated in the liver region and somewhat in the cerebellum region. Our observation could not reveal special accumulation in the cerebellum, but this may be attributed to the poor resolution of the detector used in this study and/or to the difference of the chemical form of the mercury absorbed. The present study suggests that the kidneys are the most important organ where mercury deposits in the highest concentration. Falk et al. did not refer to the deposition in the kidneys.

Assessment of dose commitment due to the radioactive mercuries in the kidneys

Unfortunately, in this study the retention function of the ^{203}Hg in the kidneys could not be accurately estimated, for the measurements of the ^{203}Hg started on the 10th day after inhalation, and the fast and intermediate components of the retention were missed. However, it was probable that the dose commitment to the kidneys due to the fast and intermediate components would not be greater than that due to the slow component, as was estimated by Johnson et al. for the dose commitment to the whole body.

The dose commitment to the kidneys delivered by the slow component of the retention of ^{203}Hg were estimated as 104 and 57 mrem for subject A and B, respectively, and those to the liver, 21 and 12 mrem, respectively, on the assumption that the slow component of the retention of ^{203}Hg in the kidneys and in the liver had the same effective half-lives as those observed for the upper abdomen.

Since the radioactivity of ^{197}Hg in the body was not determined, the calculation of the dose commitment due to the ^{197}Hg was impossible, but the dose commitment to the kidneys and liver were perhaps the same order of magnitude as those due to the ^{203}Hg, inferring from the effective energies, the counting rates and their effective half-lives in the upper abdomen (see Fig.4). Anyway, the sum of the dose commitment due to the ^{197}Hg and ^{203}Hg were far less than 8 rem, the ICRP permissible dose for 3 months.[8]

Error in the determination of radioactivities in the kidneys and liver

Some error may be introduced in the estimation of the radioactivities of ^{203}Hg in the kidneys and liver, because the estimation was made on the incorrect assumption that no radioactive mercury was involved in the organs and tissues other than the kidneys and liver. However, as the deposition in the organs and tissues other than the kidneys and liver was not large as shown in Fig.3, the error would not be serious.

REFERENCES

1. Directory of whole-body radioactivity monitors, JA 1.1. IAEA, Vienna (1970).
2. S.Aimi, A.Yasoshima, M.Sugai, B.Sato, T.Sakai and Y.Nakajima, Acta Pathologica, 2, 173-200 (1952).
3. T.Rahala, R.Aaran and L.K.Miettinen, Assessment of radioactive contamination in man, pp.553-562, IAEA, Vienna (1972).
4. J.E.Johnson and J.A.Johnson, Health Physics 14, 265-266 (1968).
5. R.H.Greenlaw and C.M.Guaife, Radiology 78, 970-973 (1962).
6. R.Falk, J.O.Snihs, L.Ekman, U.Greitz and B.Aberg, Acta Radiologica 9, 55-72 (1970).
7. ICRP publication 2, Report of ICRP committee II on permissible dose for internal radiation, Pergamon Press, Oxford (1959).
8. ICRP publication 9, Recommendations of the International Commission on Radiological Protection, Pergamon Press, Oxford (1966).