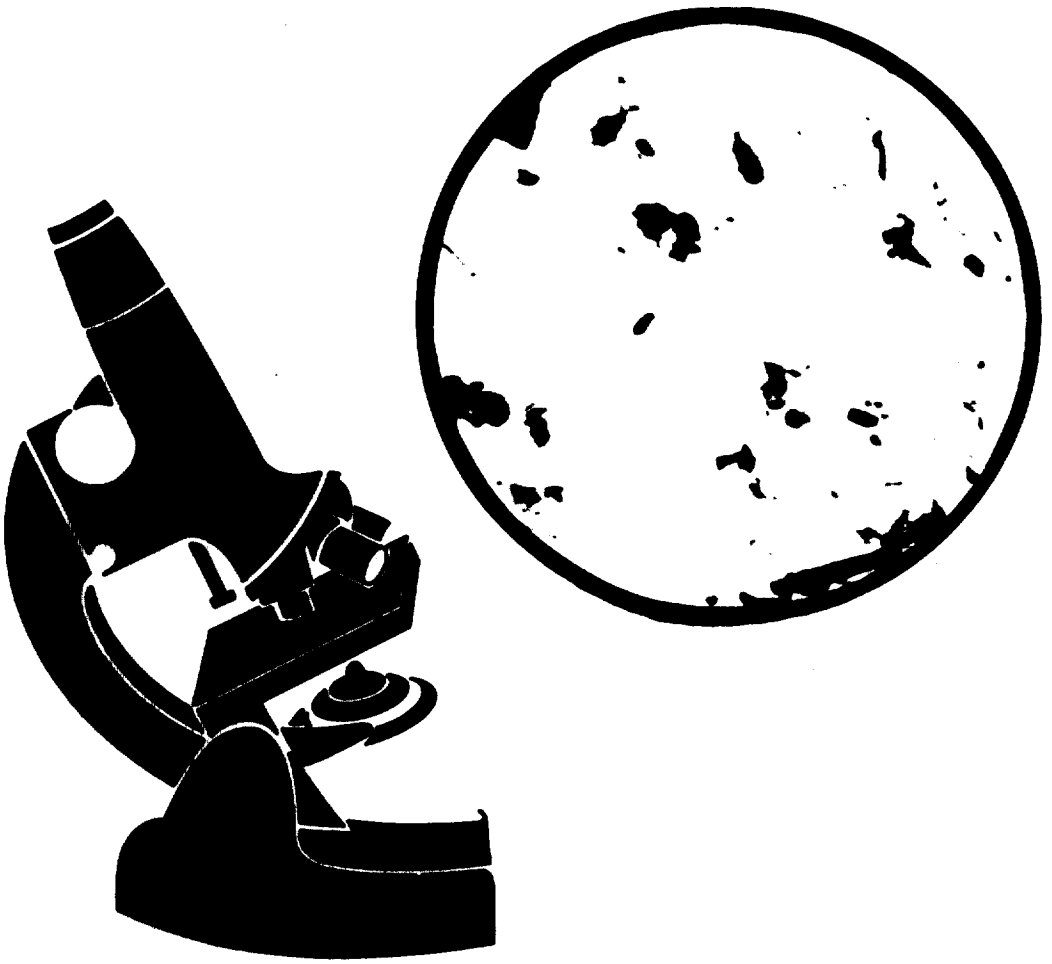
NIOSH

REVISED RECOMMENDED ASBESTOS STANDARD



U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Center for Disease Control
National Institute for Occupational Safety and Health

REVISED RECOMMENDED

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The Division of Surveillance, Hazard Evaluations, and Field Studies, National Institute for Occupational Safety and Health (NIOSH), having primary responsibility for development of a NIOSH position paper on health effects of occupational asbestos exposure, has critiqued all available data and prepared the following document for publication and transmittal to the Occupational Safety and Health Administration (OSHA), as requested by the Assistant Secretary of Labor. Primary responsibility for development of this document was shared by Richard A. Lemen and John M. Dement, with technical consultation provided by Dr. Joseph K. Wagoner. Individuals who served as the NIOSH review committee were:

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I. INTRODUCTION

When the asbestos criteria document was first published in 1972, the National Institute for Occupational Safety and Health (NIOSH) recommended a standard of 2.0 asbestos fibers/cubic centimeter (cc) of air based on a count of fibers greater than 5 micrometers (μm) in length. This standard was recommended with the stated belief that it would "prevent" asbestosis and with the open recognition that it would not "prevent" asbestos-induced neoplasms. Furthermore, data were presented which supported the fact that technology was available to achieve that standard and that the criteria would be subject to review and revision as necessary. Since the time that the asbestos criteria were published in 1972, sufficient additional data regarding asbestos-related disease have been developed to warrant reevaluation.

On June 7, 1972, the Occupational Safety and Health Administration (OSHA) promulgated a standard for occupational exposure to asbestos containing an 8-hour time-weighted average (TWA) concentration exposure limit of 5 fibers longer than 5 μm/cc of air, with a ceiling limitation against any exposure in excess of 10 such fibers/cc. The standard further provided that the 8-hour TWA was to be reduced to 2 fibers/cc on July 1, 1976.

As the result of a court case, OSHA decided that to achieve the most feasible occupational health protection, a reexamination of the standard's general premises and general structure was necessary. To this end, on October 9, 1975, OSHA announced a proposed rule-making to lower the exposure limit to an 8-hour TWA concentration of 0.5 asbestos fibers longer

than 5 μm/cc of air with a ceiling concentration of 5 fibers/cc of air determined by a sampling period of up to 15 minutes. On December 2, 1975, OSHA requested NIOSH to reevaluate the information available on the health effects of occupational exposure to asbestos fibers and to advise OSHA on the results of this study.

This document contains an updated review of the available information on the health effects of exposure to asbestos. In addition, NIOSH's proposal for a new numerical exposure limit is included.

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II. BIOLOGIC EFFECTS OF EXPOSURE ON ANIMALS

Carcinogenicity

The carcinogenicity of asbestos was studied through various routes of exposure

(a) Instillation

(1) Intratracheal Injection

This technique has been used to study co-carcinogenesis of chrysotile asbestos with benzo(a)pyrene in hamsters (Miller et al, 1965) and rats (Vosamae, 1972; Pylev., 1972; Pylev and Shabad, 1973; Shabad et al, 1974). In both species, it was demonstrated that the effect of chrysotile was additive to that of benzo(a)pyrene for tumors of the respiratory tract.

Shabad et al (1974) showed that intratracheal injection of 2 mg of Russian chrysotile on which 0.144 mg benzo(a)pyrene was absorbed (3 times at monthly intervals), or 2 mg of Russian chrysotile together with 5 mg benzo(a)pyrene (single injection) produced lung papillomas, epidermoid carcinomas, reticulosarcomas, or pleural mesotheliomas in 6/21 and 6/11 rats, respectively, within 9-28 months. No lung tumors or mesotheliomas occurred in 49 rats given 3 doses of 2 mg chrysotile alone or in 19 rats given a single dose of 5 mg benzo(a)pyrene alone during or up to 28 months of observation.

(2) Intraperitoneal (ip) Administration

Reeves et al (1971) gave ip injections of 0.3, 0.5, or 1.0 ml of a solution of 20 mg/ml amosite, crocidolite or chrysotile to groups of 11, 13, and 13 Charles River CD rats, respectively. Three peritoneal mesotheliomas were observed with chrysotile, three with crocidolite, and

none with amosite after 7-17 months. No data on control animals were reported.

Maltoni and Annoscia (1973) injected 25 mg of crocidolite into 50 male and 50 female Sprague-Dawley rats, 18 weeks old, and later observed 65 mesotheliomas-31 in males and 34 in females.

Pott and Friedrichs (1972) and Pott et al (1974) injected fibrous and granular dusts into the peritoneal cavities of Wistar rats. The dosage, number of inoculations, and results are shown in Tables II-1 and II-2.

After injection of powdered chrysotile, the latent period for the induction of tumors was found to be longer than that after injection of standard chrysotile. The rate of tumor occurrence was about 40% in both groups and was not distinctly influenced by the addition of benzo(a)pyrene. In another group, benzo(a)pyrene without asbestos induced tumors in 10% of the animals. Histologically, the types of tumors observed were connected with structures of the abdominal wall, including the serosa, and in isolated cases with those of the intestinal wall (Pott et al, 1972).

(3) Intrapleural Administration

All commercial types of asbestos have produced mesotheliomas in CD Wistar rats. A dose of 20 mg of the 5 UICC standard reference samples produced mesotheliomas in varying numbers - crocidolite, (61%); amosite, (36%); anthophyllite, (34%); Canadian chrysotile, (30%); Rhodesian chrysotile, (19%) (Wagner et al, 1974). The lowest dose used (0.5 mg chrysotile or crocidolite) produced mesotheliomas (Wagner et al, 1973). Stanton and Wrench (1972), using a dose of 40 mg asbestos dust on gelatin-coated fiber glass pledgets, found that three of the UICC samples,

crocidolite, amosite and Rhodesian chrysotile, all produced mesotheliomas in about 60% of the Osborne-Mendel rats. Pylev and Shabad (1973) induced mesotheliomas with 60 mg of Russian chrysotile. In all these studies there was a long latent period between inoculation and appearance of the tumors. Evidence that the response was dose-related was provided by Wagner et al (1973) and by Stanton (1973). Mesotheliomas have also been produced by other workers: in rats (Donna, 1970; Reeves et al, 1971), in hamsters (Smith et al, 1965) and in rabbits (Reeves et al, 1971). Groth et al (1975) reported no mesotheliomas or other neoplasms from chrysotile in 45 female discard-breeder albino rats, approximately 10 months old. However, all surviving tumor-free animals were killed at 90 or 150 days after injection--a time period insufficient for the development of mesotheliomas as demonstrated by the experiments of Wagner and Berry (1969).

The suggestion has been made that natural oils and waxes (Harrington, 1962) and contaminant oils from milling of the asbestos fiber (Harrington and Roe, 1965; Roe et al, 1966) or from plastic storage bags (Commins and Gibbs, 1969) contributed to the incidence of pleural tumors. However, samples from which the oils had been removed gave very similar results to untreated fiber (Wagner and Berry, 1969; Wagner et al, 1973).

Morgan and Holmes (1970) and Morgan et al (1971) showed that when asbestos was injected intrapleurally, the majority of the fibers were cleared from the lungs during the first 10 days; subsequently there was also a very slow elimination through the gut. In feeding experiments almost all of the fibers were eliminated. After intrapleural or subcutaneous inoculation, only a minute fraction of the finer fibers were translocated through the tissues. This finding was supported by the

studies of Kanazawa et al (1970).

The fiber diameter, length, and shape may be important in disease production. All of the eight separate sub-samples which were pooled in the UICC Canadian chrysotile reference sample (Timbrell and Rendall, 1972), when ground separately to a finer powder, produced a higher incidence of mesothelioma than the pooled sample. The highest incidence (66%) was produced by a separate superfine chrysotile sample (20 mg dose) fractionated from fine grade asbestos by water sedimentation (Wagner et al, 1973). Using UICC crocidolite, Stanton and Wrench (1972) found that partially pulverized material gave fewer mesotheliomas than did the standard unpulverized fiber. Prolonged fine grinding is known to destroy fiber and crystalline structure (Occella and Maddalon, 1963). Stanton (1973) showed that fibers of other materials, including glass, could induce mesotheliomas, but only when the diameter was of the same order as that of asbestos when measured by light microscopy.

In addition to the UICC standard reference samples, other fibers were injected intrapleurally into rats by Wagner et al (1973). Out of a group of 32 rats, mestheliomas occurred in 18 animals injected with a sample of brucite, 3 injected with a ceramic fiber, 1 each with barium sulphate, glass powder, and aluminum oxide. None occurred with a coarse glass fiber.

Wagner et al (1976) conducted a series of experiments comparing the biologic effects of a pure asbestos-free cosmetic talc with the superfine chrysotile asbestos used in previous experiments. In an intrapleural inoculation experiment, 48 rats were inoculated with each dust. Eighteen rats of the chrysotile group developed mesotheliomas, but

no tumors were seen in those given talc.

Further evidence on the importance of fiber diameter was provided by Wagner et al (1976), who reported on rats injected intrapleurally with glass fiber (Table II-3). Two samples of glass fiber were used, one with a median fiber diameter of 0.12 μm and the other with a median diameter of 1.8 μm. Four mesotheliomas were observed in 32 rats injected with the finer fiber and none with the coarser fiber. Also, the degree of mesothelial cell hyperplasia was more pronounced in the rats injected with the finer fiber. These results were comparable with those of the previous experiment.

Shabad et al (1974) reported that when 20 mg of Russian chrysotile was injected intrapleurally 3 times into 67 rats, 31 developed mesotheliomas within 2 years.

(b) Ingestion

Gross et al (1974) reported the results of a series of feeding experiments with chrysotile and crocidolite fed to rats of various origins. In groups of rats varying in number from 10 through 35, no significant differences in tumor incidence were observed in comparison with controls. Survival rates were not reported, sample sizes were small (from 10 through 35) and no pathologic details were given.

In another experiment, Wagner et al (1976) fed 100 mg/day of talc (5 days/week) or chrysotile in malted milk powder for 100 days over a 6-month period to groups of 32 Wistar SPF rats; 16 controls were fed only malted milk. The mean survival from the start of feeding was 614 days for talc, 618 for chrysotile, and 641 days for the controls. The only tumors which may have been associated with ingestion were two gastric leiomyosarcomas;

one in an animal fed talc and the other in one fed chrysotile. None occurred in the controls.

(c) Inhalation

Lynch et al (1957) exposed AC/Fl hybrid mice by inhalation to a commercial preparation of chrysotile asbestos and observed a higher incidence of multiple pulmonary adenomas in the exposed group of animals, 45.7% (58/127), as compared with the 36.0% (80/222) in controls. These results were reported as not statistically significant.

Reeves et al (1974) exposed groups of 30 Swiss mice to dusts of crocidolite, amosite, and chrysotile for 4 hours/day, 4 days/week, for 2 years at a mean concentration of about 50 mg/m^3. Two of the animals exposed to crocidolite developed papillary carcinomas of the bronchus, as did one of the nonexposed controls.

Gross et al (1967) observed carcinomas of the lung in rats repeatedly exposed to chrysotile dust with a mean concentration of 86 mg/m^3 for 30 hours/week. Twenty of 72 rats surviving for 16 months or longer developed adenocarcinomas and 4 developed squamous-cell carcinomas, whereas no tumors occurred in 39 controls. The authors suggested that the presence of trace metals from the hammers of the mill used to prepare the fiber was a factor in causing these tumors. However, this suggestion was not confirmed by subsequent experiments (Reeves et al, 1974; Wagner et al, 1974), thus leading Gross et al (1974) to retract the trace metal hypothesis for asbestos-induced neoplasia.

Reeves et al (1971) found squamous carcinomas of the bronchus in 2 of 31 rats which survived exposure to crocidolite for 2 years at a concentration of 49 mg/m^3 for 16 hours/week. Five rats in a group of 40

exposed to chrysotile developed pulmonary adenomatosis, but no malignant tumors were observed in rats exposed to either chrysotile or amosite.

In a subsequent experiment, Reeves et al (1974) exposed groups of 69 Charles River CD rats to crocidolite, amosite, and chrysotile for 4 hours/day, 4 days/week, for 2 years, at mean concentrations of about 50 mg/m^3 (Table II-4). In addition, groups of 20 rabbits, 32 guinea pigs, and 68 gerbils were exposed for 18 months to the same three asbestos dusts as the rats mentioned above. No tumors were observed, but mean survival times were not stated.

Wagner et al (1974) exposed groups of C/D Wistar rats to the five UICC asbestos samples at concentrations of about 12 mg/m^3 of dust for 7 hours/day, 5 days/week, for several lengths of exposure: 1 day, 3 months, 12 months, and 24 months. At the end of the periods of exposure, the amount of dust in the lungs of animals exposed to the two chrysotile samples was much less than in the animals exposed to the three amphibole samples. However, all types of fiber produced asbestosis which was progressive after removal from the dust. Furthermore, whereas no tumors were found in the control group, carcinogenicity was demonstrated in the groups exposed to chrysotile (Canadian or Rhodesian) and the amphiboles (Table II-5). An increasing incidence of neoplasms was observed with increasing exposures to each form of asbestos. Even as little as 1 day of exposure - when the animals were allowed to survive and were observed - produced neoplasia (Table II-6). One-day exposures to Canadian chrysotile produced lung tumors. Mesotheliomas were observed in 11 rats, 2 of which were exposed for only 1 day, one to amosite, and one to crocidolite.

Wagner et al (1976) compared rats exposed for a 2-year period to a

pure nonfibrous cosmetic talc, with another group of rats exposed to superfine chrysotile. Similar degrees of fibrosis were found in each group while one adenocarcinoma was found in an animal exposed to the chrysotile.

(d) Fiber Analysis in Tissue

Following inhalation, asbestos fibers found in sections of lung tissue were usually <3 μm in diameter and <100 μm in length. Thicker or longer fibers were either not inhaled or were rapidly cleared from the respiratory tract. On a weight basis, only a very small proportion of inhaled fiber was retained. An account of the inhalation of fibers is given by Timbrell (1965, 1972). Electron-microscopy is essential for studies of asbestos in tissue as many of the fibers of chrysotile and amphiboles are too small in diameter to be seen with the light microscope (Langer and Pooley, 1973).

The retention of different types of asbestos in animals following exposure to the same concentrations of respirable dust was described by Wagner et al (1974). For the amphiboles, there was a similar pattern with an almost proportional increase of lung dust with the dose. Much less dust was found for the chrysotiles and no increase of dust content in the lungs was shown. Dust in the lungs of animals exposed for 6 months had been partially cleared 18 months after the inhalation period. About 74% of the amosite and crocidolite and 41% of the anthophyllite were eliminated. The elimination rate of chrysotiles could not be exactly determined because of their low content in the lung (Figure II-1) (Wagner et al, 1974).

The penetration and clearance of radioactive UICC crocidolite has been studied in rats. After 30 days, the lung content of crocidolite was

reduced to 75% of the initial value (Evans et al, 1973).

In early experiments, guinea pigs and monkeys exposed to the four commercial types of asbestos developed fibrotic lesions of the lung and pleura similar to those seen in human cases of asbestosis (Vorwald et al, 1951; Wagner, 1963; Holt et al, 1965). In more recent experiments, this finding has been confirmed in rats (Wagner et al, 1973).

The question whether asbestos fibers can move from their site of primary deposition in the body and induce cancer in other sites is still a vexing one. Volkheimer (1973) and Schreiber (1974) have reported that particles and plant fibers ingested by experimental animals and man can penetrate the wall of the gastrointestinal tract and be transported throughout the body, possibly appearing in the urine. Westlake et al (1965) fed a diet containing 6% of chrysotile to rats and reported that the animals had fibers in the wall of the colon. Cunningham and Pontefract (1973) performed a similar experiment and reported that asbestos fibers appeared in the blood and various tissues. A more recent report by Gross et al (1974) concluded, however, that there was no satisfactory evidence from their study of transmigration of fibers outside the gastrointestinal tract.

In studies in which chrysotile labelled intrinsically with radioactive trace metals by neutron irradiation was injected intrapleurally into rats, Holmes and Morgan (1967) found evidence of where a small amount of the fiber passed from the pleural cavity and lungs into such other organs as the liver. In a later, similar experiment, Morgan et al (1971) reported that a population of radionuclides, consistent with that expected on the basis of the labelled chrysotile, was found in the heart, the lungs,

the diaphragm, and the chest muscles.

Karacharova et al (1969) and Friedrichs et al (1970) found some evidence of movement of asbestos fibers from an ip site of injection into various tissues in rats. The latter group of investigators reported that movement was inversely related to the length of the fiber, becoming essentially zero for fibers 20 or more μm long.

Roe et al (1967) and Kanazawa et al (1970) found evidence of transport of asbestos fibers from subcutaneous sites of deposition to such organs as the spleen, the liver, kidneys, and the brain of mice. Cunningham and Pontefract (1973, 1974) reported that iv-injected asbestos localized mostly in the liver and the lungs. The later paper found further that chrysotile injected iv into pregnant rats crossed the placenta and appeared in the livers and lungs of the fetuses.

Mutagenicity

Sincock and Seabright (1975) found that chrysotile and crocidolite asbestos dust in a concentration of 0.01 mg/ml in culture medium induced chromosomal aberrations in Chinese hamster cells. However, these changes were not observed with glass fiber or glass powder.

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SUMMARY TABLE OF ASBESTOS-INDUCED CARCINOGENICITY IN ANIMALS

Author	Date	Finding	Type of Animal	Dosage	Type of Fiber
INTRATRACHEAL INSTILLATION					
Miller	1965	Tumors of respiratory tract	Hamster	Unknown	Chrysotile with benzo (a) pyrene
Vosamae	1972	"	Rats	"	"
Pylev	1972	"	"	"	"
Pylev & Shabad	1973	"	"	"	"
Shabad et al	1974	Lung papillomas, epidermoid carcinomas reticulosarcomas, pleural mesotheliomas 6/21 and 6/11 rats within 9-28 mon	"	2 mg Russian chrysotile 5 mg benzo (a) pyrene	Russian chrysotile
INTRAPERITONEAL ADMINISTRATION					
Reeves et al	1971	3/13 peritoneal mesotheliomas with chrysotile 3/13 peritoneal mesotheliomas with crociodolite 0/11 peritoneal mesotheliomas with amosite After 7-17 mon	"	0.3, 0.5 or 1.0 ml of solution of 20 mg/ml.	Amosite Crocidolite Chrysotile
Maltoni	1973	31/50 mesothelioma in males 34/50 mesothelioma in females	Sprague-Dawley rats (18 wk old)	25 mg crocidolite	Crocidolite
Potts and Friedrichs	1972	40% tumor occurrence	Wistar rats	2, 6.25, 25, 75, 100 mg	Chrysotile A
Pott	1974	"	"	2, 10, 50 mg	"

SUMMARY TABLE OF ASBESTOS-INDUCED CARCINOGENICITY IN ANIMALS (CONTINUED)

Author	Date	Finding	Type of Animal	Dosage	Type of Fiber
INTRAPLEURAL ADMINISTRATION					
Wagner	1973	61% tumors with crocidolite 36% tumors with amosite 34% tumors with anthophyllite 30% tumors with Canadian chrysotile 19% tumors with Rhodesian chrysotile	Rats	20 mg	Crocidolite Amosite Anthophyllite Canadian chrysotile Rhodesian chrysotile
Stanton and Wrench	1972	Mesotheliomas in 60% rats	"	40 mg	Crocidolite Amosite and Rhodesian chrysotile
Pylev and Shabad	1973	Mesotheliomas	"	60 mg	Russian chrysotile
Groth et al	1975	No mesotheliomas-but animals killed 90-150 d after injection-insufficient latent period	Albino rats	Unknown	
Wagner	1976	18/48 mesotheliomas- 0/48 mesotheliomas-talc	Rats		Chrysotile Talc
Reeves et al	1971	1/15 mesothelioma with crocidolite 2/12 mesothelioma with chrysotile	"	.5 ml	Amosite Crocidolite Chrysotile
Reeves et al	1971	2/13 mesothelioma with chrysotile	Rabbit	.8 ml	Chrysotile
Shabad et al	1974	31/67 mesotheliomas within 2 yr	Rats	20 mg	Russian chrysotile

SUMMARY TABLE OF ASBESTOS-INDUCED CARCINOGENICITY IN ANIMALS (CONTINUED)

Author	Date	Finding	Type of Animal	Dosage	Type of Fiber
INGESTION					
Gross et al	1974	No significant difference in tumor incidence observed; survival rates not reported sample sizes were small	Rats	5% fiber by weight in food	Chrysotile and Crocidolite
Wagner et al	1976	2 gastric leiomyosarcomas, 1 in animal fed talc and 1 fed chrysotile	32 Wistar SPF rats	100 mg/d/ 5 d/wk 100 d over a 6-mon period	Chrysotile or Talc
INHALATION					
Lynch et al	1957	45.7 (58/127) pulmonary adenomas in exposed group 36.0% (80/222) pulmonary adenomas in controls	AC/F hybrid mice	Dust concentrations ranged from 150,000,000 to 300,000,000 particles per cc.	Chrysotile
Reeves et al	1974	2/30 bronchiogenic carcinoma with chrysotile	Swiss mice	50 mg/m^3 4 hr/d, 4 d/wk for 2 yr	Crocidolite Amosite Chrysotile
Gross et al	1967	20/72 rats surviving 16 mon or longer developed adeno-carcinomas 4/72 rats developed squamous-cell carcinomas 0/39 tumors in controls	Rats	86 mg/m^3 for 30 hr/wk	Chrysotile dust
Reeves et al	1971	2/31 rats developed carcinoma of the bronchus with crocidolite exposure 3/40 rats developed adenomatosis with chrysotile exposure	"	49 mg/m^3 for 16 hr/wk for 2 yr	Crocidolite Chrysotile Amosite

SUMMARY TABLE OF ASBESTOS-INDUCED CARCINOGENICITY IN ANIMALS (CONTINUED)

Author	Date	Finding	Type of Animal	Dosage	Type of Fiber
INHALATION					
Wagner et al	1974	Asbestosis produced with all types of fibers Lung Cancer / Mesothelioma / Fiber 11/146 — 1/146 — amosite 16/145 — 2/145 — anthophyllite 16/141 — 4/141 — crocidolite 17/137 — 4/137 — chrysotile (Canadian) 30/144 — 0/144 — chrysotile (Rhodesian)	C/D Wistar rats	12 mg dust hr/d -- d/wk for several lengths of exposure (1 d, 3 mon, 12 mon, 24 mon)	Chrysotile Amosite
Sincock and Seabright	1975	Chromosal abberation in Chinese hamster cells	Hamster	0.01 mg/ml	Chrysotile Crocidolite

TABLE II-1

TUMORS IN ABDOMEN AND/OR THORAX AFTER INTRAPERITONEAL INJECTION OF DIFFERENT FIBROUS AND GRANULAR DUSTS

Dust	Form*	Dose i.p. (mg)	Effective Number of Dissected Rats	First Tumor After ... Days	Average Survival Time of Rats with Tumors (days after inj.)	Rats with Tumor (%)
Chrysotile A UICC	f	2	37	431	651	16.2
"	f	6.25	35	343	501	77.1
"	f	25	31	276	419	80.6
"	f	4 x 25	33	323	361	54.5
"	f	3 x 25	33	449	449	3.0
" milled	f	4 x 25	37	400	509	32.4
Palygorscite	f	3 x 25	34	257	348	76.5
Glass fibers S + S 106	f	2	34	692	692	2.9
"	f	10	36	350	530	11.1
"	f	4 x 25	32	197	325	71.9
Gypsum	f	4 x 25	35	579	583	5.7
Nemalite	f	4 x 25	34	249	315	73.5
Actinolite	g	4 x 25	39	-	-	-
Biotite	g	4 x 25	37	-	-	-
Haematite (precipit.)	g	4 x 25	34	-	-	-
Haematite (mineral)	g	4 x 25	38	-	-	-
Pectolite	g	4 x 25	40	569	569	2.5
Sanidine	g	4 x 25	39	579	579	2.6
Talc	g	4 x 25	36	587	587	2.8
NaCl-Control	-	4 x 2m	72	-	-	-

*f = fibrous
g = granular
From Potts and Friedrichs (1972)

TABLE II-2

TUMORS IN ABDOMEN AND/OR THORAX AFTER INTRAPERITONEAL INJECTION OF GLASS FIBERS, CROCIDOLITE AND CORUNDUM

Dust	Form*	Dose i.p. (mg)	Effective Number of Dissected Rats	First Tumor After ... Days	Average Survival Time of Rats with Tumors (days after inj.)	Rats with Tumor (%)
Glass fibers						
MN 104	f	2	73	421	703	27.4
"	f	10	77	210	632	53.2
"	f	2 x 25	77	194	367	71.4
Glass fibers						
MN 112	f	20	37	390	615	37.8
Crocidolite	f	2	39	452	761	38.5
Corundum	g	2 x 25	37	545	799	8.1

*f = fibrous
g = granular
From Pott et al (1974)

TABLE II-3

PERCENTAGE OF RATS DEVELOPING MESOTHELIOMAS AFTER INTRAPLEURAL INOCULATION OF VARIOUS MATERIALS

Material	Percentage of rats with mesotheliomas
SFA Chrysotile	66
UICC crocidolite	61
UICC amosite	36
UICC anthopyllite	34
UICC chrysotile (Canadian)	30
UICC chrysotile (Rhodesian)	19
Fine Glass Fibre (code 100)	12
Ceramic fibre	10
Glass powder	3
Coarse glass fiber (code 110)	0

From Wagner et al (1976)

TABLE II-4

INHALATION CARCINOGENESIS FROM VARIOUS FORMS OF ASBESTOS

Form of Asbestos	Number of Tumors
Controls	no tumors
Amosite	2 pleural mesotheliomas
Crocidolite	3 squamous-cell carcinoma, 1 papillary carcinoma and 1 adenocarcinoma, all of lungs.
Crysotile	1 papillary carcinoma, 1 squamous-cell carcinoma of lungs, and 1 pleural mesothelioma.

From Reeves et al (1974)

TABLE II-5

NUMBER OF ANIMALS WITH LUNG TUMORS OR MESOTHELIOMA ACCORDING TO TYPE OF ASBESTOS

Dust	No. of Animals	Tumor Type		
		Adenocarcinoma	Sq. Carcinoma	Mesotheliomas
Controls	126	0	0	0
Amosite	146	5	6	1
Anthopyllite	145	8	8	2
Crocidolite	141	7	9	4
Chrysotile (Canadian)	137	11	6	4
Chrysotile (Rhodesian)	144	19	11	0

From Wagner et al (1974)

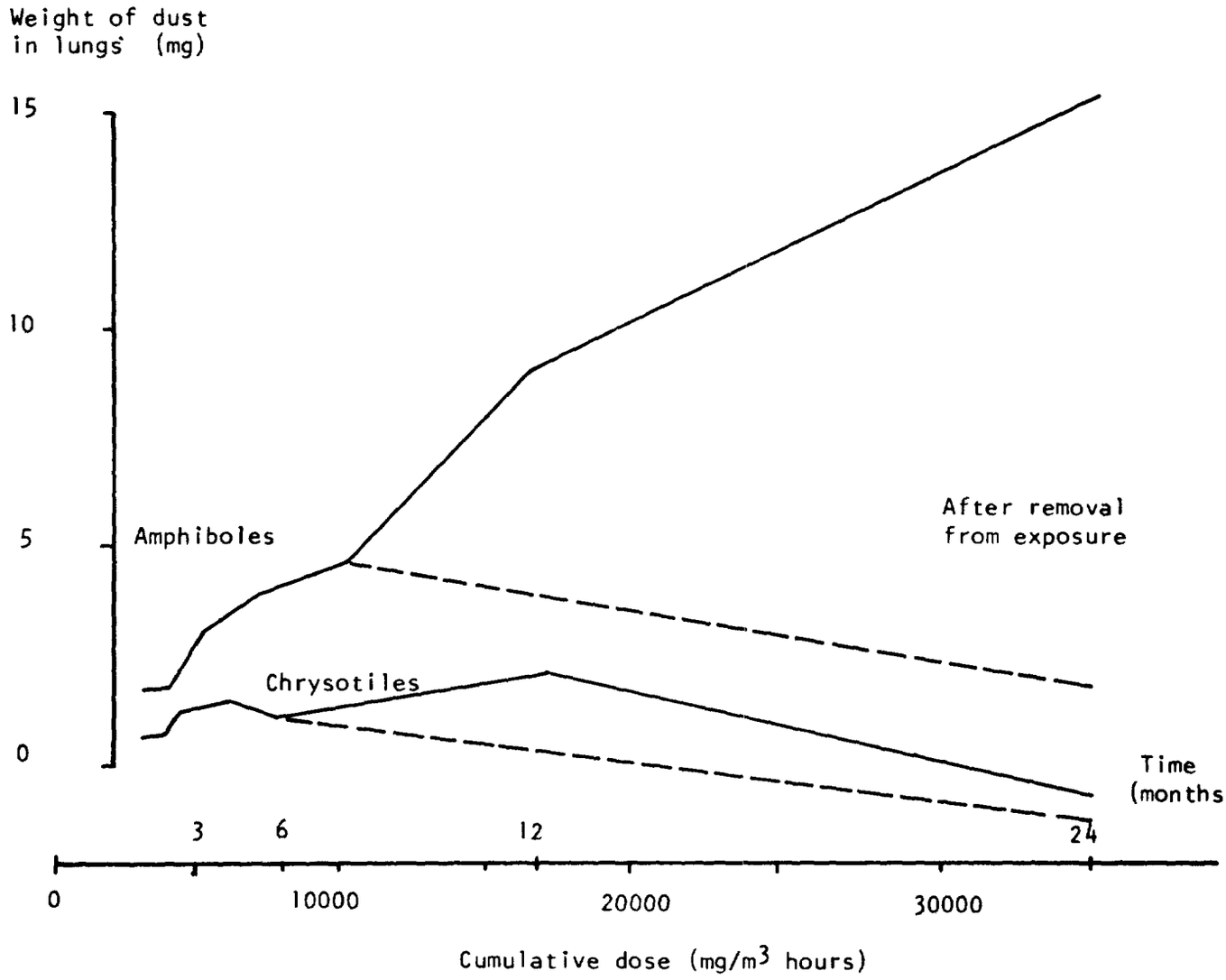
TABLE II-6

NUMBER OF ANIMALS WITH LUNG TUMORS OR MESOTHELIOMA ACCORDING TO LENGTH OF EXPOSURE

Length of Exposure	No. of Animals	No. with Lung CA	No. with Pleural Mesotheliomas	% of Animals with Tumors
Controls	126	0	0	0.0
1 d	219	3	2	2.3
3 mon	180	8	1	5.0
6 mon	90	7	0	7.8
12 mon	129	35	6	31.8
24 mon	95	37	2	41.0

From Wagner et al (1974)

Effects of Inhalation of Asbestos in Rats



Mean weight of dust in lungs of rats in relation to dose and time.
from Wagner et al (1974)

FIGURE II-1