A CASE STUDY OF HUMAN CONTAMINATION DUE TO INHALED THULIUM-170 OXIDE

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Abstract

One worker incidentally inhaled submicron particles of thulium-170 oxide. Data obtained by in-vivo counting and bioassay over about 450 days after inhalation fitted to a sum of three exponential terms having effective half-lives of about 3, 23 and 90 days, respectively, though the half-life of 3 days was not distinctly determined. Attempts were made to express the daily fecal and urinary excretion by power function and to relate the excretion with the decrease of the chest burden. In addition, the distribution and transfer of thulium in the body were discussed.

1. Introduction

An incident occurred in the course of the sealing of thulium-170 sources for non destructive test in a hot laboratory at Oarai Laboratory, Japan Atomic Energy Research Institute (JAERI). The process of the sealing which involved the mounting of a neutron activated thulium oxide pellet (about 50 Ci of ^{170}Tm) in a titanium metal capsule (6 mm ϕ x 11 mm) and subsequent arc welding (3,000°C, in argon gas), was carried out in a hot cell by one worker. Following the welding process, the worker stepped in the cell and stayed there for about 5 minutes so as to carry out the sources from the cell. Leaving the cell he made a contamination check and found his hands and clothing contaminated in some measure. Then, he felt a doubt whether he had inhaled air born particles of the thulium oxide. Any air monitor was not running throughout the time of the work because it was early in the morning.

Unfortunately, four days later the worker was sent to Tokai Laboratory, JAERI, where a whole-body counter was installed. By the first measurement it was found that an appreciable amount of ^{170}Tm was deposited in his chest. Though the exposure was not itself very serious, to obtain as much information as possible the determination of ^{170}Tm by in-vivo counting and bioassay was followed until the levels of the activity were very low.

2. Methods

2. 1. In-vivo counting

Measurement was made to determine the deposition of ^{170}Tm in the chest of the contaminated subject with a whole-body counter.[1] The other series of measurements with this counter were carried out to know the distribution of ^{170}Tm in the body. The whole-body counter consisted of a 8 in. ϕ x 4 in. NaI(Tl) detector in a cubical steel room, a multichannel analyzer and associated electronics.

In chest counting, the 8 in. ϕ x 4 in. NaI(Tl) detector was placed above the chest at the distance of 22 cm from the bed on which the subject was lying on the back. In this case, the xyphoid sternum was adjusted to an edge of the crystal. Occasionally the position of the subject on bed was replaced with a prone position, to obtain the distribution of ^{170}Tm in the chest.

In profile counting, the crystal provided with a 5 cm thick lead collimator having a 5 cm slit, was moved manually along the body axis to four fixed positions, that is, above the head, chest, lower abdomen and the thigh, keeping the distance from the crystal to the bed at 42 cm.

All measurements were carried out, using the energy band from 25 to 90 keV which contains the X- and gamma-ray lines of ^{170}Tm (52, 84 keV).[2,3,4]

In order to obtain the counting efficiency, calibrating measurement with a RANDO phantom (Alderson Research Lab., USA) was made using 149 ^{170}Tm sources in small polyethylene capsules, the total activity of which was 0.40 μCi. These capsules were inserted in hole grids within the lungs of the phantom. The arrangement of capsules simulated the uniform distribution of the contaminant in lungs. Therefore, it might differ from the truth and some systematic error might exist.

The lung size of the subject was evaluated by means of radiograph techniques, and the effective tissue thickness of the subject's chest wall was estimated according to the method which was described in detail else where.[5,6] As the result, both data of the subject were somewhat larger than those of the phantom, and it was concluded that the counting efficiencies observed on the phantom required 10 per cent corrections.

2. 2. Bioassay

After the detection of ^{170}Tm with the in-vivo counter, the subject was asked to collect the samples of urine and feces. Consequently, the sampling program was not started until 4 days after the inhalation. Both programs of the urine and fecal sampling were initiated on the 24-h sampling basis but afterward changed on the 2 or 4 consecutive day sampling basis. These procedures of sampling were continued until 134 days. After a long interval, additional samples of urine and feces were obtained for three days from 445 to 447 days.

The thulium-170 contents of the samples were determined by beta counting, for which a gas flow proportional counter was used. The counter had a detection limit of about 3 pCi. For the counting the simplest procedure was adopted as follows. In urine samples the radioactive thulium was coprecipitated with basic calcium phosphate after adding a thulium carrier. The resulting precipetates were dried, powdered and prepared for counting. Feces was ashed in a furnace before counting.

3. Results

3. 1. Retention in the chest and distribution in the whole-body

Measurement for ^{170}Tm in the chest of the subject with a whole-body counter was carried out over the period from 4 to 447 days after the inhalation. The results of twenty-four measurements are plotted in Fig. 1(a). A least squares best fit analysis by a computer was tried on the plots to fit the data to a sum of exponentials. A good fit to a sum of two exponentials was obtained as shown in Fig. 1(a) with effective half-lives of 23 ± 4 days and 90 ± 11 days.

Location of ^{170}Tm in the whole-body was roughly measured with a whole-body counter by means of the manual scan technique described above. The counting was carried out 9, 73 and 126 days after inhalation. Since it was difficult to determine the activity in the four different parts of the body, i.e., the head, chest, lower abdomen and the thigh, the deposition of ^{170}Tm in those parts of the body was expressed in terms of counting rate. The counting done on the 3 different days showed that the deposition in the chest predominated over the rest of the body, but the tendency of the decrease of the counting rates at the four different parts of the body suggested the redistribution in the body at the

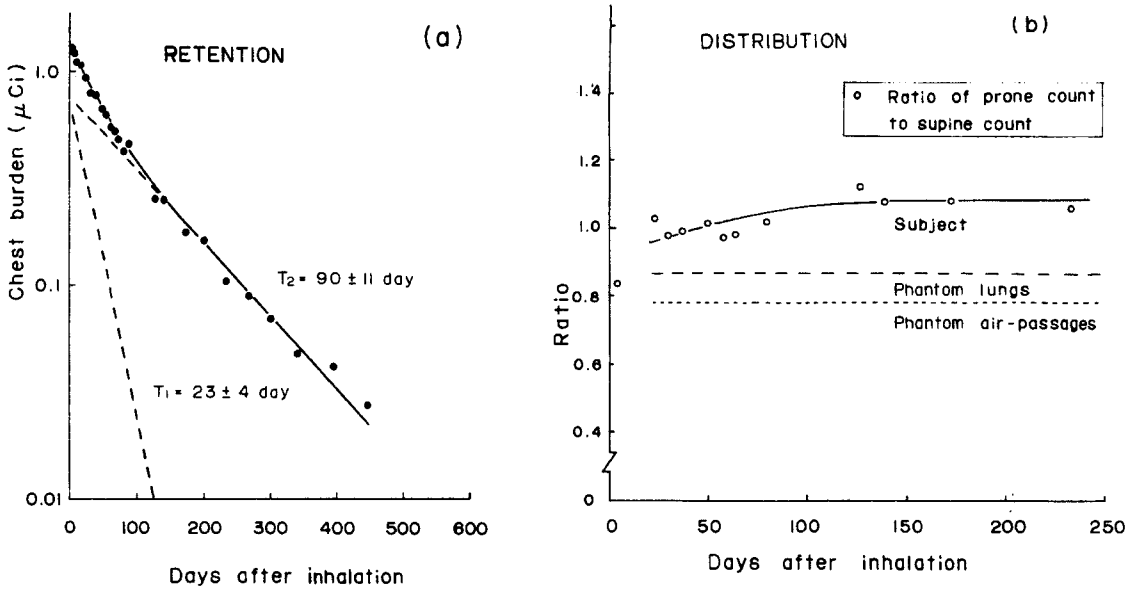

Fig. 1. Retention (a) and Distribution (b) of thulium-170 in chest.

late stage of contamination (126 days).

3. 2. Distribution in the chest

To get an idea of detailed distribution of ^{170}Tm in the chest, the subject was measured both in a prone and in a supine positions by a fixed crystal-bed geometry. Twelve measurements were made over the period from 4 to 232 days after inhalation. The ratios of prone counts to supine counts were calculated. In Fig. 1(b) the ratios are plotted against time. A fitted-curve is shown by a solid line.

In a geometry similar to that taken for the human subject the phantom was measured in a prone and supine positions two times each; one, with ^{170}Tm sources in the lungs, and the other, with the sources in the lower air-passages below the throat. In the latter, the thulium-170 sources were simulated to the deposition in the trachea and the bronchia. The ratios of the counting in both positions were 0.87 and 0.78 for the sources in the lungs and in the lower air-passages, respectively, as shown in Fig. 1(b) by a broken line and by a dotted line. The ratios obtained from the phantom were lower than any ratios of the subject, which were between 1.0 and 1.1, except for 0.84 at the first measurement. The ratio for ^{170}Tm in the lungs (0.87) was higher than that for ^{170}Tm in the lower air-passages (0.78).

From these results, it is presumed that the minimum ratio of the subject at the first measurement (0.84) might indicate the initial deposition of ^{170}Tm in the tracheo-bronchial parts of the air-passages. The rather high ratio of the subject over a period of observation as compared with that of the phantom seemed to be explained by 1) the difference of geometry due to the size of the body and due to inhomogeneous deposition in the chest and by 2) the difference of the absorption and scattering of the photons through the media, i.e. the lungs, adjacent organs, surrounding soft tissue, rib cage, etc.[7]

3. 3. Urinary, fecal and total excretion

Forty-seven 24-h urine samples were subjected to analysis until 134 days after inhalation. The results obtained through beta counting are shown in Fig. 2(a) where the urinary excretion rates in μCi/d are plotted semi-logarithmically against time in days after inhalation with the maximum value of 1.6 nCi/d.

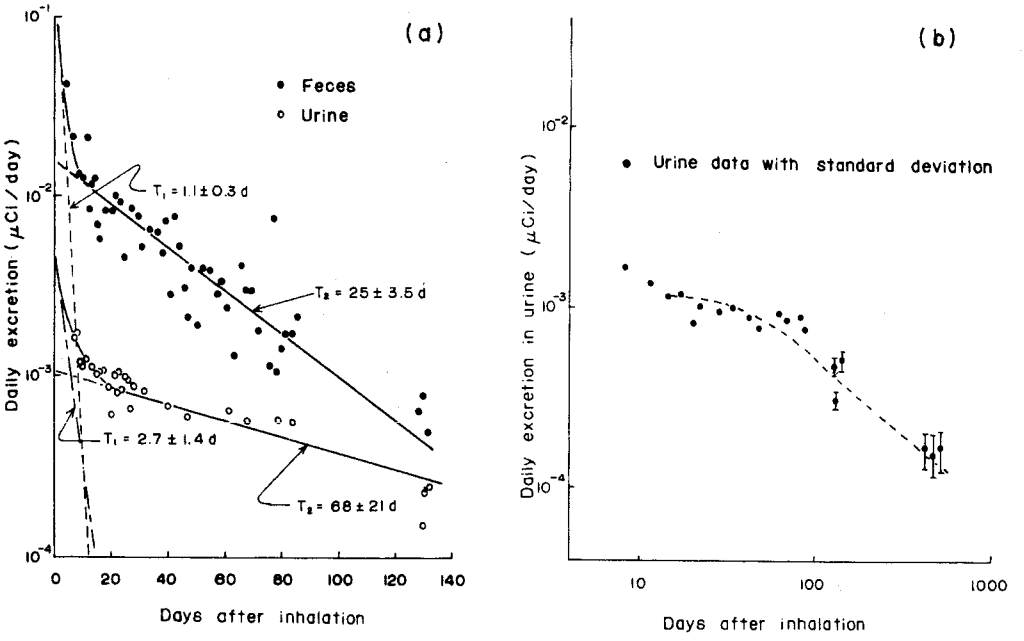

Fig.2. Excretion data of thulium-170, plotted semi-logarithmically (a) and logarithmically (b).

In this figure thirty plots from 47 measurements were taken to illustrate the excretion. With the aid of creatinine determination the samples with insufficient contents were excluded from the plots. A least squares best fit to a sum of two exponentials was obtained as shown in Fig. 2(a) with effective half-lives of 2.7 ± 1.4 days and 68 ± 21 days.

In order to see the long-term trend of urinary excretion, the data of the sample taken during the period from 445 to 447 days added to the graph of urinary excretion rates on a log-log scale. This is shown in Fig. 2(b). The plots in this figure are shown along with a curve which is arbitarily drawn to show the long-term pattern. This pattern of urinary excretion was similar to those calculated from the radionuclide in the lungs, when the biological half-lives in the lungs were 30 and 300 days (these correspond to effective half-lives of 23 and 90 days shown in Fig. 1(a), respectively) and the exponent of the power function of urinary excretion was assumed to be $-1.0 \sim -1.7$. This calculation method is shown in the ICRP Publication 10A.[8]

During the 134 days of observation, there were 49 fecal samples in total. Over the period from 4 to 85 days all outputs of feces except one were collected. The results of determination are presented semi-logarithmically in Fig. 2(a) with the maximum value of 43 nCi/d. A good fit to a sum of two exponentials was again obtained with the effective half-lives of 1.1 ± 0.3 days and 25 ± 3.5 days.

The total activity of ^{170}Tm excreted daily in feces and urine was obtained by combining the fecal and urinary data. In this case the daily feces and the total of a single output collected on the same day as 24-h urine samples, were combined together. Here again a good fit to a sum of two exponentials was obtained. The exponentials had half-lives of about 5.4 days and about 31 days, respectively. Since there was no data for the time earlier than 7 days after inhalation, the estimated half-life for the rapid component of excretion (5.4 days) might have some ambiguity.

The daily excretion of ^{170}Tm in feces collected from 4 to 134 days after inhalation was consistently higher than that in urine collected for the same period. The ratio of urinary to total excretion changed from 0.06 to 0.3 during the above observation period. Whether this ratio changed with time was tested by

regression analysis. The coefficient of correlation obtained was 0.86 and this correlation was significant at the 1 per cent level (linear correlation was supposed until 134 days).

4. Discussion

4. 1. Half-lives

It may be interesting to compare the three sets of effective half-lives obtained from the data of urine, feces and chest. The shortest half-life appeared in the short-term component of fecal excretion (about 1.1 days). On the other hand, the longest half-life appeared in the long-term component of chest clearance (about 90 days) and the intermediate half-lives of similar length, in chest and feces (about 23 days and 25 days each). Therefore, the behavier of ^{170}Tm inhaled in the body as the oxide was presumed as follows.

(1) Within the first ten days there was a very rapid clearance, though, unfortunately, no data supporting this were obtained on the deposition and excretion for the first 4 days. The major part of deposition in the naso-pharyngeal region and in the ciliated area of the tracheo-bronchial region was excreted in feces via the gastro-intestinal tract and the minor part of the deposition was excreted in urine with a biological half-life of less than 3 days after being absorbed into the blood.

(2) In the next period of about 4 months, there was a rapid decrease with a biological half-life of about 30 days. During this period, the fecal excretion involved 1) the material initially deposited in the pulmonary region, subsequently moved up the bronchial tree and swallowed, though a certain quantity of the material was removed through the very rapid clearance phase above mentioned, and 2) the material initially deposited in the pulmonary region, absorbed in blood and afterward excreted via bile and others. These exogenous and endogenous component of excretion could not be separated by measurements.

(3) In the third period, the deposion in the chest decreased exponentially with effective half-lives of 90 $\pm$ 11 days which corresponded to the biological half-lives of 140 to 450 days with a mean of about 300 days. The activity detected in the chest would be mainly due to the non-transportable ^{170}Tm deposited in the lungs though the measurements by chest counting included the radionuclide in the lungs, lymph nodes and chest wall. In addition, as described in the results, the urinary excretion data (Fig. 2(b)) were explained by the two components which had about 23 and 90 days half-lives which were the same as those in the chest.

In short, in this case study we assumed that the retention of ^{170}Tm in the chest fitted a sum of three exponential terms having effective half-lives of about 3, 23 and 90 days, respectively, though the half-life of 3 days was not distinctly determined. On these assumptions, it was estimated that at least 1.5 μCi of ^{170}Tm were initially deposited in the lungs of the subject.

4. 2. Distribution

The nature of the work caused the inhalation and the subsequent study concerning the aerosols strongly supported that the inhaled material was thulium-170 sesquioxide ($^{170}Tm_2O_3$) which was insoluble in water. Since it was impossible to make observation on the material inhaled, particle size investigation was carried out on the other thulium oxide pellet in which thulium-170 was previously formed by neutron activation. Thulium aerosol produced on the various conditions was measured with an electron microscope and a cascade impactor. Repeated measurements on the aerosols showed that the activity median aerodynamic diameter (AMAD) of this particle size distribution changed with the duration time of arc welding and with time after welding, and fluctuated between 0.01 μm with a geometric standard deviation, $_g$, of 5 and 0.5 μm with σ_g of 1.4. Although there was no evidence that this was the case in the incident, we estimated that submicron particles were inhaled in the incident.

Using the compartment model proposed by the Lung Dynamics Task Group,[9] the depositions of thulium-170 in the lungs of the subject were evaluated, as a class Y compound. The percentage depositions obtained were about 1% for the

naso-pharynx region (N-P), about 8% for the tracheo-bronchial region (T-B) and about 60% for the pulmonary region (P). The dominant deposition in the pulmonary region predicted the presence of the long-term component of the retention in the chest as seen in Fig. 1(a). Moreover, the characteristics of the non-transportable submicron particle might be responsible for the rapid excretion at early stage and the subsequent slow excretion in urine as in Fig. 2(a).

Human exposure to thulium-170 oxide has been reported in literature. Eakins and Morgan,[10] and Strambi and Testa[11] investigated different inhalation cases and studied excretion patterns, but no thulium-170 could be detected in urine.

Thomas and Kingsley[12] studied inhalation of $^{171}Tm_2O_3$ in beagle dogs and reported that 63% of the sacrificed body burden was in the skeleton, 18%, in the lungs and 11%, in the liver 128 days post exposure. However, on our observations, the depositions in the skull and in the femur were not clarified though the possibility remained.

4. 3. Urinary and fecal excretion in relation to chest retention

The urinary, fecal and total excretion rates of ^{170}Tm in μCi/d observed during the period from 7 to 126 days after inhalation were plotted against time in days after inhalation, on log-log paper, after being corrected for radioactive decay. Each set of values could be described by a power function, $y = At^{-B}$, where y is the activity excreted per day in μCi/d, t, time in days and A and B, constants. The values of A and B were 0.002, 0.058, 0.085 (μCi/d) and 0.25, 0.65, 0.71 for urinary, fecal and total excretion, respectively.

Integration of these power functions from t = 7 to 126 days gave the total amounts of urine, feces and total excreta during the period. They were 0.1, 0.57, 0.69 μCi, respectively. On the other hand, according to the direct chest counting, about 0.75 μCi were lost through biological routes from the chest region during the period from 7 to 126 days after inhalation. Although it was impossible to take into account the rapidly decreased component of the excretion which might appear for the first 10 days, this value, 0.75 μCi, agreed fairly well with the total amount (0.69 μCi) excreted during the same period. This attempt was also made on the exponential expression of the same data, and the similar result obtained.

Acknowledgements

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