FINAL PROGRESS REPORT FOR

GRANT 2501 OH 00332

AQUEOUS SURFACE CHEMISTRY

OF ASBESTOS MINERALS

Principal Investigator:

Ross W. Smith
University of Nevada
Reno, Nevada

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Summary

Data was obtained on the manner and quantity in which hydroxyl and other ions leave asbestos mineral's surfaces as a function of aging time in water. In relatively pure water systems a parallelism was noted between magnesium dissolution and pH change for all asbestos minerals studied. The magnesium and hydroxyl dissolution reactions are diffusion controlled. Silica is more readily dissolved from crocidolite than from either chrysotile or amosite. The work is presently being extended to dissolution of minor metal ions associated with asbestos fibers.

Additional dissolution work was carried out in various salt solutions buffered near neutrality. Magnesium readily dissolved from chrysotile in these systems as did also magnesium, iron and sodium from crocidolite and magnesium, iron and manganese from amosite. It was also possible to extract a small quantity of nickel, but not chromium, from chrysotile. In buffered salt solutions extrapolation of dissolution data indicates that metal ions should continue to dissolve from the minerals for decades.

Electrokinetic work shows that chrysotile placed in water initially has a surface approaching that of pure $Mg(OH)_2$, but after long aging in water its surface approaches that of nonasbestiform serpentine.

Biological work attempting to relate pretreatment of asbestos fibers to their carcinogenicity and fibrogenicity indicates that chrysotile appears more likely to induce tumors in rats than acid treated chrysotile or other asbestos minerals.

Detailed Report

In the original proposal for this grant, it was proposed that:

1) a systematic study of the aqueous surface chemistry of asbestos minerals be undertaken;

2) the details of adsorption on the surface of the minerals be studied by electron microscopy;

3) coagulation and dispersion of the minerals by heavy metal ions be studied.

Later, through discussion and correspondence with the National Institute for Occupational Safety and Health, it was decided that additional studies should be undertaken investigating the carcinogenicity and/or fibrogenicity of fibers that had been treated in various ways.

Regarding item (1) above, the following data have been obtained and conclusions have been reached:

The kinetics of dissolution of asbestos minerals in pure aqueous systems were investigated over a temperature range of 5°C to 45°C. In this study a parallelism was noted between the rate of dissolution of magnesium from magnesium silicates and the rate of pH change. Further, rate of the dissolution reaction was directly proportional to the specific surface area of the asbestos minerals.

Both magnesium ion and hydroxyl ion concentrations were temperature sensitive only in the initial stage of the reaction between the mineral chrysotile and water. Mechanism of dissolution of ionic species from the mineral was considered in terms of the energy of activation. The activation enthalpies were calculated to be 5.5 and 6.5 kcal per mole for dissolution of magnesium and increase of hydroxyl ion concentration in solution, respectively. These numerical values indicate that the magnesium and hydroxyl dissolution reactions are diffusion controlled. Further, the diffusion is probably through a layer of water near the minerals' surface.

For the fibrous amphibole minerals amosite and crocidolite short term dissolution experiments showed congruent dissolution in water. This short term dissolution behavior was dependent on initial pH, surface area and rate of stirring if the system was stirred. The rate of dissolution was in the order crocidolite > amosite. Ultimately higher pH values were obtained with amosite compared to crocidolite. Kinetic experiments lasting for short times in the

temperature range 5-45°C showed that the rate of pH increase and final pH were higher at lower temperatures. A higher rate of dissolution of soluble silica at higher temperatures was thought to be responsible for the phenomenon. The ratio $(Mg^{2+})/(SiO_{2(ag.)})$ was found to decrease with time and temperature. Analysis of crocidolite extractions showed negligible dissolution of ferrous iron from the minerals.

Long term aging experiments with amosite and crocidolite showed that the equilibrium pH ultimately started decreasing at long aging time. The decrease probably is the result of the formation of $FeOH^+$, $MgOH^+$, etc., complexes or readsorption of $Mg(H_2O)_6^{2+}$, $FeOH^+$, and $MgOH^+$ ions back onto the negatively charged mineral surface sites exposed during leaching of the fibers.

Activation enthalpies calculated for these two amphibole minerals from the short term experiments were of similar magnitude to those calculated for chrysotile.

Dissolution of silica from asbestos minerals was studied. Figure 1 shows the amount of dissolved silica as a function of pH after one hour aging. Crocidolite liberates more silica than chrysotile. The phenomenon is not surprising if one considers the difference in structure of the two minerals. The amphiboles, such as crocidolite, in which the silicate oxygens are on the outside of the layers and the metallic hydroxides are masked within, must have better resistance to acids. In case of chrysotile, the magnesium hydroxide part of each layer is closest to the fiber surface, and the silica tetrahedra are within the structure. Thus, the poor resistance of chrysotile to acid attack is readily explained. It is surprising, however, that amosite, an amphibole, liberates almost the same amount of dissolved silica as chrysotile. Visual observation of crocidolite and amosite suspensions indicates that they are finely dispersed and appear colloidal in nature. Also it takes a long time to filter them. In contrast, chrysotile slurries show two distinct layers of water and chrysotile, and the filtering rate is relatively rapid.

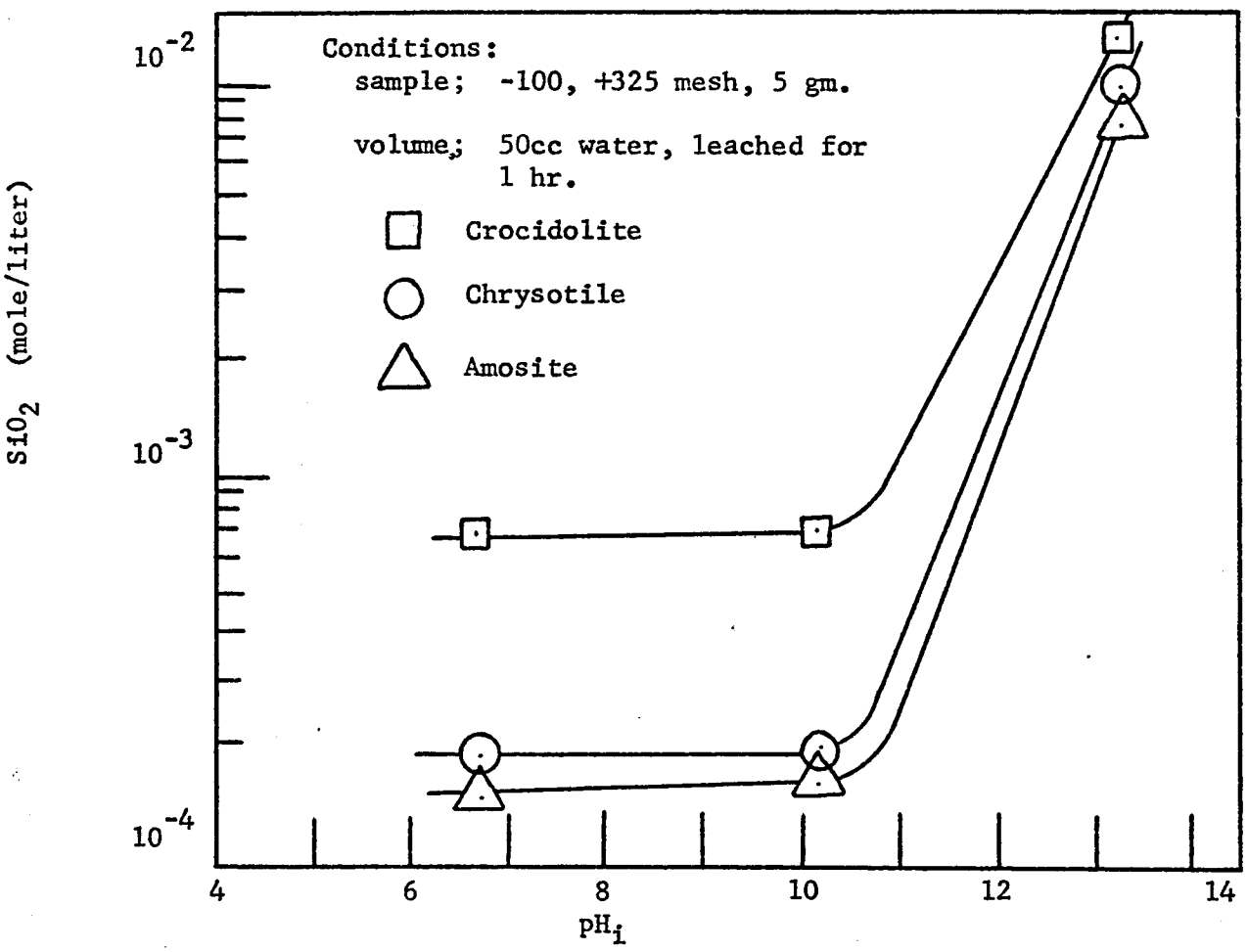

Figure 1. Dissolved silica as a function of pH.

No attempt was made to measure the concentration of the dissolved silica below neutral pH, since solubility of silica is rather low in mildly acid environments. In strongly alkaline solutions silica dissolves much more readily. The dissolved species can be considered to be H_2SiO_3, $HSiO_3^-$ and SiO_3^{--}. Below pH 10, the most predominant dissolved silica species is H_2SiO_3. Between pH 10 and pH 12, $HSiO_3$ may be present. At more alkaline values than pH 12 the dissolved silica may be SiO_3^{--}. Equilibrium relations for these species may be written as follows:

$$SiO_2 + H_2O = H_2SiO_3$$

$$SiO_2 + H_2O = HSiO_3^- + H^+$$

$$SiO_2 + H_2O = SiO_3^{--} + 2H^+$$

$$H_2SiO_3 = HSiO_3^- + H^+ \qquad \log\frac{(HSiO_3^-)}{(H_2SiO_3)} = -10 + pH$$

$$HSiO_3^- = SiO_3^{--} + H^+ \qquad \log\frac{(SiO_3^{--})}{(HSiO_3^-)} = -12 + pH$$

During our studies an extremely interesting finding was of the change of specific surface areas of finely ground chrysotile (-325 mesh) before and after acid leaching. In fact, the mean specific surface area of the acid leached chrysotile is several times greater than that of untreated chrysotile. Table 1 shows the specific surface areas of various types of asbestos samples.

Table 1

The Specific Surface Area of Asbestos Samples

Sample	Specific Surface Area $m^2/gr.$
Chrysotile, -325 mesh	23.0
Chrysotile, -325 mesh, leached	150.0
Chrysotile, -100 + 200 mesh	33.4
Chrysotile, - 20 + 35 mesh	30.0
Chrysotile, ~10 mm	16.6
Chrysotile, fiberized	20.4
Crocidolite, -325 mesh	6.67
Amosite, -325 mesh	6.22

The work on dissolution of metal ions from asbestos minerals in relatively pure systems is currently being extended to include dissolution of minor metal ions associated with asbestos fibers.

In addition to the studies in essentially pure water systems, dissolution experiments were carried out in aqueous solutions of selected salts. It was thought that these experiments would more closely approximate behavior of asbestos fibers when subjected to mammalian body fluids.

In this latter investigation most of the dissolution experiments were carried out in initially neutral salt solutions, some of which were buffered. Emphasis was placed upon monitoring the dissolution of silica and the major cations from the minerals. These cations were Mg^{2+}, Fe^{2+} and Mn^{2+} from amosite, Mg^{2+}, Na^{+}, and Fe^{2+} from crocidolite and Mg^{2+} from chrysotile. In addition, an attempt was made to obtain data on Co^{2+}, Ni^{2+} and Cr^{3+} leached from chrysotile. No Cr^{3+} was detected in any of the solutions. Co^{2+} was detected in only those tests conducted under acid conditions. Small quantities of Ni^{2+} were detected in neutral as well as acid systems and Ni^{2+} extraction appeared to be proportional to Mg^{2+} extraction with the approximate relation [Conc. Ni extracted = 1/3000 Conc. Mg extracted] obtaining. Salt solutions studied included Na^{+}, K^{+}, NH_4^{+} and Zn^{2+} chloride, acetate and phosphate solutions. Salt concentrations used were from 0.01 molar to 1.0 molar. The pH of most solutions was adjusted to pH7 although some studies in the NH_4^{+} system were carried out at pH 4.8.

From the work in salt solutions, several conclusions have been reached including:

1) As the ratio of mineral to solution decreases, the rate of cation removal (expressed as a percentage of that initially present) from the asbestos minerals increases.

2) Dissolution of cations from the asbestos minerals increases with vigor of agitation. A straight line plot of cumulative percent cation extracted versus natural log of the extraction number allows extrapolation of experimental data to obtain estimates of fiber dissolution over long periods of time. Data on the extrapolated amounts of several metals extracted from asbestos minerals (1 gm. mineral in 40 ml IN NH_4Cl solution, stirred) are shown in Table II.

Table II

Extrapolated Data from Long Time Extraction Experiments

Values tabulated are precent of total in mineral removed.

Time	Amosite			Crocidolite			Chrysotile
	Mg	Fe	Mn	Mg	Fe	Na	Mg
1 year	5.3	5.0	15.5	23.9	8.8	7.2	68.8
10 years	6.3	6.1	18.9	27.9	10.6	8.2	75.7
20 years	6.5	6.4	19.5	29.0	11.2	8.4	77.8

The data of this table show that quantities of metal ions can continue to dissolve from asbestos minerals in buffered salt solutions for decades. The finding may be of importance when considering long range effects of asbestos fibers residing in mammalian lungs.

3) The amount of Mg and SiO_2 extracted from the minerals in neutral salt solutions increases from amosite to crocidolite to chrysotile, in order of increasing specific surface area.

4) The dissolution of chrysotile is effected by the buffer capacity of the leach solution. The amount of extractable Mg and SiO_2 from chrysotile increases with increasing buffer strength of solution.

5) Calculations made from extraction data of the ammonium acetate solutions indicate that the breakdown of $Mg(OH)_2$ in chrysotile is nonstoichiometric in these buffered systems.

6) A correlation exists between Ni and Mg extracted from chrysotile.

7) The cation exchange capacity of the minerals with the NH_4^+ ion is low and apparently not related to cation removal. The capacity of the minerals to adsorb Zn from 1N $ZnCl_2$ is roughly equivalent to the total amount of cations removed from each mineral.

From an electrokinetic study of variation of point of zero charge (PZC) of both simple and complex oxide minerals, interesting data were obtained relative to the changing nature of asbestos mineral's surfaces upon aging in aqueous media.

Figure 2 shows PZC data obtained as a function of aging time in water for chrysotile, non asbestiform serpentine and crocidolite.

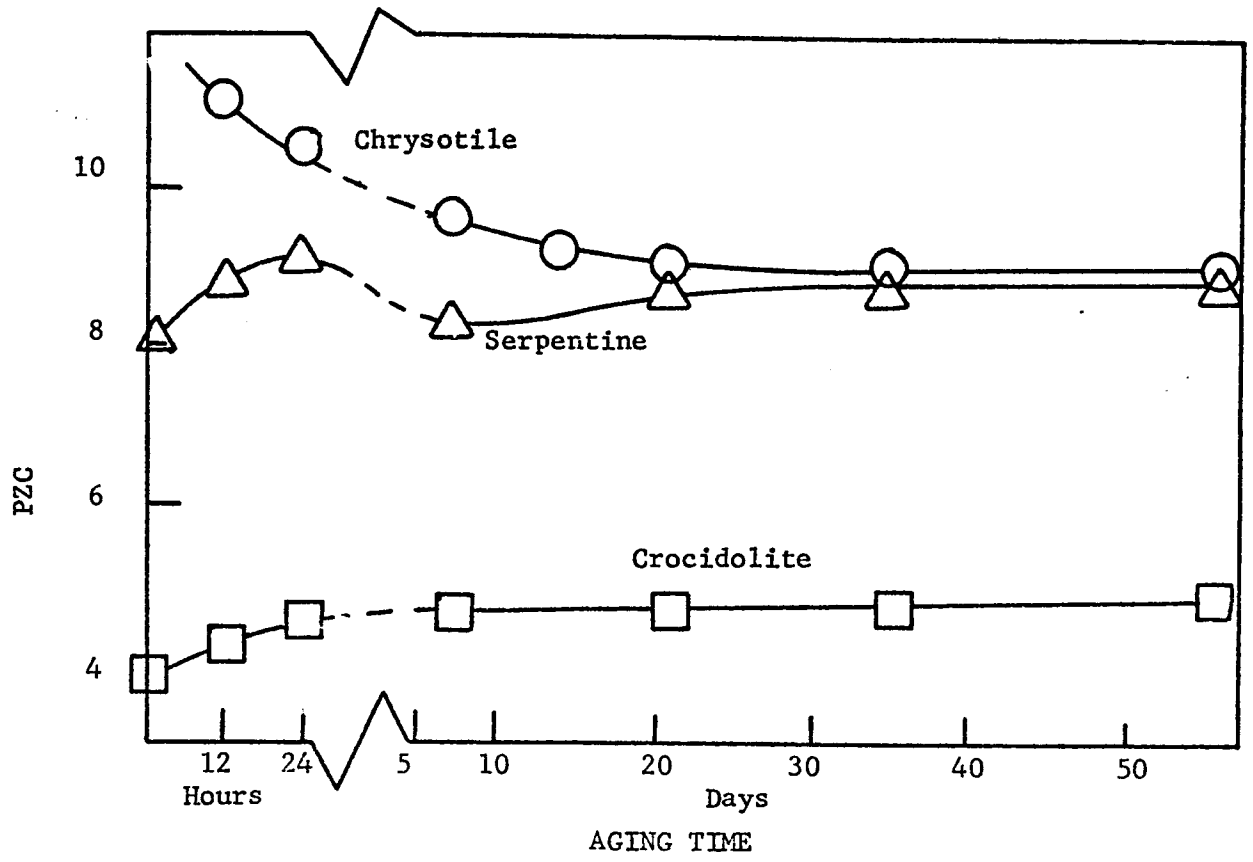

Figure 2. Variation of PZC of chrysotile, serpentine and crocidolite as a function of aging time in water.

According to Figure 2, chrysotile initially has a high PZC value (approximately the same as brucite, pure $Mg(OH)_2$). However, the PZC decreases as a function of time, appearing to roughly level off near 9 after long aging time. Presumably, magnesium is leaving the chrysotile surface as a function of time shifting the PZC to more acid values. Of course at the same time, some smaller

quantity of silica should be going in solution. After long aging some magnesium, perhaps in a new magnesium silicate form, should go back out of solution and the process of dropping PZC should slow down. Ultimately equilibrium should be achieved. The "new" surface, however, will be different from the initial surface. If one looks at the curve for serpentine an interesting phenomenon is observed. The PZC (8 at the start of aging) increases with aging time rather rapidly, then drops, and ultimately rises again to a value nearly that of chrysotile at long aging times. It appears that ulitmately, the surfaces of the two minerals become quite similar at least as regards electrokinetic behavior. Presumably in both cases an equilibrium is set up between complex magnesium hydroxy, silicate, and mixed species and a new surface phase which appears to be similar in character for the two different minerals. This surface is probably a 3Si-2Mg surface. The rise in PZC for crocidolite as a function of aging time can be explained partly in terms of dissolution of an amorphous surface followed by readsorption of complex aqueous species.

The significance of the electrokinetic work is, however, the apparent dissimilarity of chrysotile and non asbestiform serpentine surfaces immediately after placing them in water and their similarity after several weeks aging in water.

Regarding item (2) of the original proposal, experiments were undertaken adsorbing negatively charged gold particles onto the surface of chrysotile in aqueous environments. The pH of the suspensions was varied. Visual study of the adsorption was performed by observing chrysotile fibers so treated under the electron microscope.

Adsorption of negatively charged gold particles was seen to take place both at the edges and along the curved surface, showing the presence of positive sites at the surface and the edges. However, unlike the surface sites, not all the edges seemed to have adsorbed charged gold particles. This may be because of the manner in which bonds are broken when fibers are fractured. If positive sites

are not exposed upon fracture or upon subsequent leaching, no adsorption would be expected.

The amount of adsorption was greater in the acid pH range down to about pH 4. A working hypothesis capable of accounting for the observed behavior of chrysotile could be constructed by regarding the surface of chrysotile fibers as a magnesium hydroxide layer on a silica substrate. In contact with relatively pure water the fiber surface dissociates partially until an equilibrium of the order of that attained by pure magnesium hydroxide is reached. Under these conditions a slight excess of hydroxyl ions appear to exist at the fiber surface which accounts for the observed negative zeta potential after long aging. Increasing the hydroxyl ion concentration of the suspending medium represses the dissociation of the fiber surface by a common ion effect. This phenomenon could explain why there is a lesser amount of adsorption of gold particles in the basic solutions. On the other hand, when the suspending medium was acidic, the dissociation of surface was more pronounced because of the interaction of the surface hydroxyl groups with hydrogen ions. Probably, the net result was to bring about an excess of dissociated magnesium sites at the surface of the fiber which gave the particle a positive zeta potential and hence greater adsorption of gold particles. However, in yet more acid media the chrysotile was guite soluble. Visible evidence for this phenomenon was observed in micrographs of suspensions of pH 2 and 4. In these electron micrographs, the regular features of chrysotile fibers indicating tubular morphology had disappeared causing the fibers to look like flat laths, having serrate and pitted surfaces. Adsorption of gold particles was much less under such conditions.

Item 3 of the original proposal was abandoned in favor of the experiments involving dissolution of asbestos fibers in buffered salt solutions.

The studies relating to effect of pretreatment of asbestos fibers to their fibrogenicity and carcinogenicity were begun during the summer of 1970. These

studies were primarily conducted by Dr. Robert Thomas of Chico State College, Chico, Calif. Some of this work has not yet been completed. Some work was also performed by Dr. William Smith, Fairleigh Dickinson University, Madison, New Jersey.

In the work carried on by Dr. Thomas, intrapleural injections of asbestos samples were administered to rats. At various time intervals, rats that received untreated asbestos samples were sacrificed and necropsies performed. The thoracic cavity was opened and examined under a dissecting microscope. Observations were recorded and tissues taken for histological examination. Rats that have died have been similarly handled. Results to date are shown in Table III in which are shown animals receiving treatment and surviving for more than 30 days. The few animals which died within 30 days of treatment were considered to have died as a result of the injection or subsequent infection. In all cases these animals were not considered in the analysis of the results but were replaced with other animals where possible.

Table IV lists the results of the post-mortem examination. Fifty-four per cent of the animals receiving an injection of asbestos developed mesothelioma. The first death resulting from a mesothelioma occurred in the crocidolite group 54 weeks after injection. Two further lethal mesotheliomas were noted in this group at 66 and 76 weeks. Lethal mesotheliomas occurred in the chrysotile group at 65, 65, 70, and 72 weeks post injection. The first lethal mesotheliomas in the amosite animals did not occur until the 81st week. This does not agree with the results obtained by several other investigators who found an earlier occurrence of mesothelioma with amosite than with chrysotile or crocidolite. It should be pointed out, however, that at this point of the study, 80 per cent of the posted animals which received amosite have developed mesothelioma compared to only 40 per cent and 54 per cent for chrysotile and crocidolite respectively.

Fibrosis within the thoracic cavity was evident in all the animals

receiving asbestos injections with but two exceptions. It is expected that the injections were somehow misplaced in these two instances. Neoplasms outside the pleural cavity were found in approximately 19 per cent of the animals posted to date. Mammary neoplasms have been found in approximately 21 per cent of our animals. In more instances the mammary tumors were surgically removed and histologic examination performed. Other common neoplasms noted involved the adrenals and genital organs.

The animals which developed mesotheliomas appeared to be under no physical stress until just before death. In the majority of these animals, death appeared to be due to a large intrapleural hemmorrhage. The tumors found varied in size from a large mass completely enveloping the right lung to a few small nodules on the parietal pleura and diaphragm. Histologically, the tumors appear to be similar to those reported in other studies with spindle cells predominating.

At this point of the study, no statistical analysis would be valid and no conclusions can be made regarding the effect of the acid and water leaching of the asbestos fibers on carcinogenesis. Indications are, however that there will be no appreciable differences. The relationship between fiber size and tumor yield also awaits analysis.

Table III

Numbers of Experimental Animals

Sample	Number of Animals	Necropsies Performed to Date
Chrysotile A (Untreated)	8	8
" (1 N HCl-1 hr)	8	8
" (H_2O-1 wk)	8	2
" (H_2O-6 mo)	8	0
Chrysotile B (Untreated)	8	8
" (1N HCl-1 hr)	8	8
" (H_2O-1 wk)	8	2
" (H_2O-6 mo)	8	0
Amosite (Untreated)	8	8
" (1N HCl-1 hr)	8	8
" (H_2O-1 wk)	8	4
" (H_2O-6 mo)	8	0
Crocidolite (Untreated)	8	8
" (1N HCl-1 hr)	8	8
" (H_2O-1 wk)	8	4
" (H_2O-6 mo)	8	0
Chrysotile A-325 (Untreated)	8	0
" " (6N HCl-2 hr)	8	0
Chrysotile B-325 (Untreated)	8	8
" " (6N HCl-2 hr)	8	4
Amosite 325 (Untreated)	8	0
" " (6N HCl-2 hr)	8	0
Crocidolite 325 (Untreated)	8	4
" " (6N HCl-2 hr)	8	0
Serpentine 325 (Untreated)	8	2
" " (6N HCl-2 hr)	8	4

Table IV

Necropsy Findings

Sample	Number of Animals	Mesothelioma	Other Neoplasms	Fibrosis
Chrysotile A (Untreated)	8	4	2	8
" (1N HCl- 1 hr)	8	4	1	7
" (H_2O-1 wk)	2	1	1	2
" (H_2O-6 mo)	0			
Chrysotile B (Untreated)	8	6	3	8
" (1N HCl-1 hr)	8	6	3	8
" (H_2O-1 wk)	2	0	1	2
" (H_2O-1 mo)	0			
Amosite (Untreated)	8	4	1	8
" (1N HCl-1 hr)	8	8	1	8
" (H_2O-1 wk)	4	2	0	4
" (H_2O-6 mo)	0			
Crocidolite (Untreated)	8	4	2	8
" (1N HCl-1 hr)	8	4	1	8
" (H_2O-1 wk)	4	2	0	4
" (H_2O-6 mo)	0			
Chrysotile A-325 (Untreated)	0			
" " (6N HCl-2 hr)	0			
Chrysotile B-325 (Untreated)	8	4	1	8
" " (6N HCl-2 hr)	4	0	0	4
Amosite 325 (Untreated)	0			
" " (6N HCl-2 hr)	0			
Crocidolite 325 (Untreated)	4	3		4
" " (6N HCl-2 hr)	0			
Serpentine 325 (Untreated)	2	0	1	2
" " (6N HCl-2 hr)	4	0	1	4
Saline Controls	8	0	3	0
Mg 0	2	0	3	0
Fe_2O_3	2	0	0	1

Some further tests on the biological acticity of treated fibers was performed, as noted before, by Dr. William Smith. In his studies Dr. Smith measured short term biologic effects on hampsters.

His findings can be summarized as follows:

1) Serpentine was the least active sample. HF treatment of serpentine, however, enhanced biologic activity and resulted in a product that was distinctly more irritating than untreated serpentine.

2) The sample of chrysotile was more active than serpentine but less active than crocidolite.

3) HCl treatment of chrysotile reduced activity as judged by findings at 3 months, but findings at 5 months suggest no difference between responce to HCl treated chrysotile as compared to untreated chrysotile.

4) HF treatment of chrysotile enhanced biologic activity and resulted in a product that was distinctly more irritating than untreated chrysotile.

5) HCl treatment of crocidolite reduced biologic activity and resulted in a product that was distinctly less irritating than untreated crocidolite.

6) HF treatment of crocidolite reduced activity as judged by findings at 3 months, but findings at 5 months suggest no difference in response to HF treated crocidolite as compared to untreated crocidolite.

In addition a study was initiated by Dr. Thomas of the migration of asbestos fibers from a subcutaneous injection site in mice. Conflicting reports are found in the literature as to whether or not asbestos fibers do indeed migrate through the tissues and if so, by what route. There is also some disagreement as to whether or not the fibers show a preference for specific tissues. In this study, asbestos fibers were injected subcutaneously in the flank of mice. Lymph nodes in the immediate area of the injection and from the pectoral area were removed from individual mice one day post-injection and continuing up to three months. Blood samples were obtained prior to sacrificing the animals and examined for the

presence of asbestos. Histological examinations were made of the lymph nodes using standard techniques. A paper reporting results of this study is in preparation.

Publications, Theses and Reports

Theses:

Trivedi, N., "Electrokinetic Behavior of Asbestos Minerals as a Function of Aging Time in Water", M.S. Thesis, Univ. of Nevada (1970).

Malghan, S. G., "The Dissolution Kinetics of Fibrous Amphibole Minerals in Water", M.S. Thesis, Univ. of Nevada (1971).

Allen, M., "Dissolution and Cation Exchange Properties of Some Asbestos Minerals", M.S. Thesis, Univ. of Nevada (1972).

Gupta, A. K., "Reaction Rate Studies of Asbestos Minerals with Acids", M.S. Thesis, Univ. of Nevada (1972).

Publications:

Choi, I. K. and Smith, R. W., "Kinetic Study of the Dissolution of Asbestos Fibers in Water", Journ. of Col. and Interf. Sci., Vol. 40, No. 2, pp. 253-262 (1972).

Smith, R. W. and Trivedi, N., "Variation of Point of Zero Charge of Oxide Minerals as a Function of Aging Time in Water", Accepted for publication in Trans. AIME.

Publications in Preparation:

Thomas, R. E., and McGuire, J. E., "Lymphatic Migration of Asbestos Fibers From a Subcutaneous Injection Site".

Choi, I. K. and Smith, R. W., "Theoretical Model for the Surface Area of Asbestos Minerals".

Malghan, S. G., Choi, I. K., and Smith, R. W., "Kinetics of Dissolution of Amosite and Crocidolite in Aqueous Solutions"

Choi, I. K. and Smith, R. W., "Identification of the Transition Elements from Asbestos Minerals and Their Chemical Behavior in Aqueous Solution".

Publications Planned:

Allen, M. and Smith, R. W., "Dissolution of Asbestos Minerals in Salt Solutions".

Gupta, A. K. and Smith, R. W., "Reaction of Asbestos Minerals with Selected Acids".

Progress Reports*:

Choi, I. K., "Some Surface Properties of Asbestos Minerals", p. 22, in Minerals Research Progress Report, July 1971, Dept. of Chemical and Metallurgical Engineering, Univ. of Nevada, Reno.

Allen, M., "Dissolution and Cation Exchange Properties of Some Asbestos Minerals", p. 1, in Minerals Research Progress Report, July 1971, Dept. of Chem. and Met. Engr., Univ. of Nevada, Reno.

Smith, R. W. and Trivedi, N., "Variation of Point of Zero Charge of Oxide Minerals as a Function of Aging Time in Water", p. 37, in Minerals Research Progress Report, July 1971, Dept. of Chem. and Met. Engr., University of Nevada, Reno.

Thomas, R. E., "Carcinogenesis of Asbestos Fibers as Related to Surface Chemistry", p. 54 in Minerals Research Progress Report, July 1971, Dept. of Chem. and Met. Engr., Univ. of Nevada, Reno.

Malghan, S. G., "Characterization of the Activity of Submicroscopic Surface Regions of Chrysotile", p. 77 in Minerals Research Progress Report, July 1971, Dept. of Chem. and Met. Engr., Univ. of Nevada, Reno.

*Twenty copies of the report, "Minerals Research Progress Report (1971)" were sent to the National Institute for Occupational Safety and Health, PHS during the summer of 1971.

Malghan, S. G., "Dissolution Studies of Amosite and Crocidolite in Aqueous Solutions", p. 65 in Minerals Research Progress Report, July 1971, Dept. of Chem. and Met. Engr., Univ. of Nevada, Reno.

Sharma, Deva D., "A New Method of Trace Element Analysis of Asbestos Minerals" to be included in Minerals Research Progress Report about July 1973, Dept. of Chem. and Met. Engr., Univ. of Nevada, Reno.

Thomas, Robert E., "Carcinogenesis of Asbestos Fibers as Related to Surface Chemistry", to be included in Minerals Research Progress Report about July 1973, Dept. of Chem. and Met. Engr., Univ. of Nevada, Reno.

McGuire, James E., and Thomas, Robert E., "Migration of Asbestos Fibers in the Lymphatic System of Mice", to be included in Minerals Research Progress Report about July 1973, Dept. of Chem. and Met. Engr., Univ. of Nevada, Reno.

Allen, Merrill, "Dissolution of Asbestos Minerals in Neutral Salt Solutions" to be included in Minerals Research Progress Report about July 1973, Dept. of Chem. and Met. Engr., Univ. of Nevada, Reno.

Allen, Merrill, "The Correlation Between Ni and Mg Dissolution from Chrysotile" to be included in Minerals Research Progress Report about July, 1973, Dept. of Chem. and Met. Engr., Univ. of Nevada, Reno.