*Originally published in Japanese in the Japan Journal of Industrial Health, 35 (1993), p. 178-87*

# ESTIMATION OF ASBESTOS EXPOSURE AMONG WORKERS REPAIRING ASBESTOS CEMENT PIPES USED FOR CONDUITS

Shinji KUMAGAI,*[1] Shigeharu NAKACHI,*[2] Norio KURUMATANI,*[3] Shingo NAKAGIRI*[4] and Akihiko KATAOKA*[5]

Asbestos cement pipes (ACPs) containing 15 to 20% chrysotile or crocidolite have been used for underground conduits. Even today 16.2% of all conduits in Japan are ACPs, though the production of ACPs was suspended in 1985. When such a conduit is accidentally damaged the workers belonging to the Waterworks Bureau of a local government cut off the damaged conduit using a high-speed disk cutter and replace it with a new conduit. This operation develops a cloud of dust and the workers involved run the risk of asbestos exposure. It was the aim of the present study to estimate asbestos exposure levels among these workers. First, in the experiment, we established the typical working conditions and requested an experienced worker to cut an ACP using a high-speed disc cutter in a hole dug in the ground as he routinely does. The experiment was repeated three times. During a bout of each experiment, dust was sampled at several points both inside and outside the hole. Second, a self-administered questionnaire survey was conducted to obtain information from the workers regarding their working conditions in cutting ACPs. The subjects of the survey were 1,048 men belonging to conduit repair sections of the Waterworks Bureau of 119 local governments. The results obtained can be summarized as follows.

1) Each bout of cutting ACPs required about five minutes. The concentration of asbestos fibers longer than 5ƒÊm with 3: 1 aspect ratio ranged from 48 to 170 fibers/ml (92 fibers/ml on an average) inside and 1.7 to 15 fibers/ml outside the hole. The concentration inside the hole exceeded the ceiling limit (10 fibers/ml) recommended for asbestos by the Japanese Association of Industrial Health. A concentration of 92 fibers/ml is equivalent to 0.96 fibers/ml as 8-h time-weighted average.

2) The number of subjects with experience of cutting ACPs was 849 (81.0%). The average length of service in conduit repair section was 14.2 yr. Based on the information obtained from each subject regarding the average working days per yr for each decade from 1946, the cumulative days to date expended in cutting ACPs was estimated to average 235d, that is, 17d per yr. Only 18.1% of the subjects used a protective respiratory device.

3) On the assumption that these workers worked 17 d per yr in cutting ACPs for 14 yr and were exposed to 1 fiber/ml of asbestos per d, the life-time excess mortality rate of lung cancer would be 30 per 100,000 and that of mesothelioma 30 per 100,000 by OSHA's model, and that of lung cancer would be 15 and that of mesothelioma 28 by Hughes' model.

These results suggested that workers belonging to the Waterworks Bureau have a possibility of being exposed to relatively high levels of asbestos when cutting ACPs and have a risk of developing asbestos-related diseases.

Key words: asbestos cement pipe; asbestos exposure; worker; Waterworks Bureau; life-time excess mortality; lung cancer; mesothelioma

*[1] Department of Occupational Health, Osaka Prefectural Institute of Public Health
*[2] Nanrokai Matsuura Clinic
*[3] Department of Public Health, Nara Medical University
*[4] Occupational Health and Safety Unit, All Japan Prefectural and Municipal Workers' Union
*[5] Kansai Occupational Health and Safety Center
Received for publication, July 8, 1992

## I. Introduction

The total volume of water supplied annually by Japanese waterworks is about 16.2 billion tons (1989). [1] Water from lakes, dams or rivers, or groundwater, is collected, purified, sterilized, and conveyed to end users by cast iron, asbestos cement, polyvinyl chloride (PVC) or pipes of other material. The total length of the nation's water pipes is 438,000km, of which asbestos cement pipe ("ACP") or conduit accounts for 16.2% (1989). [1] AC pipe is made by (1) mixing asbestos (chrysotile or crocidolite) into cement and silica so as to amount to 15-20% of the total volume, and combining same with water, (2) spreading the resulting mixture into sheet form and wrapping it in layers around a metal core so as to form a pipe, (3) removing the metal core and curing the pipe in an autoclave (at about 180°, 10 kg/cm$^2$), drying it, and (4) cutting the pipe into predetermined lengths.[2] The reason for mixing asbestos into the cement is that cement alone cannot withstand the pressure of the water or the force imparted by vehicles passing over the pipe.

It is known that breathing in asbestos causes lung cancer, chronic disease of the lining of the lungs (malignant mesothelioma), and asbestosis.[3,4] Ebihara[5] has reported on malignant mesothelioma of a worker who had been employed in the production of ACP for 23 years. There are two problems associated with the use of ACP for water supply. One is the possibility that after prolonged use particles of asbestos may separate from the pipe and be mixed in the water. Saito et al.[6] have studied the concentration of asbestos in drinking water; whereas no asbestos was found in water conveyed in PVC water pipe, they reported that crocidolite was found in the drinking water of regions where ACP was in use. The second problem is that when an ACP is broken, waterworks teams or others undertake repairs and are liable to breathe in asbestos fiber dust, as high-speed disc cutters are used to cut the pipe.

ACP has been used for conveyance of water in Japan since about 1932, but its use increased swiftly after about 1951, after which the combination of heavy vehicular traffic and aging of the pipe resulted in frequent ruptures, and subsequent replacement of ACP by pipe made of other, stronger materials, such as cast iron or ductile iron. Consequently, production of ACP after peaking at 3,340,000 pipes in 1965 (these pipes were 3 to 5m long), declined and production ceased in 1985 (information as per a personal communication regarding the inspection data of ACP for use by Japan Water Works Association members, and total length). The Ministry of Health and Welfare created a system for subsidizing the replacement of ACP with ductile iron pipe and complete elimination of ACP is expected by 10 years in the future.[8] However, the appearance of symptoms of lung cancer and malignant mesothelioma caused by asbestos exposure takes place after a latent period of, commonly, 20-40 years,[4] for which reason there is worry over the influence of exposure on the health of workers who installed or repaired ACP. It was thought that this made it necessary to investigate the actual conditions of exposure to asbestos fibers when ACP is being cut, but a literature search failed to identify any prior studies. Because of this it was decided to measure the concentration of asbestos fibers released during simulation of the cutting of ACP in order to ascertain the extent that workers can be said to have been exposed to asbestos fibers as a result of cutting pipe. This report includes, in addition, the results of a questionnaire survey of waterworks employees, done in order to learn of the existing conditions at the time of cutting ACP.

## II. Methodology

### 1. Measurement of Asbestos Concentration When ACP is Cut

To reproduce conditions of the cutting of ACP, a trench 1.2m deep was dug in a 1.5m$^2$ field within the grounds of a waterworks, a base (10 cm high) for the pipe was installed, and ACP (diameter, 100 and 150mm) was placed on that base, after which a skilled waterworks employee, wearing a face mask, used a high-speed disc cutter (made by the Meiho Co., dry cutter MDC-300E) to cut the pipe. Normal repair work calls for cutting the existing pipe on both sides of a rupture, after which a new ACP would be cut to the required length, inserted, and bonded to the existing pipe. In the present field experiment, since the only work done was to cut pipe, measurement of asbestos fiber was done while the pipe was cut two times (total, about 5 minutes).

A holder (Analytics) provided with a membrane filter (diameter 25mm, pore size, 0.8μm) for sampling the asbestos was affixed to the worker's collar (Fig. 1, No. 1), and a portable suction pump (by Shibata Kagaku Kikai, MP-2N) was used to collect asbestos dust at 1.0 liters/min. At the same time measurements were made at one point within the trench (about 1m from the worker, at a height of 0.8m; Fig. 1, No. 2) and outside the trench (at a distance of about 0.5m; Fig. 1, Nos. 3 and 4). For this latter sampling work, membrane filters (Toyo Filter Paper Co., diameter 47mm, pore size 0.8μm) were placed in holders and the suction pumps (No. 2: Yuasa Shokai AL-410); Nos. 3 and 4: Yuasa Shokai, D-50P), asbestos dust was collected at 1.0 liters/min at Nos. 2 and at 10 liters/minute at Nos. 3 and 4.

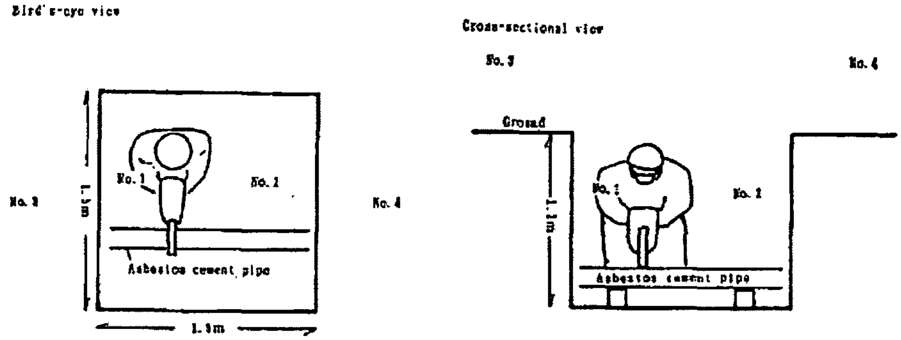


**Fig. 1. An illustration of the experimental setting for cutting an asbestos cement pipe set in a hole in the ground; a bird's-eye view and a cross-sectional view. No. 1 to No. 4 represent the sampling sites for asbestos. No. 1 and No. 2 are inside and No. 3 and No. 4 are outside the hole.**

The sampling was done using both dry pipe (diameter 150mm) and moist pipe (diameter 100mm) that had been steeped in water for two weeks so as to fully absorb water. This was done in consideration of the probability that moisture content of ACP to be repaired would vary according to the duration of time before repair or the degree of rupture. Further, although this was not being done at the time of actual work in the field, in order to study the effect that spraying water by use of a hose on the broken surface of ACP would have in suppressing the release of asbestos dust, sampling was done at the position assumed by the worker when doing the cutting. Additionally, in order to determine the background value of asbestos concentration, asbestos concentration was measured at a point 100m from the worker. The sampling method was the same as for No. 3 and sample intake was done for a period of 2 hours.

After the sampling, the filters were processed by use of a transparency solution (diethyl oxalate : diethyl phthalate = 1 : 1; phthalate dissolved at the rate of 0.05 g/ml) and using a phase-contrast microscope (Olympus BHB, 400x) the numbers of fibers with an aspect ratio of 3:1 or greater were counted. X-rays were used to confirm that the ACP contained chrysotile or crocidolite.

## 2. Questionnaire Results Concerning the Work of Cutting ACP

The cooperation of waterworks departments or bureaus of 119 local governments in 16 prefectures (for convenience, all referred to as "bureaus" below) was obtained for implementation of a questionnaire administered to male employees who are or were "workers belonging to the conduit repair section," the limitation to the repair section being made because those in other departments are believed to have had or presently have virtually no contact with ACP. Questionnaires were distributed to 1,408 male employees of water bureaus at 55 governments, and 1,138 completed forms were collected from them (rate of recovery, 80.8%), of which 423 responses conforming to the above criterion were selected for analysis. Because difficulties were encountered in distributing questionnaires to all bureau employees at the other 64 governments, distribution was limited to 776 men who were then working in pipe repair sections or had worked in such departments and completed forms were collected from 723 (rate of recovery, 93.2%) after which elimination of unusable responses yielded the forms completed by 625 men. Thus, two target groups were used but in both instances because the objective was the entire workforce it is considered that the selected respondents belong to a single sample population. As a result, the total 1,048 subjects are analyzed below as a single body. Questionnaire items were age, timing when hired by the water bureau, timing when assigned to the present or past section, timing and frequency of performance of ACP cutting work, conditions regarding use of aids protective against inhalation of dust when doing cutting, smoking history, and so on. The survey was done two times, in February and July, 1991.

### 3. Estimation of the Risk of Lung Cancer or Malignant Mesothelioma Induced by the Work of Cutting ACP

The risk of mortality from lung cancer or malignant mesothelioma to waterworks bureau workers who had been assigned to do ACP repairs was estimated using the exposure conditions obtained by the present study, models of the OSHA of the United States,[9,10] and the model developed by Hughes.[11] For the lung cancer mortality rate in the absence of asbestos exposure, use was made of Japanese national lung cancer mortality data for men by age bracket (1990, by esophageal cancer, bronchial cancer and lung cancer, stratification by 5-year brackets)[12] and for the survivors for each age, the simplified life tables for Japanese males (1990)[12] were used. Further, calculations of the incremental number of deaths for each age were made and the total from the age at which exposure began to age 75 was taken as the lifelong mortality risk.

**Table 1. Asbestos concentrations measured while cutting asbestos cement pipes (ACPs) using a high-speed disk cutter.**

| Sampling site | | Asbestos concentration (fibers/ml) | | |
|---|---|---|---|---|
| | | 1st trial* | 2nd trial* | 3rd trial* |
| No. 1 | Breathing zone | 60 | 48 | 63 |
| No. 2 | Inside the hole | 91 | 170 | — |
| No. 3 | Outside the hole | 1.7 | 8.5 | — |
| No. 4 | Outside the hole | 6.6 | 15 | — |
| No. 5 | Background | 0.00052 | | |

* ACPs used in the experiments were dry for the 1st trial and wet for the 2nd and 3rd trial. Water was sprinkled during the cutting in the 3rd trial.

## III. Results

### 1. Asbestos Concentration When Cutting ACP

The results of measurement of asbestos concentrations are shown in Table 1. When pipe cutting is was begun, the area where the worker was standing became white owing to the dust from the cutting and the exhaust gas from the engine of the high-speed disc cutter, and the white area gradually expanded until it covered the entire bottom of the trench. Asbestos concentration at the inhalation position of the worker (No. 1) was 60 fibers/ml when cutting dry pipe and 48 fibers/ml when cutting moist pipe; although the latter figure is somewhat lower than the first, the difference is not great but in both instances the values are high. Further, concentrations at the point about one meter from the worker (No. 2) in the trench were even higher, at 91 and 170 fibers/ml. It is thought that this is because outdoor air currents caused dust from the place where the pipe was being cut to drift to the No. 2 position, and that depending on the direction of the wind the concentration at the place where the worker is could reach the same level as at the No. 2 position. Comparison of values obtained when the dry pipe and the moist pipe was inconclusive; at the place where the worker was the value of the former was somewhat higher, but at No. 2 the value for the latter was twice as high as that of the former. The average value for concentration of asbestos in the trench was 92 fibers/ml, and assuming that during times when there was no pipe cutting there was no exposure to asbestos, the weighted 8-hour average concentration (8-h TWA) was calculated at 0.96 fiber/ml.

Outside the trench (Nos. 3, 4) the concentration of asbestos was from 1.7 to 15 fibers/ml or from 1/3 to 1/100 or so of the value in the trench. Even so, this value was 10,000 times the background value (0.00052 fibers/ml), indicating that the asbestos dust generated by cutting the ACP had spread to the peripheral area.

When the cutting was done while water was sprayed from a hose the asbestos concentration was 63 fibers/ml, that indicates that wetting did not have the effect of reducing the dispersion of fiber particles.

### 2. Questionnaire Results

The occupational history of the subjects was as shown in Table 2. The average age is 42.4 years and average duration of waterworks employment 20.1 years. Present assignments are: repair sections, 54.7%; water purification departments, 13.9%; administration and technical, 31.3%, and the average duration spent in the repair sections is 12.9 years. Among the subjects 849 or 81.0% of the total have had experience cutting ACP (they are called "ACP cutters" below). Their average age is 43.4 years and average duration of employment 21.4 years; the average duration they spent in the repair section was 14.2 years.

The number of persons studied who had been assigned to pipe or conduit repair, and the number who had been done pipe cutting while so assigned, are shown in Table 3. The ratios of subjects in repair sections to the total subjects in 1976-85 and 1986 onward were 74.2% and 70.0% respectively, followed by 58.3% for 1966-75, when the ratio was above 50%, whereas for 1946-55 and an56-65 the ratios were lower, at 2.6% and 27.6% respectively. The ratio of subjects who performed ACP cutting while in repair sections in each 10-year period was highest in 1966-75, at 79.4%, followed by 1976-85 and 1956-65 with nearly equal ratios of 71.9% and 70.9% respectively. After 1986, 56.4% had been ACP cutters, showing that even recently there has been ACP cutting work performed. Further, the number of days in a year when ACP cutting was done, by decade, can be seen in Fig. 2. In every 10-year period, 1-10 days is the highest frequency, followed by 11-25 days, from which the overall frequency of such work was not high, and only a very small number of subjects had done such work more than 101 days in a year. Concerning frequencies of cutting work for each 10-year period, the ratio of subjects who did 26 days or more of cutting work in a year is highest in 1956-65, and declines after that.

Table 2. Occupational history of the subjects.

| | All subjects | | Subjects with experience of cutting ACPs* | |
|---|---|---|---|---|
| Number | 1,048 | | 849 | |
| | mean | SD | mean | SD |
| Age | 42.4 | 9.1 | 43.4 | 8.7 |
| Length of service in years at | | | | |
| Waterworks Bureau | 20.1 | 9.5 | 21.4 | 8.8 |
| Conduit Repair Section | 12.9 | 9.4 | 14.2 | 9.3 |
| Present assignment | Number | (%) | Number | (%) |
| Conduit Repair | 573 | (54.7) | 481 | (56.7) |
| Water Purification | 146 | (13.9) | 113 | (13.3) |
| Office or Technical Work | 329 | (31.3) | 255 | (30.0) |

* Asbestos cement pipes.

Table 3. Number of subjects belonging to the Conduit Repair Section and number of the persons cutting ACPs*1 for each decade from 1946 through 1991.

| Year | Number of the subjects belonging to the Conduit Repair Section | Number of the subjects cutting ACPs*1 |
|---|---|---|
| 1946-55 | 27 ( 2.6*2) | 12 (44.4*3) |
| 1956-65 | 289 (27.6*2) | 205 (70.9*3) |
| 1966-75 | 611 (58.3*2) | 485 (79.4*3) |
| 1976-85 | 778 (74.2*2) | 559 (71.9*3) |
| 1986-91 | 734 (70.0*2) | 414 (56.4*3) |

*1 Asbestos cement pipes. *2 Proportion to all subjects (1,048). *3 Proportion to the subjects belonging to the Conduit Repair Section.

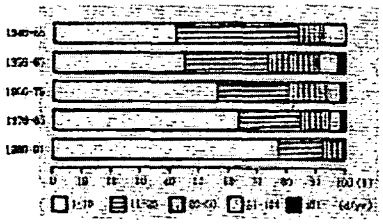

Fig. 2. Distribution of the average d/yr when the subjects were engaged in cutting asbestos cement pipes by 10-yr interval from 1946 through 1991.

The cumulative numbers of days when pipes were cut, up to the time of the survey, are shown in Fig. 3. Calculation of these numbers was done by the following method. Frequency was tabulated on an annual basis for each 10-year period in steps of 1-10 days, 11-25 days, 25-50 days, 51-100 days, and 101 or more days, and each of these is represented as being 6, 18, 38, 76, and 150 days respectively from which the cumulative number of days from the initial time when pipe cutting was done was calculated. Subjects having cumulative days of 1-100 are the most numerous, at 46.8%, followed by 101-200, at 23.2%, and the average was 235 days. Because the average period spent in the repair section was 14.2 years, in average terms ACP cutting work was performed about 17 days per year per subject. If the above calculation is modified by using for the periods 1-10 days, 11-25 days, 25-50 days, 51-100 days, and 101 or more days the values of 1, 1, 26, 51 and 101 days, the annual average for ACP cutting work was 9 days, and if the values of 10, 25, 50, 100 and 200 days are used, the average is 23 days. These are the minimum and maximum assumed values for average work days.

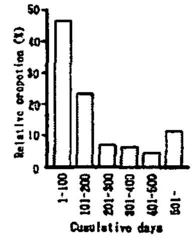


Fig. 3. Cumulative days to date when the subjects were engaged in cutting asbestos cement pipes.

Table 4. Estimated life-time risk (death per 100,000 persons) among the workers cutting ACPs under the models proposed by OSHA[9,10] and Hughes.[11] The values of lung cancer and mesothelioma represent excess death rate from asbestos exposure.

| Model | Frequency of cutting ACP (d/yr) | Lung cancer | Mesothelioma | Total |
|---|---|---|---|---|
| OSHA | 9 | 16 | 16 | 32 |
| | 17 | 30 | 30 | 60 |
| | 23 | 41 | 40 | 81 |
| Hughes | 9 | 9 | 15 | 24 |
| | 17 | 15 | 28 | 43 |
| | 23 | 21 | 37 | 58 |

Lung cancer : $R_L = R_E \times K_L \times F \times D_L$···Eq.(1), where $R_L$ : excess death rate of lung cancer caused by asbestos exposure, $R_B$ : expected death rate of lung cancer based on the Japanese male age-specific lung cancer death rates in 1990, $K_L$ : constant (0.01 in OSHA's model, 0.005 in Hughes' model), $F$ : exposure level in fibers/ml, $D_L$ : exposure duration in years (at 10 years before observation point in OSHA's model and at observation point in Hughes' model). Mesothelioma : For $(T-10) \geq D$, $R_M = K_M \times F \times \{(T-10)^n - (T-10-D)^n\}$, for $D > (T-10) \geq 0$, $R_M = K_M \times F \times (T-10)^n$, and for $0 > (T-10)$, $R_M = 0$···Eq.(2), where $R_M$ : excess death rate of mesothelioma caused by asbestos exposure, $K_M$ : constant ($1 \times 10^{-8}$ in OSHA's model, $0.2 \times 10^{-8}$ in Hughes' model), $F$ : exposure level in fibers/ml, $T$ : time after first exposure in years (used $T$ instead of $(T-10)$ in Eq.(2) in Hughes' model), $D$ : exposure duration in years, $n$ : power (3.0 in OSHA's model, 3.2 in Hughes' model). Calculations were done for each age until the age of 75 yr by life table method, and then summed to obtain total life-time risk.

At present 18.1% of subjects who do cutting work use dust masks (national certification masks) and almost all of these subjects replied that they had begun wearing a mask within 5 years. There are, in addition, subjects who utilize gauze masks or towels but they are few in number, at 5.1% and 17.1%. The remaining 59.7% adopt no protective measures. With regard to smoking, in the ACP cutting group the ratios of those who presently smoke and those who previously were smokers, and non-smokers, was 66.7%, 20.5%, and 12.7%.

### 3. Lifetime Risk of Lung Cancer or Malignant Mesothelioma Attributable to Cutting ACP

The conditions of exposure, used as assumptions for estimating risk, are based on the field experiment and questionnaire results and are as follows. Because the average age of subjects is 43 years and average period of waterworks bureau employment 21 years, the start of waterworks employment was taken as 1970 at the age of 22 years. The concentration of asbestos subjects were exposed to when cutting ACP was taken as 1 fiber/ml under 8-h TWA, and the annual average number of days worked while in the repair sections (average, 14 years) was 17 (minimum, 9; maximum, 23). The period when subjects were assigned to repair sections was normalized as 1970-91. Inasmuch as future exposure to asbestos cannot be determined at this time asbestos exposure is taken as that extending up the present time.

On the basis of the above assumptions, the life-time risk up to age 75 of contracting lung cancer or malignant mesothelioma as a result of cutting ACP was estimated with results as shown in Table 4. The estimated value for the excess death rate from lung cancer, with annual average work days at 17, is 30 persons using the OSHA model (per 100,000 persons) and 15 persons using the Hughes model (per 100,000 persons). If the days of work is taken to be the low number, 9 days, the results are 16 persons and 9 persons, and if the high number of work days, 23, is used the values are 41 and 21. The estimated value for the excess death rate from malignant mesothelioma, using 17 days as the annual average work days, is 30 persons (per 100,000) with the OSHA model and 28 persons (per 100,000) using the Hughes model; yielding similar values for the two. If the days of work is taken to be the low number, 9 days, the results are 16 persons and 15 persons, and if the high number of work days, 23, is used the values are 40 and 37. As the result, the total excess death rates from lung cancer and malignant mesothelioma in the sequence of 9, 17, and 23 days of annual work, are 32, 60 and 81 persons using the OSHA model and 24, 43 and 58 using the Hughes model.

## IV. Observations

### 1. Exposure to Asbestos When Cutting ACP

ACP has been made with diameters from 50 to 1,500mm,[2] and pipe which has had frequent need of repair is 50-200mm in diameter.[13-15] For this study, 100mm and 150mm pipe was used. The depth at which pipe is laid varies according to the relevant situation, but pipe of 350mm or less is buried at about one meter from the surface.[16] For cutting to be done it is necessary to completely expose the pipe, requiring earth to be removed from under the pipe, slightly deepening the immediate area. Since in the present experiment the trench was excavated to a depth of 1.2 meters and a base of about 10cm height was installed, it is believed that conditions approximated actuality. In the experiment both dry pipe and moist pipe were cut, and in both cases the asbestos concentration in the trench was high, from 48 to 170 fibers/ml, and no difference based on the pipe being dry or moist was observed. Further, no effect was observed of sprinkling water on the surface being cut. The high-speed disc cutter is a tool that uses a disc blade of about 5mm thickness, to cut ACP. This causes scattering of fine dust particles at a high velocity during the cutting of pipe, and it is thought that such dispersion is not influenced by the pipe being moist or sprinkling with water. It is also thought that although the cutting is performed out of doors it is performed in a narrow trench, slowing the decline of concentration through dispersion and creating a high concentration at the work site.

OSHA[10] has undertaken a number of studies on measures to control dust particles resulting from asbestos-related work, and has indicated that there was a possibility of a high concentration when cutting ACP. No papers have been published in Japan on cutting of ACP but there has been a report dealing with use of an electric drill on calcium silicate asbestos-cement board used as outdoors building material. Calcium silicate asbestos cement board is made by combining coal or cement, calcium silicate etc. with about 20% asbestos (chrysotile, or amosite) with water, formed into sheets, cured and dried; the content of asbestos as well as method of manufacture is close to the content and method for ACP.[17] As electric saws use rotary blades to cut, it is thought that the particles released are coarser than those from a high-speed disc cutter, that cuts by grinding but the work itself is about the same in both cases. According to Kimura,[18] the concentration of asbestos to which a worker is exposed when no suction device is used during work is 147-393 fibers/ml, and Hisanaga et al[19] have reported 103-787 fibers/ml for the same work. Values obtained for this study were somewhat lower than these but Kimura and Hisanaga et al collected data indoors whereas in the present instance work was done outside.

According to the results of the questionnaire, only 18.1% of the workers were users of face masks. There were some others who used gauze masks or towels but they were not many. Therefore, most workers cut ACP without use of protective masks and in the absence of protective devices are exposed to asbestos particles.

A Japan Association of Industrial Health advisory gives 10 fibers/ml as the standard for 15-minute average exposure to asbestos dust (ceiling value). If values obtained by measurements in the trench are adjusted to a 15-minute base the result is 16-57 fibers/ml; the entire range exceeds the advisory's limit. Further, as stated in the conclusions above, conversion to 8-h TWA yields the average 0.96 fiber/ml. This assumes that there is no exposure to asbestos other than when cutting pipe, but if exposure to asbestos subsequent to the cutting is taken into consideration, it is thought that the actual exposure is higher than the measured value. To be sure, the present study included a simulation of actual work and it is possible that a different dispersion of fibers would result when ACP that has been in use for many years is cut. Also, although it cannot be denied that because of the limited number of data points collected the average for asbestos exposure concentration on the day the pipe was cut may have a wide margin of error, but nevertheless is considered to represent the degree of exposure. The value of 0.96 fiber/ml in the case of 8-h TWA is 4.8 times greater than the allowable concentration of crocidolite as recommended by the Japan Association of Industrial Health. In addition, it is about half in comparison to the allowable level of chrysotile (0.25 fiber/ml), but exceeds the acceptable levels in the United States and Europe: for the United States (0.2 fiber/ml), Germany (0.5 fiber/ml) and Britain and Sweden (0.5 fiber/ml).

As stated at the outset, ACP has been in use in Japan as water conduits since 1951. That year 110,000 pipes were produced; output increased to 1,460,000 in 1955 and further to 3,340,000 in 1965 (personal communication from the Japan Water Works Association). Production then declined, but continued through 1985. Therefore, it can be concluded that the total length of ACP continued to increase after 1965. Estimating on the basis of the production volumes and the length of ACP that was removed, it is believed that the total length reached a peak in or about 1975 and fell thereafter. In this connection, information about the total length of ACP in Japan is available only from 1979 onward; in 1980 it was 86,806km, of 25.8% of the total conduit length, and in 1989 was 70,759km or 16.2% of the total.[1] The first subject responding to the questionnaire to start at a waterworks bureau began in 1946 but the average is 1970. Therefore it is thought that if we examine the work experience of the questionnaire subjects, in cutting ACP, by each 10-year interval, we will be able to trace the change in actual work conditions. However, because of the small number of persons who were working in a conduit repair department in 1946-55, it is possible that results for this period will not accurately reflect reality.

The ratio of workers who did ACP cutting in the conduit repair departments in 1946-55 was the lowest, 44.4%, and subsequently the ratio increased so that in each of the 1956-65, 1966-75 and 1976-85 periods it was above 70%, corresponding to the increase over time of ACP production and total ACP installed length as can be surmise from production data. The highest ratio was 79.4% for 1966-75; this was the period during which use of ACP peaked, and also was the time when road traffic increased rapidly, causing breakage of many ACP. Until that time, cutting was done using hand saws, but about in 1965 high-speed disc cutters became available. Although the ratio of workers engaged in cutting operations diminished after 1986, this is thought to represent an effect of the ending of ACP production and he consequent decline in the total length of such pipe in place. Nevertheless, since 1986, 56.4% of persons in conduit repair departments have cut ACP, and given the low rate of use of protective masks it is presumed that their exposure to asbestos has continue to take place.

A variety of tasks are undertaken by repair workers. In addition to ACP, conduits are made of cast iron, ductile iron, steel, PVC and lead and workers must deal with repairs of all such pipe. They replace hydrants and home water meters, and patrol for prevention of mishaps. Local governments contract for some of the conduit repair work to be done by outside parties. According to findings of the present study, the highest frequency of undertaking AP cutting, in every 10-year period, was in the 1-10 days a year category (Fig. 2), and it is estimated that the average annual days per subject is 17. Therefore, this is not to imply that cutting ACP is the major task of the repair departments. However, many epidemiological studies reported to date recognize a causal relationship between asbestos and lung cancer, malignant mesothelioma and other diseases.[3,4, 22] There is the thought that carcinogens have no threshold values,; in actuality five cases have been reported of the occurrence of malignant mesothelioma among residents who have not been exposed on the job in the vicinity of crocidolite mines or asbestos plants.[3] If these points are kept in mind and consideration is given to the short time but high exposure to asbestos, need does exist to adopt measures to reduce asbestos exposure. The fundamental measure adopted is to replace ACP with ductile iron or other pipe. One method is to leave the old ACP in the ground, and lay new conduit; this is being implemented by local governments as a measure for replacement of superannuated conduit, but it would be desirable to provide additional incentive for this by increasing Ministry of Health subsidies for such work, or expanding the scope of qualified subsidy recipients. It is further necessary, since total avoidance of cutting ACP is not possible, to develop new methods of cutting ACP so as not to scatter asbestos fibers, and to prepare safety manuals to prevent asbestos exposure through the use of protective masks. The latent period of lung cancer and malignant mesothelioma caused by asbestos exposure is long and symptoms often appear when the diseased person's memory concerning asbestos exposure is not sharp. It is therefore thought to be important to keep records of the dates, worker names, nature of work performed, conditions of exposure, and so on in relation to ACP cutting tasks.

**2. Estimation of Lifetime Death Risk from Lung Cancer and Malignant Mesothelioma Induced by ACP Cutting Work**

Here, a linear model as indicated by equation (1) (in Table 4) was used to estimate the excess death rate from lung cancer. This model is supported by epidemiological studies of asbestos manufacturing plants,[23] spinning mills,[24] asbestos mines and other situations and has been used to estimate excess death rates by OSHA, [9,10] the Environmental Protection Agency (EPA, US),[26] WHO,[27] Consumer Product Safety Commission (CPSC, US),[28] the Health and Safety Executive (HSE, England),[29,30] National Research Council (NRC, US)[30] and others. However, the coefficient $K_L$ in equation (1) varies greatly according to the work process and type of asbestos; the eight epidemiological studies cited by OSHA shows a two-place difference, from 0.0006 to 0.048.[10] OSHA, judging from the results of chrysotile studies and eight studies regarding amphibolic asbestos (crocidolite and amosite) uses $K_L$=0.01.[10] In view of the use of chrysotile and crocidolite for manufacture of ACP, it was judged appropriate to use the OSHA model for estimation of the risk of ACP cutting. Further, as the Hughes method utilizes as the $K_L$ value 0.005, the average gained from several asbestos plant studies,[23,32] this too was selected for use.[11] It is thought that there is a multiplier effect of asbestos exposure and smoking as causes of lung cancer,[33] making it necessary to consider the smoker ratio among the population whose excess death rate from lung cancer is to be estimated. According to the questionnaire results, the smoker ratio among the subjects who have cut ACP is 66.7%, which is not greatly different from the national average (60.5%, 1990).[34] Therefore it is thought that there is no impediment to using the Japanese mortality rate due to smoking for estimation of excess deaths.

Estimation of the excess death rate attributable to malignant mesothelioma was by use of an exponential model as indicated by equation (2) (in Table 4). This model assumes that risk increases linearly according to the extent of asbestos exposure. While adequate proof of this is not available, in epidemiological studies at gasmask factory in England[35] and at a crocidolite mine in West Australia[36] there are indications that risk increases in accordance with prolongation of the exposure period or increase in the extent of exposure. This model assumes that risk increases in parallel to the exponent of elapsed years since initial exposure. This has been observed[11,28] among American and Canadian workers handling insulation materials,[22] production workers at an Ontario asbestos plant,[37] and a British spinning machine operator.[38] The observation period of these studies, moreover, was about 40 years long and although it is not known that risk continued to increase beyond those periods, these studies have been utilized by the WHO and the above-mentioned institutions for estimation of excess death rates due to malignant mesothelioma by use of a model. Epidemiological study has found that differences in the type of asbestos, specifically, a group of subjects that had been exposed to amphibolic asbestos had a higher mortality rate from malignant mesothelioma than a group of subjects who had been exposed to chrysotile,[3] and OSHA derived the coefficient $K_M$=0.2x10$^{-8}$ on the basis of risk estimation using results of studies on both chrysotile and amphibolic asbestos.[9,10] Hughes et al have proposed $K_M$=0.04x10$^{-8}$ in case of exposure solely to chrysotile and $K_M$=0.2x10$^{-8}$ in the case of combined exposure; for the present study, the $K_M$ for combined exposure was used. Further, in both the Hughes model and the OSHA model the indexes were different, at 3.0 and 3.2.

Reflecting the differences between the two models, the estimate of lifetime excess deaths from lung cancer and malignant mesothelioma combined, in the case of 17 work days a year, is 60 persons with the OSHA model and somewhat less, 43, with the Hughes model. These values are only approximations, on which basis they can be said to be equivalent. It is necessary, further, to clearly state that, as has been mentioned by the WHO[3], estimated risk values, such as obtained by the present study, are very rough numbers, that represent a wide range of actual values. For the present study it was assume that there was no asbestos exposure other than at the time of cutting pipe, but it is thought that there is additional exposure to asbestos particles that remain in the trench after the pipe has been cut and when new pipe is attached to the existing one. Further, the annual number of 17 days of work represents cutting done by the subject but not that done by coworkers at the same work site; indirect exposure at such times has not been taken into consideration. From these points it can be said that our values are underestimations. Furthermore, some use of hand saws continued after the high-speed disc cutter became available (about 1965) and it is thought that there was less exposure to asbestos particles in the case of the hand saw as compared to the cutter. This would tend to raise the value obtained by the study.

Iwai et al[22] have estimated the lifetime excess mortality in Japan from lung cancer and malignant mesothelioma, caused by asbestos in the atmosphere (0.0004 to 0.002 fibers/ml), combined, at 1.6 to 8.2 persons (per 100,000), using a model similar to that of the OSHA ($K_L$=0.01, $K_M$=1.9x10$^{-8}$ and $T$ instead of $T$-10 in equation (2), and with risk at 4.2 times after adjusting for exposure at day and night times and on vacation days. Compared to this value range, the level of risk of conduit repair workers that were subjects of this study of pipe cutting is 3 to 50 times greater, indicating that this special group faced higher risk than the general population. Yokoyama et al[40] have reported on the occurrence of malignant mesothelioma in waterworks employees who have installed ACP over a period of years, and this possibility too is well within the range of probability judging from the risk estimation of the present study.

**V. Conclusion**

In order to clarify the actual conditions of the work of cutting ACP, a field experiment was made in order to measure the asbestos exposure concentration when pipe was cut, and a questionnaire survey of waterworks employees who have repair work experience was carried out. The information thereby gathered was used for iterations of the OSHA model and the Hughes model to estimate risk associated with lung cancer and malignant mesothelioma attributed to exposure to asbestos. As a result we have learned the following.

1) When ACP is cut the asbestos exposure concentration is extremely high, at 48 to 170 fibers/ml. Moreover, only 18.1% of workers used protective masks when performing this work.

2) The ratio of employees who undertook pipe cutting work in the conduit repair sections was highest in

1966-75, at 79.4%, followed by 1976-85 when the ratio was 71.9% and 1956-65 when it was 70.9%. Further, during all the 10-year periods the greatest frequency rating was 1-10 days a year, and the average was 17 days.

3) The result of estimation of the lifetime risk, up to 75 years of age, attributable to asbestos exposure at the time from when the pipe was first cut to the present, in the case of 17 days a year of cutting work, was that the estimated excess mortality from exposure to asbestos was found to be 60 persons (per 100,000, OSHA model) and 43 persons (per 100,000, Hughes model).

**References**

*(Translator's note: Family names of Japanese: capitals; asterisks indicate documents in Japanese. Minimal changes to the references have been made. Japanese academics are less disciplined in citations than are Americans. The spelling of given names in particular is often moot and may need clarification by the individual concerned. Most proper nouns given in Japanese have been translated without attempting verification, in most cases, but there is enough information to track down the Japanese originals if necessary.)*


1) Ministry of Health and Welfare, Environmental Health Bureau, Waterworks Environment Department, Waterworks Improvement Section (supervision). *Annual Waterworks Statistics* for 1979 to 1989, Facilities and Administration sections. Tokyo: Japan Waterworks Assoc., 1981-1991.*

2) USHIMARU Kenji. *Asbestos Cement Pipe.* Japan Waterworks Assoc., 1977: 46 (5), p. 156-163.*

3) World Health Organization. *Asbestos and other natural mineral fibers.* 1986.

4) Environmental Protection Agency, Atmosphere Protection Bureau, Planning Section (supervision). Everything about asbestos cement. Kawasaki: Japan Environmental Hygiene Center, 1987.*

5) EBIHARA Isamu, A clinical case of malignant mesothelioma among asbestos workers. *J. Japanese Soc. of Internal Med.* 1986: 75, p. 400-405.*

6) SAITO Katsumi, TAKIZAWA Yukio, HIRANO Koichiro, Concentration of asbestos fibers and their form, in water conveyed by asbestos cement conduit. *Jpn. J. Hyg.* 1992: 47, p. 851-860.*

7) Japan Waterworks Assoc. *History of Waterworks in Japan*, Overview section. 1967: p. 665-667, 724-725.*

8) All Japan Local Government Workers Union. *Fifteenth Union Waterworks Conference, Report and Agenda.* 1992.*

9) Occupational Safety and Health Administration (US). *Quantitative risk assessment for asbestos related cancers.* 1983

10) Occupational Safety and Health Administration (US). Quantitative exposure to asbestos, tremolite, anthophylite and actinolite. *Federal Register* 1986; 51: 22612-2790.

11) Hughes, JM, Weill H. Asbestos exposure quantitative assessment of risk. *Am Rev Respir Dis* 1986; 133: 5-13.

12) Hygiene Statistics Assoc. *Hygiene indicators and trends of national hygiene.* 1991: 38 (9), p. 425; 1992:39 (9), p. 427.*

13) ISHIDA Saburo. Maintenance management of conduits. *J. Jpn Waterworks Assoc.* 1977: 46 (5), p. 52-59.*

14) HOSOI, Yuhiko, MURAKAMI Jinji, KOZAI Masao, MARUTAKA Shigemiki. Observations on Rupture Characteristics of Water Conduit. *J. Jpn Waterworks Assoc.* 1989: 58 (5), p. 10-16.*

15) HOSO Yuhiko, MURAKAMI Jinji, KOZAI Masao et al. Study on rupture characteristics of water conduit in the Tokushima City water supply system. *J. Jpn Waterworks Assoc.* 1988: 57 (8), p. 2-11.*

16) OHASHI Fumio, KUBO Takeo, MATSUMOTO Junichiro, et al (ed.). *Hygiene Engineering Handbook.* Tokyo: Asakura Shoten, 1967, p. 177.*

17) Japan Standards Association. JIS A5418 (1983) Calcium silicate asbestos cement sheets. *JIS Handbook*, Construction: 1989, p. 1081-1085.*

18) KIMURA Kikuji. Asbestos and Environmental Issues. *Science of Labor*, 1987, 42 (12), p. 4-13.*

19) HISANAGA Naomi and SAKAI Kiyoshi. Three-way management dealing with asbestos, particularly concerning environmental management and work management, in the construction industry. Science of Labor, 1988 (29 (8), p. 26-30.*

20) Japan Association of Industrial Health. Report on allowable concentrations. *Industrial Health* 1991: 33, p. 277-298.*

21) Japan Asbestos Association. Asbestos regulations in other countries. *Sekimen* 1991: 542, p. 1-9.*
22) Selikoff IJ, Hammond EC, Seidman H. Mortality experience of insulation workers in the United States and Canada, 1943-1976. *Ann NY Acad Sci* 1979; 330: 91-116.
23) Henderson VL, Enterline PE. Asbestos exposure: factors associated with excess cancer and respiratory disease mortality. *Ann NY Acad Sci* 1979; 330: 117-126.
24) Dement JM, Harris RL, Symons MJ. Estimates of dose-response for respiratory cancer among chrysotile asbestos textile workers. *Ann Occup Hyg* 1982; 26: p. 869-887.
25) Liddel FD, McDonald JC, Thomas DC. Methods of cohort analysis: appraisal by application to asbestos mining. *J Royal Stat Soc Assoc* 1977; 140: 4, p. 69-491.
26) Environmental Protection Agency (US). *Asbestos health assessment updata.* Prepared by Nicholson W. Washington DC: US Environmental Protection Agency, 1984.
27) World Health Organization. *Limits of occupational exposure to asbestos – Report for the WHO conference.* Tokyo: Japan Asbestos Association, 1990.*
28) Consumer Product Safety Commission (US). *Report of the chronic hazard advisory panel on asbestos.* Washington DC, 1983.
29) Health and Safety Executive (UK). *Asbestos: the control limit for asbestos.* Prepared by Acheson AD, Gardner MJ. London: Health and Safety Commission, HMSO, 1979.
30) Health and Safety Executive (UK). *Asbestos: the control limit for asbestos. An updata of the ralevant sections of the ill effects of asbestos upon health.* Prepared by Acheson AD, Gardner MJ. London: Health and Safety Commission, HMSO, 1983.
31) National Research Council (US), Committee on Nonoccupational Health Risks. *Asbestiform fibers-nonoccupational health risks.* Washington DC: National Academy Press, 1984.
32) Weill H, Hughes J, Waggenspack C. Influence of dose and fiber type on respiratory malignancy risk in asbestos cement manufacturing. *Am Rev Respir Dis* 1979; 120: 345-354.
33) Hammond EC, Selikoff IJ, Seidman H. Asbestos exposure, cigarette smoking and death rates. *Ann NY Acad Sci* 1979; 330: p. 473-490.
34) Hygiene Statistics Association. *Hygiene Indicators. Trend of National Hygiene.* 1991: 38 (9), p. 97, 396.*
35) Jones JSP, Smith PG, Pooley FD, et al. The consequences of exposure to asbestos dust in a war-time gas mask factory. *IARC Sci Publ* 1980; 30: p. 637-653.
36) Hobbs MST, Woodward SD, Murphy B, et al. The incidence of pneumoconiosis, mesothelioma and other respiratory cancer in men engaged in mining and milling crocidolite in Western Australia. *IARC Sci Publ* 1980; 30: p. 615-625.
37) Finkelstein MM. Mortality among long-term employees of an Ontario asbestos cement factory. *Br J Ind Med* 1983; 40: p. 138-144.
38) Peto J. The incidence of pleural mesothelioma in chrysotile asbestos textile workers. In: Biological effects of mineral fibres. Lyon: IARC, 1980: p. 703 (*IARC Scientific Publications* No. 30).
39) IWAI Kazuro, HOSODA Yutaka, YOKOYAMA Kunihiko et al. Extent of asbestos exposure and its relation to the rate of occurrence of malignant mesothelioma and the extent-reaction relationship. Analysis of causes of data dispersion and calculation of risk posed by asbestos fibers in the general atmosphere. J. Atmospheric Pollution Soc. 1990: 25, p. 181-191.*
40) YOKOYAMA Kunihioko, SAKATANI Mitsunori, YAMAMOTO Akira. Clinical diagnosis of asbestos related disease. *Byori to Rinsho*, 1989: 7, p. 695-701.*

***Reprint requests to*** **Department of Occupational Health, Osaka Prefectural Institute of Public Health 1-3-69, Nakamichi, Higashinari-ku, Osaka, 537 Japan (S. Kumagai)**