Gordon Zucker, Dr. Eng. Sc.

1. Education, Expertise and Qualifications

I am Professor Emeritus of Mineral Processing Engineering at Montana Tech of the University of Montana. I graduated from Massachusetts Institute of Technology in 1951 with a Bachelor of Science Degree in Metallurgy, specializing in Mineral Engineering. I received a Master of Science Degree in 1954 in Metallurgical Engineering from the University of Wisconsin. From June 1954 to January 1956, I attended Penn State University and was a certified candidate for Ph.D in Mineral Industries, specializing in Mineral Preparation. In 1959, I received a Doctor of Engineering Science Degree in Mineral Engineering from Columbia University, School of Mines.

Following graduation from MIT and graduate work at Columbia University, School of Mines, I worked as Senior Scientist for Texas Instruments and Sperry Rand. From 1964 to 1972, I held various positions at Cadillac Gage Company, Union Carbide Corporation and Tansitor Corporation. In 1972, I joined Siemens Corporation as the Manager of Engineering. In 1975, I joined Montana College of Mineral Science & Technology in Butte, Montana and served as a tenured professor in the Department of Metallurgical Engineering until my retirement in 1994. During that period I was granted The Distinguished Anaconda Professor of Mineral Processing Engineering Chair.

During my tenure at Montana College of Mineral Science & Technology, I took annual trips to Libby, Montana to see and learn about the mining and milling operations conducted by W. R. Grace & Co. I often took students on those trips. I would explain and point out how the processing plant used unique equipment. At the time of those visits, the new wet mill had been built. I had studied W.R. Grace's original dry mill operation from documents in historical files at Montana College of Mineral Science and Technology. I also had designed a 100 tons per day dry mill which was built near Victor, Montana. I also have served as an expert witness for W. R. Grace on several occasions in personal injury litigation. In connection with that work, I have examined Grace's internal documents relating to its mining, milling and expansion operations including analytical data for most of the years from 1970 to 1990.

My specialization in Mineral Engineering has included training in mineralogy and geology. I have taught x-ray diffraction courses and made ore body geology and mining methods part of each mineral processing course content. In the engineering of minerals, geology is the description of how the minerals occur and mining is the first step in liberating the minerals from the earth.

A copy of my CV is attached as Exhibit A.

2. Executive Summary

I have been asked by W. R. Grace: 1) to review and opine generally on the geology of the Libby, Montana area, particularly surrounding the W.R. Grace mine site; 2) to provide a summary of the mining and beneficiation processes at Libby and opine as to the reduction of amphibole content of the ore during those processes; and, 3) to opine on the engineering controls for dust suspension utilized by W. R. Grace in the milling operations at Libby. Based on my review and experience, I have reached the following opinions:

1. The vermiculite ore body at Libby contains significant quantities of non-asbestos amphiboles and quantities of asbestiform or fibrous amphiboles.

2. While the amphibole content of the vermiculite ore prior to mining could have reached 15-20% in certain locations in the mine, the mining process reduced the amphibole content of the ore even before it was transferred to the mill for processing.

3. The beneficiation process at the mill was designed to reduce the level of impurities (including amphiboles) to derive the purest vermiculite concentrate possible. During each stage of the beneficiation process, the total amphibole content was reduced. W.R. Grace continuously made improvements to the process. These improvements and other constant efforts to improve vermiculite concentrate purity resulted eventually in vermiculite concentrate with only a small fraction of a percent of total amphiboles. By the 1980's, the total maximum amphibole content in the vermiculite ranged from 0.1% to 0.3%.

4. Both prior to the implementation of the wet mill and thereafter, both at the mine and the mill, W.R. Grace added and refined equipment and took measures designed to reduce employee exposures to airborne dust. Dust control at the mine was performed by suppressing road dust by watering or oiling and using vacuum equipment or water jets on drills. Cabs on trucks, shovels, loaders and other mining equipment were ventilated with filtered air. Dust control in the dry mill was done with vacuum hoods over the equipment. In the state of the art wet mill designed and built by W. R. Grace in the early 1970's, dust control resulted from the immersion of solid particles in water such that the ore was kept fully wet during the entire process, from the transfer point at the front end of the mill to the driers at the end of the process. Vacuum dust collection systems were employed where dried vermiculite concentrates were transported.

3. Nature of Vermiculite Deposit in Libby, Montana

The Libby mine site is located on top of a mountain that is part of the Rainy Creek Igneous Complex and considered to be the upper portion of a hydrothermally altered igneous pyroxinite complex which intruded into the Precambrian Belt Series rock. The mountain is generally a biotite/vermiculite deposit occurring in a pyroxinite matrix. Within the deposit are intrusions of syenite and pegmatite originating from a nearby syenite body.

Amphibole minerals are located in and along the igneous intrusions in the vermiculite ore body. The amphiboles arise from syenite dikes cutting into the pryoxinites. The amphiboles winchite, richterite and sodium-rich tremolite are the most abundant. The precise morphology of the amphibole varies and is based on whether cracks or fissures with sufficient space to permit fluid penetration and fiber growth occurred. Other minerals that are present include calcite, feldspars, talc, sphene, limonite from pyrite and quartz.

In this complex association of minerals, a major amount of the amphibole is non-asbestos, having occurred or formed with the syenite part of the ore body, with prismatic and acicular mineral forms observed. Those non-asbestos amphiboles include winchite, richterite, edenite, tremolite, actinolite and hornblende. The wall rock adjacent to the dikes and veins also has a significant portion of the fibrous amphibole that resulted from the last stage of the hydrothermal process.

4. Processing of Vermiculite at Libby, Montana

While the amphibole content of the ore prior to mining could be as high as 15-20% in some areas, the amphibole content of the ore was reduced starting with the process of extracting the vermiculite ore from the ground even before it was transferred to the mill for processing. The mining method that was employed was "selective mining" meaning that W. R. Grace attempted to identify the purest vermiculite ore for mining and attempted to avoid areas with significant impurities, including amphiboles. The ore was mined by bench quarrying where power shovels and ammonium nitrate blasting were used. The mining method resulted in the liberation of vermiculite and generated large waste rock boulders containing diopside, feldspars, amphiboles, sulphides and magnetite. The large waste rock boulders were disposed of at the mine. The vermiculite ore and remaining gangue minerals, including some of the fibrous amphibole, were hauled by truck to a primary processing plant located between the mine and the mill, where it was crushed and screened to remove oversized waste rock. Because the vermiculite was friable, it easily broke into particles smaller than an inch in size. The harder gangue minerals did not fracture as easily and remained larger than one inch and were discarded to the waste pile.

Following the primary crushing, the vermiculite ore was transferred to the mill for processing and beneficiation into vermiculite concentrate. The beneficiation process at the mill was designed to take the vermiculite ore, reduce the impurities and arrive at a concentrate. The total amphibole content of the ore was reduced during each stage of the beneficiation process at the mill. W.R. Grace continuously improved the processing and beneficiation process to arrive at the purest vermiculite concentrate possible. The result was a vermiculite concentrate product that was outstanding in terms of purity. In fact, by the 1980's, the total amphibole content of the vermiculite concentrate that was produced at the end of the beneficiation process was reduced to a maximum 0.1% to 0.3% amphibole.

The beneficiation at the mill was a very complex and detailed process. Once the larger rocks were removed at the mine, the vermiculite ore was transported by truck to a grizzly screen where it was crushed to approximately minus one inch particles. That material was conveyed by belt to a weatherproof dome where it was blended to achieve a consistent size distribution and composition, and then stored until it was conveyed to the mill opening. That material was then fed into the mill where it was processed by hammer mills, which further reduced it in size to about 4 mesh (about 0.2 inch) or smaller. The ore was then screened into four size fractions for processing. Each size fraction was processed separately but the process and the equipment changed over time.

W. R. Grace purchased the Libby operations from Zonolite Company in 1963. At that time, Zonolite Company utilized a combination "dry mill" and "wet mill". As noted above, after mining, the vermiculite ore feed entered the mill dry and was first screened to four size fractions. Particles larger than 4 mesh (0.2 inch) were pulverized to pass 4 mesh. The two coarser size fractions were processed in crushing rolls-slotted screen circuits. A size fraction was fed to crushing rolls with a set (the separation of the rolls) somewhat smaller than the openings of the screen upon which that size fraction was retained. Blocky particles were crushed by the rolls, while flakes were not. On the screen, crushed gangue minerals passed through, and flakes were retained. Some of the fibrous amphibole liberated in the crushing passed through the screens and was rejected from the process with the tailings. The finer size fractions were transferred to the wet mill. There the material was screened again and the coarser particles were fed to wet jigging equipment. In the pulsing up and down motion induced in the slurry, the flakes and fibers rose to the top of the jig compartment and were screened to remove fibers. The smaller size range was fed to shaking tables where it was wet by water and subjected to the oscillating deck of the table. Flakes tended to flow over the blocky particles and drain off the lower edge of the inclined deck. The blocky particles were kept from moving down the slope by transverse bars or riffles. The asymmetric deck motion moved those particles to the far end of the deck where they were discarded as waste.

During 1973, a new, state of the art entirely wet mill was built to completely replace the old mills. The new wet mill was slated for completion at the end of 1972, but was not fully operational until sometime in 1974. Once the new wet mill was operational, all the ore (all minus 4 mesh particles) was screened into four size fractions for processing in different circuits. The largest size fraction from the screening was processed on sets of inclined rubber-clad rolls arranged so that blocky particles were carried by water flow down the slope and out of the process as waste. Flakes of vermiculite passed through the spaces between the rolls and collected as concentrate.

The next smaller size fraction was processed using Humphrey Cones. In this circuit, the slurry of particles was poured onto the apex of a rubber-covered cone. Flakes slid down the slope of the cone into an annular compartment at the base and collected as concentrate. Blocky particles bounced down the slope of the cone and into an outer annular compartment where they were discarded as waste.

The next smaller size fraction was fed from the screens to water elutriators. The slurry of the size fraction was fed into a steel cylinder halfway up its length. Inside the cylinder, water entered at the bottom. The water entering the bottom of the cylinder filled the cylinder and displaced the water above it producing an upward flow of water. Since the particles were of similar sizes and densities, they should fall or settle at approximately the same rate. However, the flakes of vermiculite and loose fibers of amphibole would settle at a slower rate than the blocky particles. The upward flow of water carried the flakes and fibers to the top and overflowed the elutriators. The blocky particles fell to the bottom of the cylinder and were discharged as waste. The overflow passed onto wet screens which worked to retain the vermiculite flakes and allowed the fibrous amphiboles to pass through where they were collected and discarded as waste.

The smallest size ranges of ore were processed using flotation. Flotation utilizes differences in surface chemistry of the minerals to make separations. In this process, vermiculite was specifically separated from waste minerals, including amphiboles, by utilizing differences in the surface composition among the minerals. In the process at Libby, the vermiculite was selectively rendered water repellant by addition of a chemical called a collector. The other minerals, including amphibole minerals, remained wet from the water. In the processing vessel, slurry was kept in turbulence by an impeller and bubbles were generated near the bottom of the vessel. As the air bubbles rose to the surface, they gathered up the water-repellant particles (vermiculite). At the surface, the air bubbles laden with vermiculite particles were kept in a froth. By adding a large molecular weight alcohol called a frother, the froth was stabilized until it was removed from the flotation vessel. The materials that remained in the flotation vessel, which included the amphibole minerals, were discarded as waste. Over a period of years, the flotation process was improved to the point to which the larger size fractions also could be floated.

As noted above, during this beneficiation process, the amphibole content was reduced by separating the vermiculite particles and discarding the other minerals as waste. The practice was to use sets of three units of identical equipment to form a rougher-cleaner-scavenger circuit to make up for the inadequate efficiency of using one unit of the processing equipment. In effect, the ore was subjected to a series of two flotations and the tailings (waste) were given an additional chance to have the vermiculite contained in the waste recovered. Given the continuous improvement in the process, the amphibole content continued to be reduced further over time. Constant efforts to improve vermiculite concentrate purity resulted eventually in a product with only a small fraction of a percent of amphibole. In the early 1970's, the total amphibole content in the vermiculite concentrate was approximately 1%. By the 1980's, the total amphibole content in the vermiculite concentrate ranged from 0.1% to 0.3%.

The end product of the beneficiation process was known as vermiculite concentrate. At the end of the process, the vermiculite concentrates of all sizes were then recombined, dried and moved to the screening plant. At the screening plant, the concentrate was broken down into the grades that were saleable. These were not the same size ranges used in the beneficiation process. The concentrate was then shipped to expanding plants, where it was exfoliated. The exfoliation (or expansion) process resulted in a further reduction of the total amphibole content by virtue of the operating conditions in both the W. R. Grace designed expansion furnaces and the final cleaning operation in the "stoners" following expansion. In my opinion, consumers and end users of the

expanded vermiculite labeled as Zonolite were not exposed to asbestos amphiboles in excess of a few parts per million.

5. W.R. Grace's Efforts to Reduce Dust in the Mill During Vermiculite Processing Operations

As noted above, based on my review of Grace's documents and my knowledge of the mining and milling beneficiation process, it is my opinion that W. R. Grace continuously improved the processing and concentration of vermiculite that resulted in a reduction of the amphibole content in the vermiculite concentrates. At the same time, W. R. Grace undertook significant efforts to reduce the level of dust to which its employees were exposed during the vermiculite processing at the mill.

Prior to W.R. Grace's purchase of the Libby operations from Zonolite Company in 1963, dust exposure levels at the Libby mine and mill were very high. However, after W.R. Grace's acquisition, conditions gradually improved. As a result of W.R. Grace's efforts, exposure estimates for all operations decreased annually. With respect to the Zonolite Company's dry mill that was in place when W.R. Grace purchased the operations, Grace undertook efforts to:

a. **reduce exposure of employees to asbestos through dust control including the installation of a major piece of ventilation equipment and the mandatory use of approved respirators purchased by W.R. Grace;**

b. **detect employee health related issues at the earliest stage and alert them to the potential hazard through a company-wide compulsory x-ray program after which employees were referred to their family doctors; and**

c. **reduce the amphibole content in the vermiculite by efficiently operating the original wet and dry mills.**

During this period in which the old dry mill was still being operated, W.R. Grace also cooperated with two governmental agencies: United States Department of the Interior, Bureau of Mines, Health and Safety Activity and the Montana State Board of Health, Division of Disease Control. The reports of those governmental agencies and W. R. Grace documents demonstrate the substantial efforts that management made to comply with the advice received from those agencies.

In the dry mill, crushing roll-slotted screen circuits were the principal beneficiation method. Dust collection systems were utilized and respirators were made mandatory in those areas and throughout the dry mill. In the old wet mill, jigs and shaking tables were used to achieve dust control to the advisory Threshold Limit Value (TLV) according to reports of the state inspector.

Moreover, in further effort to diminish the potential for employees' exposure to airborne asbestos by orders of magnitude, as well as to increase the purity of the vermiculite concentrate, W.R. Grace designed and built a new, state of the art "wet process vermiculite mill" to replace both the dry and original wet mills. That effort to develop a new processing technology to eliminate airborne dust and amphibole in the mill required significant expenditure of manpower and money and resulted in a significant reduction in the airborne dust levels. The onset of this new wet production of vermiculite concentrate resulted in diminishing airborne dust to meet the PEL's promulgated by federal regulations.

This new wet mill was designed with processing equipment operated to remove amphibole as well as other waste minerals. By having a concentrator in which the ore is *kept fully wet from the transfer point at the front end of the mill to the driers at the far* end, fugitive emissions of amphibole dust was practically eliminated, resulting in compliance with the PEL. Efforts to greatly reduce the amount of airborne dust were successful in the wet milling operation because all the particles were kept completely wet all the time.

It is my opinion that W. R. Grace pioneered new state of the art methods of processing vermiculite and continued to improve upon those methods. At the same time, W. R. Grace conducted a program to protect their workers with ventilation and other dust control equipment, respirators, x-ray exams and internal job transfers. Prior to the implementation of the wet mill and thereafter, both at the mine and the mill, W. R. Grace added and refined equipment and took measures that were designed to reduce employee exposures to airborne dusts. This program was carried out at the mine as well as the mill by the use of personal respirators, enclosed truck cabs, Pangborn dust collectors on the primary drills, water flooding on the boulder drills and bump-free oiled roads. At the concentrate drier, skip loader and screening plant, the dust problems were eliminated by high volume dust collection systems. With the help of the U.S. Bureau of Mines, these dust-free processing operations were designed to meet the applicable PEL's.

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