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DEMOLITION

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Asbestos Exposure During Renovation and Demolition of Asbestos-Cement Clad Buildings

STEPHEN K. BROWN
CSIRO Division of Building Research, P.O. Box 56, Highett, Victoria 3190, Australia

External asbestos cement (AC) claddings become weathered after many years by the gradual loss of cement from exposed surfaces; as a result, loosely bound layers enriched with asbestos fibers are formed. This effect usually appears pronounced with roof cladding but slight with wall cladding. Asbestos fibers on such weathered surfaces may be mixtures of chrysotile with amosite or crocidolite. Renovation and demolition of old AC clad buildings could cause asbestos fiber emission, but this has not been investigated in the past. The exposure of workers to asbestos dust during these operations and precautions to minimize exposure now have been investigated at several building sites. Asbestos dust concentrations during water jet cleaning or painting of weathered AC roofing were approximately 0.1 to 0.2 fibers per milliliter (f/mL). Limited results suggest that concentrations may be reduced substantially by avoiding abrasion of surfaces. Concentrations during AC roof replacement averaged approximately 0.1 f/mL and were reduced markedly by employing more careful work procedures (*e.g.*, by careful handling of sheets or by wet stacking of sheets). Asbestos dust concentrations during demolition by removal of whole sheets averaged 0.3 to 0.6 f/mL for roofs and less than 0.1 f/mL for walls, reflecting the significant differences in extent of weathering between these elements. Suppression of asbestos emissions from roof sheets by wetting or sealing of weathered surfaces was not predictable because of the occurrence of asbestos fibers in dust trapped under sheet laps. Precautions such as respiratory protection and clothing decontamination are considered to be essential for the demolition of roofing containing amosite or crocidolite by the procedures investigated.

Introduction

Inhalation of asbestos fibers has been established as leading to specific physical disorders in workers — notably asbestosis, lung cancer and mesothelioma. Accordingly, regulations have been laid down with the aim of reducing and controlling worker exposure to asbestos dust to below specific exposure guides (hygiene standards). Also, Codes of Practice have been developed for work with asbestos products to minimize asbestos emissions and to specify worker protection where appropriate.

Work with new asbestos cement (AC) products normally does not lead to unacceptable exposure to asbestos dust unless the products are cut, machined or abraded; such work operations should be carried out with guidance from accepted Codes of Practice.[1] It is usually considered that negligible asbestos concentrations evolve from typical handling of AC products because the asbestos is bound securely into a cement matrix. The AC products that are exposed to weathering for long periods, however, undergo surface degradation involving the loss of cement and the laying bare of asbestos fibers. This degradation may be significant for various work operations associated with AC clad buildings — particularly where the products contain crocidolite or amosite for which low hygiene standards are operative.

The effect of weathering has been recognized in the United Kingdom with the Department of the Environment[2] noting that demolition and removal of old AC products could fall within asbestos regulations and have to be carried out by licensed asbestos removal professionals. Also, in recent years, such work in Australia often has been carried out using many of the precautions employed for removal of asbestos insulation, an operation that is well established as being hazardous and associated with asbestos concentrations grossly exceeding hygiene standards unless stringent work precautions are maintained. The asbestos concentrations evolved during removal and demolition of old AC products, however, do not appear to have been investigated to adequately provide a rational basis for decisions on precautionary measures. This study aims to provide such information by examining and analyzing weathered AC surfaces, by determining the exposure of workers to asbestos dust during typical work operations with weathered AC products, and by investigating methods of suppressing asbestos emissions.

Background

Asbestos cement sheeting has been manufactured since 1900 when the first patents were granted,[3] and it has been used extensively in Australia as roof and wall cladding until recently with the emergence of asbestos-free products. Asbestos cement claddings used mainly chrysotile asbestos plus lesser quantities of amosite or crocidolite (old claddings) to improve processability and product strength.[4]

It was noted many years ago that a thin layer of asbestos fibers becomes exposed with weathering on the surfaces of AC roofing, although this has little effect on mechanical properties.[3] A more recent study described a "fleece" of fibers being laid bare on AC surfaces after natural weathering for 8 to 12 years or after artificial weathering with water jets.[5] Another study found that a proportion of exposed chrysotile fibers had undergone degradation by surface reactions associated with their high affinity for calcium hydroxide and cement hydration products.[6] Little is known of the behavior of amphibole fibers during weathering. Amphibole fibers, however, do not form good bonds with cement particles[4] and are more chemically resistant than chrysotile and might be expected to be more readily laid bare on weathered surfaces.

It has been shown that asbestos fibers can be emitted from the weathered surfaces of AC claddings under the action of environmental forces, although only at very small ambient concentrations typical of those encountered in industrial cities.[7-9] Asbestos concentrations during cutting or machining of weathered claddings are likely to be similar to those encountered with new products, generally exceeding hygiene standard concentrations unless precautions are taken.[7,10,11] Other work operations, however, now are encountered with weathered AC claddings and little is known of asbestos emissions arising from them. For example, weathering also is associated with the growth of dark lichens[12] that adhere tenaciously to weathered surfaces and usually require considerable force to be removed; *e.g.* toxic washes, sweeping with stiff brooms, wet wire brushing and high-pressure water jet cleaning have been considered.[13,14] Water jet cleaning has been found the most effective, and it is in use locally and in the United Kingdom to clean AC roofing prior to painting.[15,16] Also, since vast quantities of AC cladding have been used over several decades with Australian buildings, there is increasing activity in cladding replacement and building demolition operations.

Work Operations

A series of work trials was conducted for each of the work operations: sheet cleaning, sheet painting, roof replacement and building demolition. These operations involved buildings clad in AC sheeting with up to 40 years weathering from several Melbourne suburbs, as described in Table I. For each building, sheeting surfaces were assessed for the extent of weathering and fiber exposure by close visual examination; exposed fibers were sampled and identified by infrared spectroscopy in which procedures described by Coates were used.[17] In some cases surface layers were scraped from measured areas and weighed to determine surface layer density. Also the fibrous contents of the layers were determined by weight after extraction with 0.5M hydrochloric acid (brought to boil, then cooled), capture on a 750 μm screen and ashing for 10 min at 400°C. Acid treatment of different asbestos types by this method has been found to yield 90% or more recovery.[18]

Since work trials were conducted outdoors under ambient conditions and with limited control on procedures employed, detailed measurements of ambient climate and observations of work procedures were made for each trial.

1) Sheet cleaning: roofs at Sites 1 and 2 with areas 30 and 45 m^2, respectively, were cleaned with high-pressure water jets in trials taking several hours. These were commercial contracts where operators stood in upright positions on roofing and used water jet guns with extension lances to strip the weathered layer from sheeting.
2) Sheet painting: these were simulated trials in which badly weathered roofing (Sites 5 and 8) and lightly weathered walls (Site 8) were painted with a diluted acrylic coating (28% by weight solids content) by either roller or airless spray. Generally, areas of 50 to 400 m^2 were coated in 1.5 to 4 hr. Operators worked from timber supports laid on roofing surfaces that were moved (sometimes by dragging) as work proceeded.
3) Roof replacement: old and badly weathered AC roofing was replaced by steel roofing on large commercial buildings (Sites 3 to 5, 7) or housing (Site 6) as normal building maintenance procedures. Roof replacement usually was carried out by two to six men, according to a sequence whereby small sections (20 to 40 m^2) were repetitively unfastened, removed and replaced by new

TABLE I
Sites Involved in Work Trials

Site No.	Site Description	Building Age	Extent of Surface Weathering
1	Garage, corrugated roof	39	Severe
2	Private dwelling, corrugated roof	30	Severe
3	Hall, corrugated roof	38	Severe
4	Warehouse, corrugated roof, part-painted	40	Moderate
5	Factory, corrugated roof	40	Very severe
6	Hall, corrugated roof, painted	29	-
7	Low-cost dwellings, corrugated roof	32	Severe
8	Warehouses:		
8.1	Building A — corrugated roof	40	Severe
8.2	Building B — corrugated roof	40	Severe
	— flat wall	40	Low
8.3	Building C — corrugated roof	40	Severe
	— flat wall	40	Low
8.4	Building D — corrugated roof	40	Severe
	— flat wall	40	Low

roofing. Sheets were removed whole and carried individually to the edge of roofs where they were either stacked (Sites 3, 5, 7), dropped directly into a bin at ground level (Site 4), or passed and stacked into the tray of a truck (Site 6). After removal of large areas of roofing, the stacked sheets either were lifted from the building by crane (Site 5) or dropped individually into a dump bin at ground level (Sites 3, 7). Trials were conducted for 2 to 6 hr during which 50 to 100 m^2 of roofing was replaced. Comparative trials were made at some sites after pretreatment of sheet surfaces to suppress dust emission by coating with one of the following: i) lignin sulphonate liquor,[19] a 10% by weight solids solution applied at a coverage of 0.3 L/m^2; or ii) diluted acrylic resin, a 28% by weight solids solution applied at 0.3 L/m^2.

4) Building demolition: several large (90 m × 36 m) wool storage warehouses were demolished at Site 8. The first of these (8.1) was demolished by removing wall sheets and structural bracing and then collapsing the structure with roofing sheets intact. The roofing sheets sustained little damage and subsequently were removed by several workers who formed a chain across the roof and passed and dragged the sheets to each other and finally to two men stacking them on a platform up to chest height. Other warehouses were demolished by removing all cladding from the standing structure with workers confined to platforms adjacent to wall sheets or in scissor lifts set at a height such that roofing was at chest level. Work conditions were more confined in these trials and involved closer contact with weathered sheeting. Handling of roofing sheets was visibly dusty — particularly as they were stacked in the tray of the scissor lift. Again, comparative trials were made after pretreatment of sheet surfaces to suppress dust emission.

Measurement of Asbestos Dust Concentrations

Asbestos dust concentrations were measured by personal sampling within the breathing zones of workers using the NHMRC Standard Membrane Filter Method[20] and guidelines from the AIA Reference Method[21] — except that sampling was carried out with 13 mm filters at 80 mL/min as well as 25 mm filters at 1 to 2 L/min. Fibers were counted under positive phase contrast with microscopes capable of resolving the sixth set of lines on a National Physics Laboratory Mark II test slide, a process which is acceptable performance by Health and Safety Executive (HSE) standards.[22]

The counting procedure generally used a Walton-Beckett eyepiece graticule (100 fields of 100 μm diameter) but, when necessary, the full-viewing field (20 or 50 fields of 348 μm diameter) was employed to ensure a minimum count of 25 fibers. This was done to achieve a minimum level of precision for fiber counts and not to increase the detection limit of the procedure. Assuming a theoretical Poisson distribution, this procedure results in a coefficient of variation for counts of less than 0.20, although in practice greater variability typically is found.[21] Counting by full fields has been shown to lead to different counts from graticule fields,[23] and it is not a procedure employed in standard methods. The implication of this to the present results will be discussed.

All fibers that met the geometric definition for asbestos fibers — a length to width ratio of 3 or greater, a length greater than 5 μm and a width less than 3 μm — were counted as required by standard methods.[20,21] This approach has been criticized since it is not specific for asbestos fibers and may overestimate asbestos concentrations in environments containing other dusts.[24] For this reason, additional information was gathered on the shapes of fibers counted according to the following classifications:

1) asbestos-like: fibers with substantially parallel sides and square ends (unless split); and
2) amphibole-like: fibers from Classification 1 that were straight and needle-like in appearance.

Such classifications were not used to identify or distinguish between different types of asbestos but to provide qualitative characterization of the dusts encountered.

Further, recent evidence points to the importance of fiber dimensions to carcinogenic risk,[25] and it has been suggested that size classification be undertaken during measurement of asbestos concentration.[25] In the present study, fibers were approximately sized during counting by visual comparison to graticule dimensions and later divided into suggested size classifications.[26] This analysis can only be considered a limited characterization for each fiber population since the sizing is approximate and restricted to the range of fiber diameters visible by phase contrast microscopy (greater than approximately 0.2 μm).[27]

Results

Characteristics of Weathered Surfaces

Because of the ages of the buildings involved, the extent of surface deterioration of roofing usually was severe: each sheet presented a loose surface layer enriched in asbestos compared with the original product. Characterization of the surface layers from some roofing sheets by techniques described earlier is presented in Table II. Fiber clumps sampled from roof surfaces provided infrared spectra that were free from interference by cement, which allowed ready identification. Surface layers generally contained mixtures of chrysotile and amosite, except for one surface where only chrysotile was present (Site 1) and for two where chrysotile, amosite and crocidolite were all present (Sites 5 and 6). In compari-

TABLE II
Characteristics of Surface Layers From Weathered Roof Sheets

Sample	Surface Layer Density (g/m^2)	Fiber Content of Layer (% w/w)
A	240	32
B	340	25
C	110	22
D	190	24

son, flat wall sheets with similar periods of exposure exhibited little deterioration with no significant surface layer but isolated clumps of fibers usually identified as chrysotile. Infrared spectra of bulk fibers extracted from wall sheets at Site 8 showed that they contained predominantly chrysotile and possibly a very small amount of amphibole asbestos. In general, the work operations described earlier involved contact with mixtures of chrysotile, amosite and crocidolite. The hygiene standard in Australia for the latter two types is 0.1 f/mL averaged over a 4-hr sampling period while that for chrysotile is 1.0 f/mL.[28] For any mixture of these types of asbestos the hygiene standard is 0.1 f/mL; exposures determined in this investigation will be assessed relative to such a standard.

Fiber Counting Practice

As described earlier, this investigation employed counting of 100 Walton-Beckett graticule fields where possible, but changed to counting of 20 or 50 full-fields so that at least 25 fibers were counted where fiber densities were low. Background counts for several unexposed filters were determined also. These averaged 2, 4 and 6 fibers, respectively, for the above procedures — the first value being within the limit accepted in standard methods.[21] Pickford[29] suggests that the lowest reliable detection limit (LRDL) for sample counting should be estimated from the upper confidence limit of the background count based on a lognormal distribution and assuming a coefficient of variation (cv) appropriate to the procedures employed. By assuming a cv of 0.4 for the present case, it is estimated that the LRDLs at the 5% level are 7, 14 and 21 fibers, respectively, for the above counting procedures. It can be seen that since a minimum count of 25 fibers was sought, the LRDL usually was exceeded; when a sample count was below the LRDL, the measurement was recorded as non-detectable.

Beckett *et al.*[23] found that fiber counts can be increased by a factor of 1.5 for amosite and 2.5 for chrysotile by counting small graticule fields compared to full fields. This effect was attributed to human error in full-field counting, and with the employment of a more rigorous counting technique (careful, prolonged scanning of whole field area), the factor for chrysotile counting was reduced to 1.14. Beckett *et al.* concluded that the two practices were comparable provided that full-field counts were carried out carefully and meticulously. It is believed that other laboratories have not been able to reproduce these findings.[29] In the present work, both counting practices were employed for several samples and the results are presented in Table III. The ratios of concentrations derived from the two procedures have an average value of 1.37 ± 0.64 that — while significantly different from unity at the 5% level — is similar to the ratio found by Beckett *et al.* when rigorous full-field counting was employed. The above ratio was used to correct results based on full-field counts to enable comparison with graticule field results.

Sheet Cleaning

Asbestos concentrations during water jet cleaning of roofing for several hours at two sites are presented in Table IV. The concentrations measured were 0.1 f/mL or less for both cases. A notable problem with the procedure was observed to be containment of the removed layer that usually was propelled several meters from the building perimeter. This could comprise several kilograms of asbestos-rich material at the sites investigated (Table I), and its dispersal around the grounds of a building could contribute to greater environmental concentrations of asbestos at these sites.

TABLE III
Comparative Counts for Walton-Beckett (WB) and Full (F) Fields

Sample No.	Count Results		Ratio of Asbestos Concentrations (WB/F)
	Fibers	Fields	
1	10.0	100 WB	1.15
	52.0	50 F	
2	11.5	100 WB	1.91
	36.0	50 F	
3	11.5	100 WB	0.97
	28.0	20 F	
4	12.5	100 WB	0.76
	39.5	20 F	
5	13.0	100 WB	1.53
	30.5	30 F	
6	14.0	100 WB	1.20
	28.5	20 F	
7	14.5	100 WB	0.90
	39.5	20 F	
8	16.5	100 WB	0.97
	41.5	20 F	
9	17.0	100 WB	3.36
	48.0	80 F	
10	23.0	160 WB	1.15
	30.0	20 F	
11	24.5	100 WB	0.77
	38.0	10 F	
12	25.5	110 WB	1.83
	31.0	20 F	
13	27.0	100 WB	0.98
	93.5	28 F	
14	28.5	100 WB	1.00
	35.5	10 F	
15	42.5	100 WB	1.95
	52.5	20 F	
16	84.0	100 WB	1.23
	80.0	10 F	
17	92.0	100 WB	1.71
	129.5	20 F	
			Average 1.37 ± 0.64

Sheet Painting

Limited measurements were made for this operation (Table V) since it involved only simulated trials. Results, however, do indicate the asbestos concentrations that may arise, and tentative suggestions will be made on procedures to reduce such emissions. In initial trials at Sites 5 and 8.1, asbestos concentrations were between 0.11 to 0.22 f/mL whether painting was by roller or airless spray. Considerably lower asbestos concentrations (approximately 0.01 f/mL) occurred at Site 8.3. The main difference in the work procedure at the latter site was that timber walk planks were lifted across roofing as the job progressed while, at the other sites, planks

TABLE IV
Asbestos Concentrations Near Workers Cleaning AC Roofing With Water Jets

Site No.	Work Description	Wind Speed (m/sec)	Sample Period (hr)	Asbestos Concentration (f/mL)
1	Cleaning 40 m^2 of roofing	1.5	5.3	0.08
2	Cleaning 45 m^2 of roofing	6.3	5.3	0.10

TABLE V
Asbestos Concentrations Near Workers Painting Weathered AC Sheeting

Site No.	Work Description	Wind Speed (m/sec)	Sample Period (hr)	Asbestos Concentration (f/mL)
5	Painting 80 m^2 roofing by roller;	1.9	2.0	0.22
	Painting 60 m^2 roofing by roller	3.3	1.5	0.20, 0.12
8.1	Painting 300 m^2 roofing by airless spray;	2.8	3.4	0.14
	Painting 250 m^2 roofing by airless spray	4.3	3.1	0.11
8.3	Painting 400 m^2 roofing by airless spray;	1.7	2.3	0.01, 0.01
	Painting 110 m^2 wall by airless spray	2.0	0.4	0.09, 0.12

were slid across roof surfaces. The lower mechanical disturbance of weathered surfaces may have contributed to lower emission of asbestos dust. At Site 8.3 where wall sheets were painted, there was no mechanical disturbance of the surfaces but concentrations of 0.09 and 0.12 f/mL were recorded, possibly because of the proximity of the workers' breathing zones to the surfaces as the surfaces were coated.

Roof Replacement

Asbestos concentrations near workers during replacement of weathered AC roofing at several sites are presented in Table VI. At Sites 3 to 5, these measurements were made during the full roof replacement process of unfastening, removal and disposal of old sheets and installation of new roofing. It is estimated that AC sheeting was handled for approximately one-third of this operation. At Sites 6 and 7, the measurements were restricted to the period of sheet handling to assess the effectiveness of control measures.

Concentrations measured at Sites 3 and 5 ranged from 0.03 to 0.27 f/mL and showed no correlation to sheet handling rate or ambient wind speed. Limited measurements at Site 4 were considerably lower at 0.03 f/mL, possibly because the roofing was partly coated with deteriorated paint or because sheets were dropped from the building without stacking. The effect of coating weathered roof surfaces to suppress asbestos emission was investigated at Sites 5 and 7. In trials where the roofing had been pretreated with lignin sulphonate an asbestos concentration of 0.23 f/mL was measured during roof replacement. Another measurement was 0.08 f/mL, but it was rejected because the worker had relocated the sampler to the back of his neck. In a previous case, rain washed much of the treatment from the roof prior to the trial and the asbestos concentrations measured during roof replacement — 0.05 and 0.11 f/mL — also were rejected. The treatment was considered neither suitable nor successful for dust suppression and thus was abandoned. In further trials at Site 5 roofing surfaces had been sealed with acrylic resin, effectively rebonding the surface layer, and asbestos concentrations were reduced markedly to 0.03 to 0.08 f/mL. Further measurements were made for sealed roofing at Site 7 but only during the process of sheet removal; these results were considered comparable to those determined for sealed roofing at Site 5.

At all of the above sites except Site 4, sheets were stacked during removal. Stacking was observed to create a surge of dust-laden air back across a worker as he dropped sheets. The effect of this on asbestos emission was investigated at Site 6 by stacking sheets with and without wetting. Without wetting, asbestos concentrations of 0.07 to 0.32 f/mL were observed, comparable to the range exhibited at other sites, with the higher concentrations having been measured for workers stacking sheets. The time-weighted average (TWA)[21] asbestos concentration for these trials was 0.21 f/mL. This was reduced to 0.03 f/mL for trials where sheets were wetted when stacked, suggesting that much of the asbestos emission arising in the roof replacement process was associated with sheet stacking.

Building Demolition

Asbestos concentrations during building demolition were measured only for the period of sheet handling, and they are presented in Table VII. Sheet handling was continuous and much more vigorous than for roof replacement work. Generally, sheeting was removed at a rate of 100 m^2/man-hr in demolition work as compared to 5 to 10 m^2/man-hr for the roof replacement process. Building demolition appeared to create considerably more visible dust emission and short sampling periods (30 to 60 min), were employed to limit particulate contamination on filters and to allow comparative trials on the same day.

The first series of measurements (Trial Sequence 8.1) were made with roofing collapsed to waist height and, because of site restrictions, only a limited number of measurements could be made. Asbestos concentrations at two workers stacking sheets were approximately 0.4 f/mL; at a worker passing sheets across roofing, 0.1 f/mL. When the tops of sheets were hosed down prior to removal (Trial 8.1.2) much lower asbestos concentrations (less than 0.1 f/mL) were measured, even at a worker stacking sheets. When weathered sheet surfaces were sealed with acrylic resin (Trial 8.1.3), there did not appear to be much suppression of asbestos emission compared to dry sheet removal, in contradiction to the effect found with roof replacement at Site 5.

In Trials 8.2 and 8.3, all roofing was removed by two men in a scissor lift as described earlier, such that close handling and stacking of sheets in a confined area characterized their work operation. The TWA asbestos concentration during dry roof removal was determined to be of 0.38 f/mL in trial group 8.2, and 0.60 f/mL in trial group 8.3. In both trial groups there appeared to be little effect of wind speed on measured concentrations, possibly because of the proximity of workers' breathing zones to sheet handling and the consistent way in which surface dust was forced back at workers as they stacked sheets.

When roof sheets were hosed prior to removal, lower asbestos concentration measurements were found at one site (Trial 8.2) but not the other (Trial 8.3, TWA concentration 0.50 f/mL). Also concentrations measured when removing roof sheets that had been sealed with acrylic resin were comparable (Trial 8.3, TWA concentration 0.55 f/mL) to concentrations measured during dry roof removal.

The ineffectiveness of wetting or sealing of sheet surfaces in reducing asbestos concentration measurements in Trial 8.3 was further investigated by considering other sources of asbestos emission. Much of the visible dust evolved during sheet handling appeared to originate from dust accumulated under sheet laps and ridge cappings. Samples of these were taken from Building B and Building C and were analyzed by the method used for surface layer analysis described earlier, with additional quantification of chrysotile and amosite contents of dust by infrared spectroscopy (in accordance with absorptions at 3690 cm^{-1} and 780 cm^{-1}, respectively, with calibration against UICC asbestos samples). Results of these analyses are presented in Table VIII; these results show that lap and ridge dusts of Building C contain substantial amounts of asbestos (predominantly as free fibers by visual assessment). This is consistent with the higher asbestos emissions observed at this site and the inability of surface treatments to control such emissions.

TABLE VI
Asbestos Concentrations Near Workers Replacing Weathered AC Roofing

Site No.	Work Description	Wind Speed (m/sec)	Asbestos Concentration (f/mL)		
			n[A]	Range	TWA[B]
3	Replacing dry roofing	0.6-1.5	8	0.03-0.24	0.10
4	Replacing part-painted roofing	3.3	2	0.03	0.03
5	Replacing dry roofing	1.5-4.4	8	0.04-0.27	0.10
5	Replacing lignin sulphonate-treated roofing	1.1	1	0.23	-
5	Replacing acrylic-sealed roofing	1.1-4.0	8	0.03-0.08	0.05
6	Removing dry roofing	0.5-0.7	6	0.07-0.32	0.21
6	Removing/replacing roofing with careful handling and wetting as stacked	0.9-1.5	8	ND[C]-0.07	0.03
7	Removing acrylic-sealed roofing	1.1-1.9	6	0.04-0.26	0.15

[A]n = number of measurements.
[B]TWA = time-weighted average.
[C]ND = not detectable.

TABLE VII
Asbestos Concentrations Near Workers Demolishing AC Warehouses

Trial No.	Work Description	Wind Speed (m/sec)	Asbestos Concentrations (f/mL)		
			n[A]	Range	TWA[B]
8.1	Building A demolished after collapse:				
8.1.1	— dry roof removal	6.4	3	0.10-0.47	0.32
8.1.2	— wet roof removal	3.7	2	0.05-0.06	0.06
8.1.3	— acrylic-sealed roof removal	5.2	3	0.11-0.32	0.16
8.2	Building B demolished from lift:				
	— dry roof removal	1.3-3.5	6	0.30-0.53	0.38
	— wet roof removal	1.6	2	0.10-0.13	0.12
8.3	Building C demolished from lift:				
	— dry roof removal	1.6-4.9	10	0.34-1.1	0.60
	— wet roof removal	1.6-2.7	4	0.29-0.68	0.50
	— acrylic-sealed roof removal	3.1	4	0.41-0.76	0.55
8.3/8.4	— dry wall removal	2.5-3.5	4	0.04-0.12	0.07
8.3	— acrylic-sealed wall removal	4.2	2	ND[C]-0.05	0.02

[A]n = number of measurements.
[B]TWA = time-weighted average.
[C]ND = not detectable.

TABLE VIII
Analysis of Dusts Accumulated on AC Roofing at Site 8

Sample Description	Fiber Content After Ashing (% w/w)	Asbestos Content of Roof Dust (% w/w)	
		Chrysotile	Amosite
Building B, ridge dust	<0.03	0.006	0.003
Building B, lap dust	<0.3	0.03	0.008
Building C, ridge dust	0.6	0.2	0.2
Building C, lap dust 1	7.4	3.7	0.9
Building C, lap dust 2	1.8	0.7	0.4

Asbestos concentrations near workers removing untreated AC wall sheets (Trials 8.3 and 8.4) were considerably lower than found with removal of roof sheets — even during sheet stacking — with a TWA concentration of 0.07 f/mL. Asbestos concentrations at workers removing wall sheets sealed with acrylic resin (Trial 8.3) were also low. These limited results suggest that asbestos emissions during work with the wall sheets will be small, possibly because of the low extent of surface weathering and dust accumulation that occur on such sheets.

Fiber Shape and Size Distribution

Fibers counted on sample filters were classified by shape in accordance with the criteria described earlier. For most work operations, 60% to 90% of fibers counted were classified as asbestos-like and 30% to 60% as amphibole-like. It is considered that these proportions are consistent with the emission of asbestos fibers from the weathered sheeting rather than emission of other material meeting the fiber counting criteria of the Membrane Filter Method.

Classification of counted fibers into approximate size categories also was carried out as described earlier. For nearly all counts, the most prevalent size classifications were fibers less than 0.5 μm diameter and 5 to 10 μm or 10 to 20 μ long. Usually 40% to 60% of fibers counted were less than 0.5 μm diameter, and of these, 60% to 90% were long fibers with aspect ratios (ratio of length to diameter) of 40 or greater.

Discussion

Measurements made in this investigation indicate that several work operations with weathered AC claddings are associated with measurable concentrations of asbestos near workers, even though the operations are conducted outdoors. Asbestos emissions appear to be higher for those operations associated with physical disturbance of surfaces and trapped dust, suggesting that work modifications to minimize such disturbance should reduce exposure to asbestos dust markedly. Stacking of sheets without wetting appears to be the most severe process causing asbestos dust emission; it also appears to be affected little by ambient wind speed possibly because it causes surges of dust-laden air across workers.

Asbestos concentrations at workers cleaning and painting weathered AC cladding were 0.1 to 0.2 f/mL and possibly were associated with physical disturbance of weathered surfaces (*e.g.*, by sliding timber walks across them). Suppression of such emissions by wetting sheet surfaces was not considered feasible since this would a) make roofing slippery and unsafe to work on, and b) probably interfere with painting. It is suggested that careful work practices should maintain worker exposure below hygiene standard levels and that use of low efficiency respirators (particulate penetration less than 10%) should be considered as an additional precaution to ensure such reduction. As noted earlier, specific precautions also should be taken to contain the surface layer thrown from roofing by water jet cleaning in order to prevent environmental contamination. Catch sheets around the building perimeter or enclosure of the water jet nozzle are believed to have been used successfully for this purpose.

Asbestos concentrations at workers replacing AC roofing averaged approximately 0.1 f/mL when measured over the full work operation, although isolated examples of higher concentrations did occur. In trials at Site 5 where frequent blue fibers (identified as crocidolite) were visible on roofing surfaces, the asbestos concentrations at workers were reduced well below 0.1 f/mL by sealing the weathered surface with acrylic resin. This suggests that a major source of asbestos emission was the loose surface layer. Later use of the same sealing procedure during roof demolition was ineffective, however, apparently because of a high asbestos fiber content in the dust trapped under sheet laps and ridge capping. This unpredictable factor could negate any advantage in the sealing of sheet surfaces and suggests that other means of suppression may be more worthwhile. Further measurements during roof replacement at Site 6 indicated that asbestos dust evolution was suppressed significantly by careful handling of weathered sheets and wetting of sheet surfaces during stacking. These precautions are expected to suppress dust emission from both surfaces and under laps; measurements indicate that with these precautions worker exposure will be reduced to well below the 0.1 f/mL hygiene standard. Again, the use of low efficiency respirators might be considered as supplementary protection to ensure reduced exposure to asbestos dust.

Asbestos concentrations were highest for workers demolishing badly weathered AC claddings (*i.e.*, roofing), probably because of extensive sheet handling, vigorous work rates and close sheet contact resulting from confined conditions. Asbestos concentrations during demolition of AC roofing by the procedures investigated can be expected to be typically 0.3 to 0.6 f/mL and to not be amenable to reduction by wetting of surfaces prior to demolition because of asbestos fibers trapped under laps. Based on the measurements made during sheet handling at Site 6, it is anticipated that hosing sheet surfaces during stacking would cause marked dust suppression. This procedure, however, was not possible in the cases studied because of the proximity of electrical components in the machinery employed for demolition. It is suggested that demolition of weathered AC claddings should employ careful sheet handling, wet stacking and low efficiency respiratory protection where possible, or alternatively more efficient respiratory protection for workers. Note that this assumes claddings contain amosite or crocidolite, which is believed to be typically the case for such products. Also flat sheeting used for wall cladding appears to sustain little weathering; therefore, it is anticipated that work with such products will result in asbestos exposures much below applicable hygiene standard levels, and this work requires no special precautions other than careful sheet handling and use of low efficiency respirators.

A further factor that must be considered in work operations with weathered AC claddings is contamination of a worker's clothing with asbestos fibers. Such contamination was visually apparent to a minor extent during roof replacement but to a marked extent during roof demolition — particularly where wet sheets were handled and large quantities of the wet layer adhered to contacted clothing. It is suggested that with careful sheet handling and wet stacking during roof replacement, clothing contamination will be minimal and could be dealt with by precautionary vacuuming of clothing prior to leaving the work site. With roof demolition, however, worker contact with sheeting was so close that marked contamination of clothing must be considered inevitable, and the use of protective clothing and decontamination practices will be necessary precautions.

This discussion has not considered the frequency with which workers will handle AC products and the relevance of this to their long-term asbestos exposure. The extensive usage of AC products in the past suggests that such contact will be frequent. Also while the handling of AC products usually constitutes only part of total work time (approximately one-third in the cases studied), it was noted that certain workers specialized in this task, particularly when it required specific machinery. In view of these factors and in order to maintain worker exposure to the minimum practicable level, it is suggested that the above precautions should be employed without anticipating the frequecy to which individuals will be exposed to asbestos.

Conclusions

Exterior AC building products become weathered by the local erosion of cement from surfaces so that loosely bound mixtures of asbestos fibers — often including amosite and crocidolite — are laid bare. Physical disturbance of weathered AC sheeting will cause worker exposure to measurable concentrations of asbestos dust depending on the severity of the disturbance and extent of weathering involved. Limited results suggest that worker exposure during water jet cleaning and painting of weathered claddings may be reduced to below hygiene standards by avoiding abrasion of surfaces. Exposure during AC roof replacement was maintained within hygiene standards by careful sheet handling and wetting of sheet surfaces during stacking. Similar precautions should be effective for AC roof demolition but, if inappropriate, it will be essential to employ respiratory protection for workers. Roof demolition work also caused marked contamination of clothing with asbestos, and it is considered that appropriate protective clothing and decontamination practice will be necessary for such work.

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