NorthMet Mine and Ore Processing Facilities Project

Fibers Data Related to the Processing of NorthMet Deposit Ore

Prepared for
PolyMet Mining Inc.

June 2007

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RS 61 – Fiber Information

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(EIS Report Study RS61)

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DEFINITIONS

The word "fibers" has several definitions and regulatory meanings. The following list of definitions is based on fiber definitions used by Minnesota State Agencies, topic researchers, federal government agencies, and other states.

Fiber: In this report the general term "fiber" is an all encompassing term that includes the Minnesota regulated fibers (MN-fiber) definition, federal agency definitions of fibers, and the various lengths/widths typically used by researchers in describing fiber-related health effects.

Fiber, MN- (Minnesota regulated fiber; MN-fiber): For purposes of regulating amphibole mineral fibers, Minnesota's State Agencies have defined a fiber as an inorganic mineral particle with parallel sides having an aspect ratio (length:width) of at least 3:1 and may or may not exhibit diffraction contrast (MDH Method 851 and 852). This definition includes asbestiform material as well as acicular (needle-like) crystals and cleavage fragments (Stevenson, 1978). When the transmission electron microscope is used, fibers are defined as fragments with aspect ratio of 3:1 or greater, even though many of these fragments may not meet the mineralogical definition of a fiber (Stevenson, 1978). The 3:1 aspect ratio is used principally to eliminate particulates and fiber clumps and improve the precision and accuracy of fiber counts. In this report, the term "MN-fiber" will be used to identify these types of fibers.

Asbestiform: Mineral crystals that form long, thread-like fibers. When pressure is applied to an asbestos fiber, it bends much like a wire, rather than breaks. Fibers can separate into "fibrils" of a smaller diameter (often less than 0.5 µm; referred to as "polyfilamentous") and is viewed as one of the most important characteristics of asbestos (MSHA, 2005). As described in Appendix A of the Environmental Protection Agency's "Method for the Determination of Asbestos in Bulk Building Materials", asbestiform is defined as:

With the light microscope, the asbestiform habit is generally recognized by the following characteristics:

- Mean aspect (length to width) ratios ranging from 20:1 to 100:1 or higher for fibers longer than 5 micrometers. Aspect ratios should be determined for fibers, not bundles.
- Very thin fibrils, usually less than 0.5 micrometers in width, and two or more of the following:
  - Parallel fibers occurring in bundles,
  - Fiber bundles displaying splayed ends,
  - Matted masses of individual fibers, and/or
  - Fibers showing curvature.

More recently single fiber amphibole minerals are characterized as 1) the width of amphibole asbestos fibers is generally 0.2 to 0.3 µm; 2) the aspect ratio of fibers is greater than 20:1; 3) asbestos fibers have parallel sides; 4) the ends of asbestos fibers show regular termination; 5) asbestos fibers show internal diffraction contours (Van Orden et al. 2005).

Non-asbestiform: As identified by MSHA (2005): *"… In the non-asbestiform habit, mineral crystals do not grow in long thin fibers. They grow in a more massive habit. … When pressure is applied, the non-asbestiform crystals fracture easily into prismatic particles, which are called cleavage fragments because they result from the particle's breaking or cleavage, rather than the crystal's* *formation or growth. Some particles are acicular (needle shaped), and stair-step cleavage along the edges of some particles is common.*

Cleavage fragments may be formed when nonfibrous amphibole minerals are crushed, as may occur in mining and milling operations. Cleavage fragments are not asbestiform and do not fall within the regulatory definition of asbestos. …".

As described by Stevenson (1978; Appendix I): *Amphibole minerals typically occur in non-asbestiform habits. Cleavage fragments, such as those produced from crushing and processing non-asbestiform minerals, do not meet the definition of a fiber and should be considered "fiber-like".* Minnesota State Agencies refer to all amphibole fibers as "fibers" and do not officially recognize the term "fiber-like".

Cleavage fragment: Cleavage refers to the preferential breakage of crystals along certain planes of structural weakness. Such planes of weakness are called cleavage planes. A mineral with two distinct cleavage planes will preferentially fracture along these planes and will produce acicular fragments. Minerals with one cleavage plane produce platy fragments and those with three or more cleavage planes yield polyhedral fragments. Cleavage cannot produce the high strength and flexibility of asbestiform fibers (NRC, 1984).

Micrometer: a unit of length equal to one millionth of a meter; denoted as "µm".

Minnesota State Agencies: In this report the Minnesota Pollution Control Agency, the Minnesota Department of Natural Resources, and the Minnesota Department of Health are collectively referred as "Minnesota State Agencies" due to their respective involvement with the amphibole fibers issue related to mining projects.

1.0 INTRODUCTION

The Minnesota Department of Natural Resources (MDNR) in cooperation with the United States Army Corps of Engineers (USACE) and the United States Forest Service (USFS) will prepare a joint state and federal Environmental Impact Statement (EIS) for the NorthMet Mine and Ore Processing Facilities Project (NorthMet Project) proposed by PolyMet Mining Inc. The first step in the environmental review process includes the preparation of a Scoping Environmental Assessment Worksheet (EAW) that identifies the issues that are potentially significant and should be addressed in the EIS. The Scoping EAW was prepared by the MDNR and made available to the public in June 2005, with a public meeting held in Hoyt Lakes on June 29, 2005. Public comments provided on the Scoping EAW identified fibers as a potentially significant issue that should be addressed in the EIS. A Final Scoping Decision (October 25, 2005) has been prepared by the MDNR which identifies that "The EIS will provide information about the presence of fibers in the NorthMet deposit". This report on fibers has subsequently been prepared in support of the EIS.

1.1 Interest in the NorthMet Deposit

The proposed processing facility will receive ore mined from the NorthMet deposit. PolyMet's proposed mine is to be located approximately 6 miles south of the town of Babbitt. The NorthMet deposit is part of the Duluth Complex, which extends northward from Duluth, in an arcuate belt, to just south of Ely, and then extends eastward to Hovland (Geerts et al., 1990) (Figure 1). In the area of the NorthMet deposit, the Duluth Complex cross-cuts the older footwall Virginia Formation rocks. The Complex does not contact the Biwabik Iron Formation at NorthMet. There are volumetrically insignificant sill-like intrusions in the Virginia Formation and the Biwabik Iron Formation presumed to be related to the Complex.

Northshore Mining's Peter Mitchell Mine is also located near Babbitt, and taconite ore mined from the Biwabik Iron Formation at the Peter Mitchell Mine and processed at the Silver Bay plant has received previous attention from the public with regard to potential releases of amphibole fibers to air and water. This amphibole exists because of thermal metamorphism of the iron-formation driven by the intrusion of the Duluth Complex.

PolyMet's proposed mine is in close proximity to Northshore Mining's existing mine (Figure 2). Ore in intrusive rocks to be mined from the NorthMet deposit in the Duluth Complex is 700 million years younger than the metasedimentary taconite ore obtained from the Biwabik Iron Formation at Northshore

Mining's Peter Mitchell Mine and was formed under entirely different conditions. Recognizing the differences in the NorthMet deposit to be mined by PolyMet versus the Biwabik Iron Formation mined by Northshore Mining, the Minnesota Pollution Control Agency (MPCA), Minnesota Department of Natural Resources (MDNR) and the Minnesota Department of Health (MDH) (collectively referred to as Minnesota State Agencies) requested that PolyMet provide additional information on its mining and processing operations, including fibers-related data.

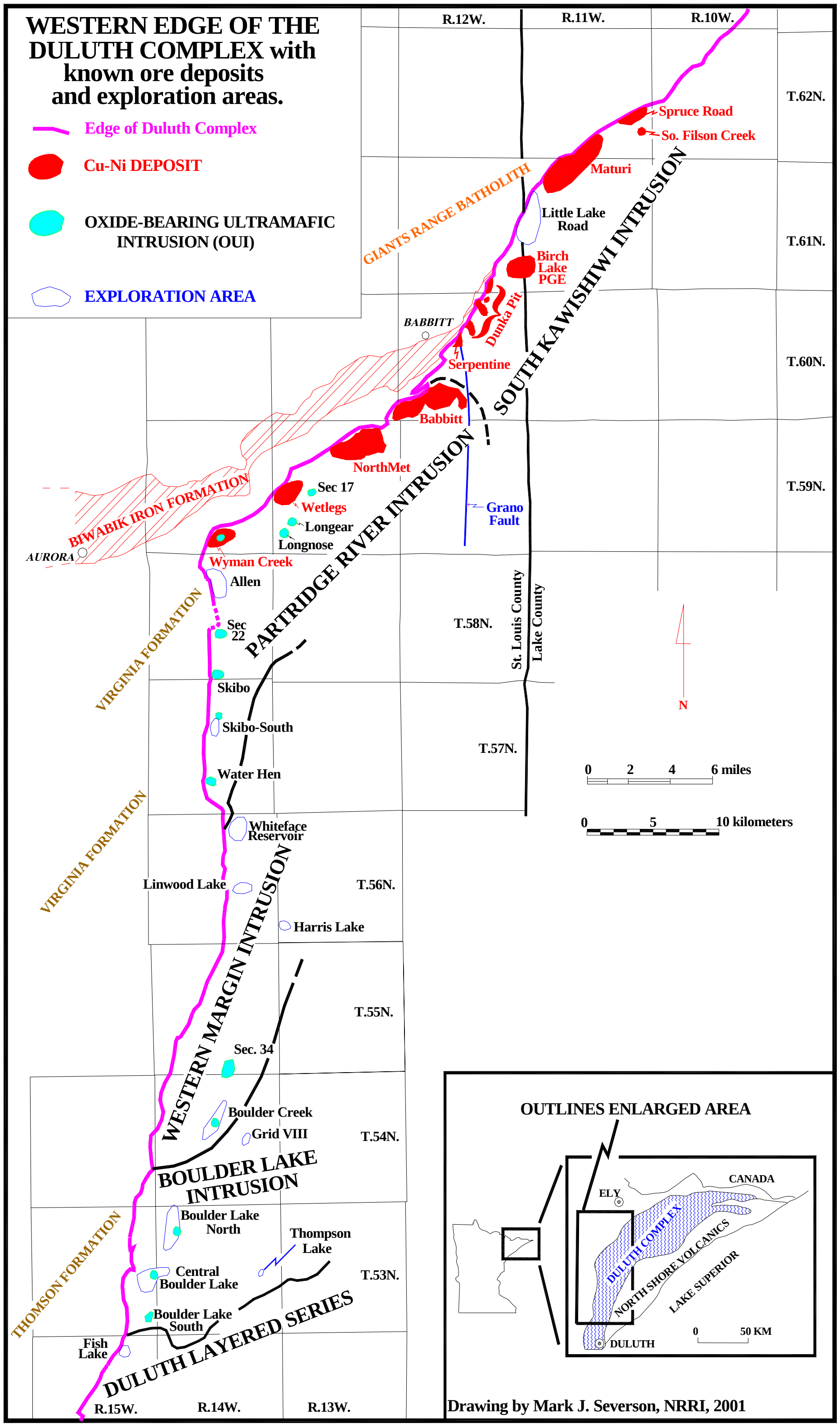
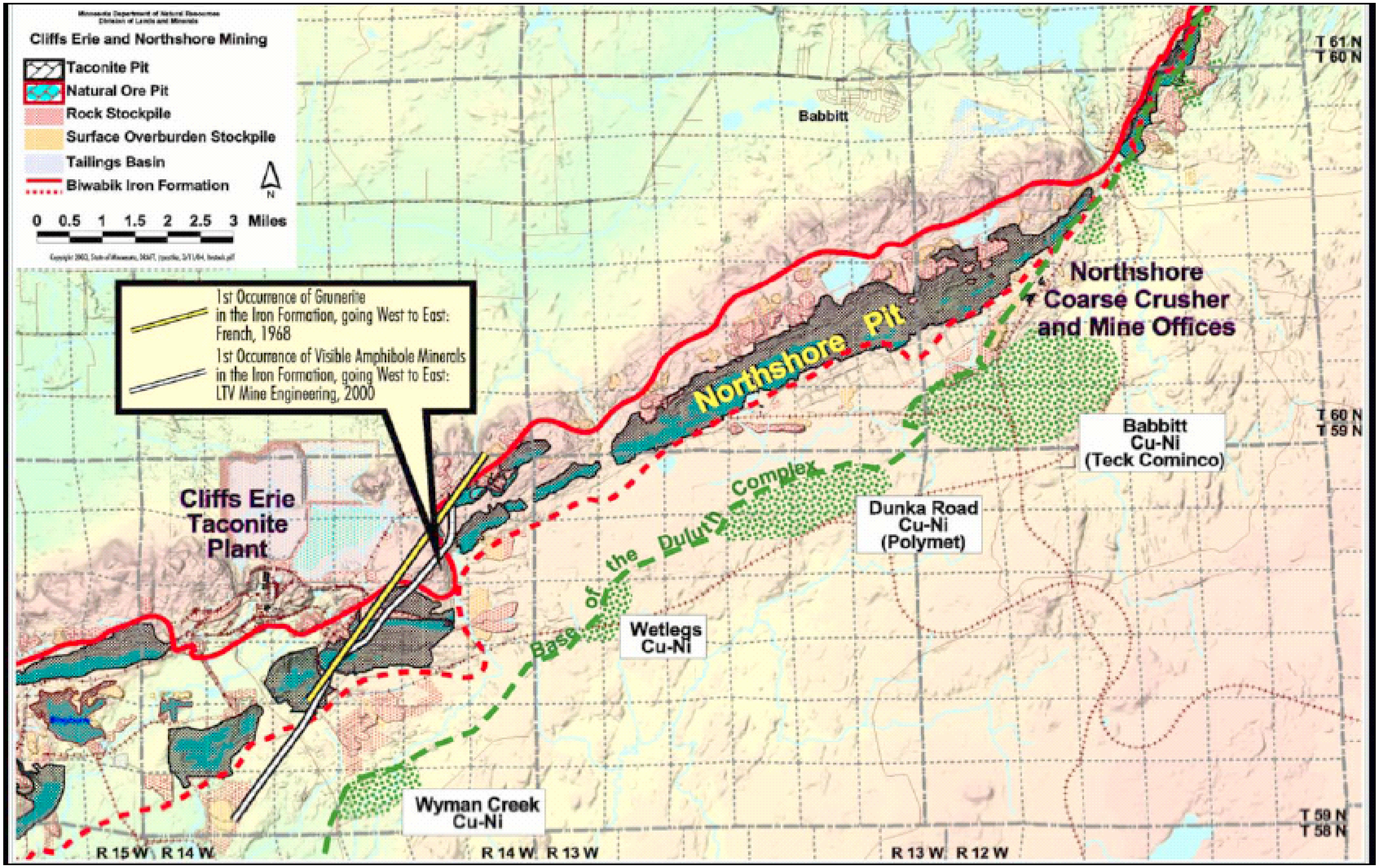


Figure 1. Location map of copper-nickel deposits in the Duluth Complex (from Miller et al., 2002).



(map courtesy of Minnesota Department of Natural Resources, Division of Lands and Minerals, 2003 as described in Zanko et al. 2003).

Figure 2. Map of Cliffs Erie (formerly LTV Steel Mining Company) and Northshore Mining Company properties showing line where grunerite and other amphibole minerals first appear (going east) at the eastern end of the Biwabik Iron Formation. (From, Zanko et al. 2003)

PolyMet's fibers-related information will take into account the following items:

- Critical discussion points for fibers in relation to the NorthMet project include: a) the presence of amphibole minerals in the NorthMet deposit; b) the potential for amphibole minerals to be associated with processing ore from the NorthMet deposit; c) the types of fibers and their dimensions potentially associated with processing ore from the NorthMet deposit; and d) the potential release of amphibole fibers to the environment and proposed measures to reduce or minimize the potential releases.

- Minnesota State Agencies regulate amphibole fibers, with these fibers being defined as a particle or fragment having a minimum of a 3:1 aspect ratio; no minimum length. This definition does not differentiate between asbestiform and non-asbestiform fibers. This definition does not differentiate fibers based on relevant physical properties such as length or width. This report provides a broader discussion of fibers than that encompassed by the Minnesota State Agency definition.

- The focus of the fiber discussion in Minnesota is on amphibole fibers. However, the MEQB (1979) also identified the presence of serpentine minerals in the Duluth Complex. Available information on serpentine minerals from the NorthMet deposit will also be provided.

- Fibers as defined by Minnesota State Agencies, and labeled as "MN-fibers" in this report, fall within the definition of particulate matter (PM_{10}**;** particles 10 microns or smaller). The physical dimensions of the MN-fibers indicate they are part of the fine particle fraction (2.5 microns or smaller). A discussion on particulate matter and proposed air emission control technologies is included.

- A literature review on asbestos related diseases and potential health risks from environmental exposure to short fibers (sometimes referred to as cleavage fragments in the literature) and long fibers is provided in this report. This review includes a discussion on fiber dimensions (length/width) because its importance is emphasized in the published literature and government peer review panel discussions and findings (ATSDR 2003; EPA 2006), and it is considered important in assessing potential impacts from the project. Therefore, this report provides a broader discussion of fibers than may have been originally envisioned or thought necessary by the Minnesota State Agencies.

1.2 Crystalline Morphology and Relevance to the Fibers Discussion

Mineralogical and morphological differences are important to the asbestiform/non-asbestiform discussion. The minerals that can crystallize as asbestiform fibers belong to two groups: serpentine and amphibole (USGS 2001). Serpentine and amphibole minerals can have fibrous or nonfibrous structures.

Serpentine is always formed by metamorphism of olivine, though there may be intermediate metamorphic reactions which form the olivine, therefore it can occur in rocks which originally contained no olivine. Serpentine is a sheet silicate and is a group of common rock-forming hydrous magnesium iron phyllosilicate ($(Mg, Fe)_3Si_2O_5(OH)_4$) minerals; it may contain minor amounts of other elements including chromium, manganese, cobalt and nickel. In mineralogy and gemology, serpentine may refer to any of 20 varieties belonging to the serpentine group. Owing to admixture, these varieties are not always easy to individualize, and distinctions are not usually made. There are three important mineral polymorphs (same chemistry, different crystal habits) of magnesium serpentine: antigorite, chrysotile and lizardite. http://www.galleries.com/minerals/silicate/serpenti/ serpenti.html). Chrysotile is the asbestiform type of serpentine and tends to have relatively long and flexible crystalline fibers (ATSDR 2001).

The amphiboles are a very large group of minerals with a wide range of chemical compositions while sharing a common crystal structure (USGS 2001). The normal forms for all of the amphiboles are prismatic, blocky, or rod-like crystals (USGS 2001). However, certain of the amphibole minerals, for example grunerite (amosite), riebeckite (crocidolite), tremolite, actinolite and anthophyllite may occasionally occur in asbestos forms although these are rare in comparison to the non- asbestos varieties (Virta 2002). The asbestiform varieties are characterized by long, thin fibers, while non-asbestiform varieties such as cleavage fragments form shorter fibers with greater widths (Gamble et al, 2003). Amphiboles are of minor commercial importance with regard to the production of asbestos, but because the asbestiform fibers are more brittle than chrysotile fibers they have received a large amount of attention with regard to potential health effects.

The non-asbestiform and asbestiform habits of the same amphibole mineral are chemically similar (Virta 2002). The main difference between them is their morphology. Subtle differences in their crystal structure can lead to marked differences in physical properties (USGS 2001). Geology governs morphology. The asbestiform and non-asbestiform mineral habits reflect different modes of formation (Hurlbut and Klein 1985).

The way in which crystals form affects how these crystals will break or shatter, which in turn affects the characteristic of the fibers that are formed. Subtle differences in their crystal structure can lead to marked differences in physical properties. The commercial use of the asbestos amphiboles depended upon these properties, including their capacity to be readily split into long, thin fibers with high tensile strength. The frameworks for silicate minerals are composed of oxygen and silicon, arranged in the shape of a pyramid or tetrahedron, with silicon in the center and oxygen at the four corners (USGS, 2001). The silicate tetrahedra can occur as double chains, as in the amphiboles (Virta, 2002). These can be further divided into asbestiform or non-asbestiform crystal structures as described below. Non-asbestiform and asbestiform amphiboles are chemically indistinguishable. The main difference between them is their crystal shape.

Non-asbestiform: Non-asbestiform prismatic crystals are the common crystalline habits of amphiboles. In the non-asbestiform habit, mineral crystals do not grow in long thin fibers. They grow in a more massive habit (MSHA,2005). Crystal growth, is random, forming multidimensional prismatic patterns. The common crystalline habit of the amphiboles present with plagioclase is in a non-asbestiform habit (MEQB, 1979).

A characteristic of non-asbestiform crystalline habits is that when pressure is applied to the crystal, the crystal fractures, forming crystals or cleavage fragments of the acicular variety (slender needle-like crystals). Cleavage refers to the preferential breakage of crystals along certain planes of structural weakness. Such planes of weakness are called cleavage planes. A mineral with distinct cleavage planes will preferentially fracture along these planes and will produce acicular fragments. The strength and flexibility of cleavage fragments are approximately the same as those of single crystals. Cleavage cannot produce the high strength and flexibility of asbestiform fibers. (NRC, 1984). Acicular crystals are long and needle-like but are thicker than the fibrous variety. As defined by the American Geologic Institute (1980), a mineral fragment must be at least three times as long as it is wide to be called acicular (3:1 aspect ratio).

Asbestiform: In the asbestiform habit, mineral crystals grow in a single longitudinal dimension forming long, thread-like fibers. When pressure is applied to an asbestos fiber, it bends much like a wire, rather than breaks. Fibers can separate into ‘‘fibrils’’ of a smaller diameter (often less than 0.5 µm). This effect is referred to as ‘‘polyfilamentous,’’ and should be viewed as one of the most important characteristics of asbestos (MSHA, 2005). Mineralogists call asbestiform amphibole minerals by their mineral name followed by “asbestos”. Thus, asbestiform tremolite is called tremolite asbestos. The definition of an asbestos fiber includes a length to width aspect ratio. Asbestos fibers are typically defined as long and very thin fibrils generally greater than 10 µm in length and less than 0.5 µm in width (aspect ratio, length:width greater than 20:1).

Five basic physical properties distinguish asbestiform fibers from other material. Compared with the non-asbestiform variety of the same mineral, the asbestiform properties are as follows (NAS 1984):

- Microscopic, fiber-like dimensions and morphology (i.e., fibers are much longer than wide);
- Enhanced strength and flexibility;
- Inverse relationship between diameter and strength (i.e., the smaller the diameter, the greater the strength per unit cross-sectional area);
- Enhanced physical and chemical durability;
- High quality, relatively defect free structure.

Recent risk models (Van Orden, 2005) characterize single fiber asbestiform amphibole minerals as having the following characteristics:

- the width of amphibole asbestos fibers is generally 0.2 to 0.3 µm;
- the aspect ratio of fibers is greater than 20:1;
- asbestos fibers have parallel sides;
- the ends of asbestos fibers show regular termination;
- asbestos fibers show internal diffraction contours.

Due to the regulation of asbestos, there are also regulatory definitions of an asbestos fiber:

- OSHA defines an asbestos fiber for counting purposes as a particle with a length greater than 5 microns (µm) and an aspect ratio greater than 3:1.
- USEPA (1987) defines a reportable and countable fiber for the Asbestos Hazard Emergency Response Act (AHERA) as any particle with a length greater than 0.5 µm and an aspect ratio greater than 5:1 when analyzing air samples for fiber content.
- The Minnesota State Agencies identify a fiber as any particle with an aspect ratio of 3:1 or greater, with no minimum length.

The aspect ratio is used principally to eliminate particulates and fiber clumps and improve the precision and accuracy of fiber counts. Dr. Wylie testified at OSHA hearings (57 FR 24310, June 8, 1992) that "…

it's very important that we qualify, when speaking of aspect ratio, length, because aspect ratio by itself as a population characteristic has no meaning …." The aspect ratio is not a defining characteristic of asbestos fibers and "*is not a useful parameter for sizing as it is dimensionless, provides no information on width, shows no association with risk of disease, and therefore is of little use in the discussion of risk or exposure*" (Langer et al. 1991, Wylie et al.1993 as quoted in Gamble et al. 2003). Beyond the roles played by length and diameter, no data exist to demonstrate that fiber aspect ratio plays a role in determining the pathogenicity of fibers (Middendorf, 2007). As discussed previously, additional information about the fibers, including morphology and chemistry, are needed to determine whether a fiber is asbestiform or non-asbestiform.

The distinction between asbestiform and non-asbestiform fibers is not considered important for regulatory purposes in Minnesota, because the Minnesota State Agencies definition of a fiber is any mineral particle having a 3:1 aspect ratio and this definition includes both asbestiform and non-asbestiform fibers. However, the available fibers literature makes a strong distinction between the two types of fibers and this information is considered important as it provides additional perspective on potential exposures and potential health effects.

1.3 Environmental Sampling and Analysis Plan – Fibers

An Environmental Sampling and Analysis Plan (SAP) was prepared and submitted to the Minnesota State Agencies in June 2005, with Section 3.2 of the SAP discussing sample collections and analysis for fibers. Additional considerations by PolyMet, state agency review of the SAP, and subsequent discussions between the state agencies and PolyMet resulted in focusing the fibers related sampling and analysis on the flotation pilot study. The intent of the flotation pilot study was to simulate the processing of ore and generate data for PolyMet's production and process models and calculations, and for direct use in assessing potential environmental impacts for the EIS. Therefore, it was critical for the flotation pilot study to process ore that was representative of the NorthMet deposit. Document RS32 summarizes the results of the pilot study. Addendum 1 to Section 3.2 of the SAP (Appendix A of this report) and Section 3.2.9 in the MDNR's Scoping Decision Document dated October 25, 2005 document the following points:

- Materials from the flotation phase of the pilot plant processing of the bulk ore sample were to be collected and analyzed for the presence of fibers. Material to be sampled from the flotation phase of the pilot studies included head feed (ore), tailings, and process water. These samples are considered to be representative of the ore, tailings, and process water likely to be associated with processing ore from the NorthMet deposit.

- The crushing and grinding of ore is expected to be the most significant source of potential fibers release to the air. Material from the bulk ore sample was crushed and ground but the process could not be sampled for potential release of amphibole fibers. The ore crushing and grinding produced a head feed material for the flotation process. The head feed samples will be used as an indicator of potential fiber emissions from the PolyMet facility.
- Tailings and process water samples will be used to provide information on fibers potentially associated with the tailings basin.

- Analysis of Head Feed and Tailings Samples:
  - The head feed and tailings samples will be treated as bulk materials and analyzed with Polarized Light Microscopy (PLM) according to EPA methodology (EPA/600/R-93-116) to initially determine the presence/absence of asbestos minerals.
  - Transmission Electron Microscopy (TEM) will provide a detailed scan, with fiber counting following MDH methodology (MDH Method 851 or 852).
  - The TEM analysis will identify fibers by length and width. As approved by the Minnesota State Agencies this detailed data is then to be labeled for reporting purposes according to the following length and/or length:width aspect criteria:
    - "Minnesota Department of Health (MDH) Fiber" – particles with an aspect ratio of 3:1 or greater (MDH Method 851 or 852).
    - "Occupational Fiber" – particles that are 5 µm in length or longer, and have a length to diameter ratio of at least 3:1.
    - "Asbestos Fiber" – particles that are 5 µm in length or longer, and have a length to diameter ratio of at least 20:1.
  - TEM will also be used to speciate fibers into the following groups: Amphibole, Chrysotile, Non-amphibole – Non-chrysotile, and Ambiguous.

        - Amphibole fibers will be identified by mineral chemistry (Cummingtonite-grunerite; Actinolite; Tremolite; Hornblende; Other) and summed to provide a total Amphibole count.

- Analysis of Process Water Samples

    - Samples will be analyzed for asbestos fibers by TEM according to EPA Method 100.2; EPA Method 100.2 identifies asbestos structures greater than 10 µm in length and reported as fibers per liter (f/L).

    - Samples to be analyzed for fibers by TEM, using MDH fiber counting rules (MDH Method 851).

- The results of these analyses will be used to identify potential impacts and propose mitigation to minimize impacts.

- A literature review will be performed on asbestos related diseases and risks from environmental exposure to short fibers, long fibers, and cleavage fragments. The results of this literature review will be summarized in the EIS.

2.0 BACKGROUND INFORMATION ON GEOLOGY AND MINERALOGY

2.1 Project Setting

A large resource of copper-nickel sulfide exists in northern Minnesota along the basal contact of the Duluth Complex which is a long arcuate mafic intrusion of Keweenawan age (approx. 1,100 million years old), extending from Duluth on the south, north-northeast toward Ely, and then east-northeast to a point near Hovland on the Lake Superior shore (MEQB 1979; Miller et al. 2002) (Figure 1). The copper-nickel mineralization is in the basal heterogenous troctolites of the Duluth Complex (Figure 1). Footwall rocks in the NorthMet area are Virginia Formation sedimentary rocks. Three major units have been identified within the Duluth Complex: anorthositic series, layered series (previously known as the troctolitic series), and the felsic series.

- Anorthositic series. Occupies the central part of the Duluth Complex in map view, containing rocks having greater than 55-60% plagioclase, with olivine, augite, and various oxide minerals occurring interstitially to the tabular plagioclase crystals (MEQB, 1979).

- Layered series: The layered series is of principal interest for copper-nickel mining. This series is below the anorthositic series. Rocks are made up of plagioclase, olivine, pyroxenes, and oxide minerals. Plagioclase is the predominant mineral making up 50 to 80% of the rocks, with olivine the second most abundant mineral making up 10 to 40%. The inclusions mapped at the surface along the basal contact of the Duluth Complex in the Hoyt Lakes – Kawishiwi area are basalts from the roof of the intrusion, metasedimentary inclusions (Virginia Formation) are common in drill core in the lowest parts of the intrusion.

- Felsic series: These granitic rocks are scattered throughout the eastern part of the Duluth Complex; these rocks have gradational to sharp contacts with rocks of the anorthositic and troctolitic series.

2.2 NorthMet Deposit

The NorthMet deposit is located within the Duluth Complex of northeastern Minnesota (Figure 1). The NorthMet deposit is situated along the western edge of the Duluth Complex within the Partridge River intrusion (Figure 2). The deposit consists of varied troctolitic and gabbroic rock types that have been subdivided into at least seven igneous stratigraphic units in drill core logging.. All of these igneous units, which are described below, exhibit shallow dips (10º-25º) to the south-southeast (Miller et al., 2002; Hammond, 2004).

The regional and local geology of the NorthMet deposit are well known. Over 1,000 exploration holes have been drilled in this part of the Duluth Complex, and nearly 800,000 feet of core have been re-logged in the past fifteen years by a small group of industry and university research geologists (Geerts, 1994; Miller et al., 2002; Hammond, 2004). Following is a composite description of the units in the NorthMet area, from the base to top:

Unit 1: consists of a heterogeneous mixture of troctolitic to gabbroic rocks, with abundant inclusions of hornfelsed sedimentary footwall rocks and lesser discontinuous layers of ultramafic rock. Unit 1 is the dominant sulfide-bearing member in the NorthMet deposit. At least three Platinum group element ("PGE") enriched "stratabound" layers are present within Unit 1, the uppermost of which has the highest concentrations of PGE. Unit 1 is 200 feet to 1000 feet thick, averaging 450 feet.

Unit 2: consists of homogenous troctolitic rocks, with minor sulfide mineralization, and a fairly persistent basal ultramafic layer that separates Unit 2 from Unit 1. Unit 2 averages about 200 feet thick.

Unit 3: consists of a fine-grained, poikolitic, anorthositic troctolite. Unit 3 is the major marker bed within the deposit due to its fine-grained nature and the presence of distinctive olivine oikocrysts that give the rock a mottled appearance. Unit 3 averages 250 feet thick.

Unit 4: consists of homogenous ophitic augite troctolite with a local ultramafic layer at, or near, the base of the unit. It averages about 300 feet thick.

Units 5, 6, and 7: consist of homogenous anorthositic troctolite grading to ophitic augite troctolite; units 6 and 7 have persistent ultramafic bases.. These units average about 1,200 feet in thickness, but because the top of Unit 7 has not been seen in drill core, this figure is probably a minimum.

2.3 Potential for Occurrence of Asbestos/Amphibole/Serpentine Mineral Fibers

Analysis of the potential for the release of asbestiform or amphibole fibers to air and/or water, along with any potential concerns for associated health risks, needs to begin by evaluating the source rock. The Duluth Complex has been studied extensively (MEQB, 1979; Severson and Hauck, 1990; Geerts et al., 1990; Geerts, 1994; Miller et al., 2002). Analysis of representative samples of the NorthMet deposit shows that the ore body is dominated by primary igneous silicate minerals – calcic plagioclase feldspar, olivine, pyroxene, and biotite. Chlorite and serpentine are locally present due to the alteration of olivine and pyroxene. The Duluth Complex contains minor amounts of amphibole minerals (MEQB 1979). As estimated by Stevenson (1978) and as summarized by the MEQB (1979), the Duluth Complex has approximately one-third of the amphiboles that the Biwabik Iron Formation contains in the area near Babbitt.

Amphibole (Grunerite-Cummingtonite, etc.) in the iron-formation was formed from pre-existing minerals, by thermal metamorphism related to the intrusion of the Duluth Complex (note that the Complex as now seen is an erosional remnant of a much larger original system that probably overlaid the iron-formation and the Giants Range Granite in the eastern Mesabi Range. Amphibole (generally hornblende) in the Complex is due to reaction during cooling which altered (mostly) pyroxene. Because pyroxene is a minor constituent of the Complex in the NorthMet area there is a natural limit to how much amphibole can be formed.

The available information for the Duluth Complex with regard to the presence of amphibole and serpentine minerals and asbestiform fibers includes the following:

- Presence of amphibole minerals
    - Amphibole minerals are expected to be present in the Duluth Complex at low concentrations; approximately 2.3% on a volume basis, based on available data from samples considered to be representative of material that might be mined from the Duluth Complex (Stevenson 1978).
    - PolyMet's petrographic observations did not identify amphibole minerals in drill core samples from Unit 1 (the dominant sulfide-bearing member of the NorthMet deposit). Amphibole minerals were identified in lean ore samples associated with Units 3 and 4, ranging from 3% to 6% (as modal percent) in the drill core samples.
- Presence of serpentine minerals
    - Serpentine minerals are expected to be present in the Duluth Complex at low concentrations; approximately 1.5% on a volume basis (MEQB 1979). Serpentine minerals were not identified in the samples included in Stevenson's (1978) bench-scale ore concentration tests on 9 mineralized "gabbro" samples from the Duluth Complex.
    - PolyMet's petrographic observations identified serpentine in drill core samples from Unit 1, in trace amounts. Serpentine was also identified in drill core samples from lean ore and waste rock, and in tailings samples, ranging from trace amounts up to 30% (as modal

percent). Overall, PolyMet's petrographic observations provide estimates that serpentine is approximately 2% of the minerals associated with the waste rock (most Duluth Complex rock is quite fresh and unaltered)

- Presence of asbestiform fibers
    - Chrysotile (the asbestiform subgroup of serpentine minerals) was not identified in the samples of mineralized "gabbro" assessed by Stevenson (1978). The MEQB (1979) did not identify chrysotile as a mineral of concern for the Duluth Complex.
    - Stevenson (1978) identified the presence of an unusual actinolite with asbestiform habit that was found in gabbroic rocks adjacent to one of the samples used in his study. However, no minerals in asbestiform habit were identified in the nine process samples of Duluth gabbro assessed in Stevenson's (1978) study. This information was summarized by the MEQB (1979) and that discussion identified *"… the occurrence of visible asbestiform amphibole is rare (0.50 gm in 5 x 10^6 gm of gabbro) and associated with rare centimeter-sized cavities in mineralized rock. …"*.
    - The MEQB (1979) identified that the concentration of asbestiform amphibole minerals in the Duluth Complex ore is expected to be quite low, *"… less than 0.1 ppm by weight in the mineralized areas of the Duluth Complex (Weiblen and Stevenson 1978) …"*. The earlier studies included in the Regional Copper-Nickel Study Report (MEQB, 1979) have shown that plagioclase accounts for a large percentage (50 to 80%) of the Duluth Complex, with olivine (10 to 40%), augite, and various oxide minerals occurring interstitially to the tubular plagioclase crystals (MEQB, 1979). Non-asbestos amphibole minerals were expected to average approximately 2.0% by volume (MEQB 1979). This information indicates that non-asbestiform, non-amphibole minerals are expected to predominate in the Duluth Complex. The MEQB (1979) identified that asbestiform amphibole minerals that might be present in the Duluth Complex are expected to be rare and if present, to be very low on both a weight and volume basis.
    - Severson and Hauck (1990) identified patches of deuteric alteration ("uralitization") within all units of the Partridge River Troctolitic Series. These patches are characterized by fine-grained mats of radiating bundles of chlorite, hornblende, actinolite, sericite, ± tremolite which often interpenetrate with adjacent plagioclase crystals. The alteration is described as irregular, with no systematic distribution related to mineralization or

faulting, and not associated with any particular rock unit or horizon (Severson and Hauck, 1990). The uralitization does not specifically identify asbestiform amphibole minerals, but the association of "fine-grained mats of radiating bundles" and actinolite suggests the potential presence of asbestiform amphibole minerals in parts of the Duluth Complex.

The Copper-Nickel Study (MEQB 1979) and PolyMet's petrographic data indicate that some amphibole and serpentine minerals will likely be associated with the processing of ore from the Duluth Complex. Given the presence of amphibole and serpentine minerals associated with the NorthMet deposit, it is likely that amphibole and serpentine MN-fibers will be associated with the processing of ore from the Duluth Complex. However, the probability of releasing asbestiform amphibole fibers from the processing of ore from the Duluth Complex is low given that chrysotile was not identified in the samples from the Duluth Complex and the rare occurrence of the asbestiform amphibole minerals and the smaller amount of amphibole minerals present in the Duluth Complex (MEQB, 1979). This conclusion by the MEQB is supported by the results of the mineralogical and fibers related data specific to the NorthMet deposit (SGS, 2004).

A composite sample representative of rod mill feed (ore), and a composite sample representative of scavenger tails, was collected during pilot plant testing in 2000, using ore from the NorthMet deposit (SGS, 2004).

- As identified in Table 1, the corresponding mineralogical evaluation of the rod mill feed and scavenger tail samples collected from this earlier pilot plant testing showed that both samples were dominated by silicate minerals – calcic plagioclase feldspar, pyroxene, olivine, biotite, chlorite, serpentine (scavenger tail only), and amphibole – with only minor amounts of sulfides (primarily pyrrhotite and cubanite) and trace amounts of carbonate minerals. Plagioclase feldspar, the major mineral occurring in the ore body, has not been shown to be carcinogenic (MEQB, 1979; Wilson et al., 2000; Koskela et al., 1994).

- The two samples were analyzed at the McMaster University Occupational and Environmental Health Laboratory for asbestos fibers using dispersion staining with Polarized Light Microscopy (PLM) (NIOSH Method 9002). PLM is typically used as an initial scan for asbestos minerals considered to be bulk materials. No material meeting the length to width criteria (length > 5 um and aspect ratio 3:1) for the analytical technique to be considered asbestos was detected. A certificate of analysis was obtained for the samples (SGS 2004). Given the representative sample of the ore (rod mill feed), the results were interpreted to mean that fibrous amphibole minerals would not be expected to be present in the NorthMet ore body.

The results of the rod mill feed and scavenger tail sample analysis (SGS 2004) and previous studies on ore from the Duluth Complex (MEQB, 1979) indicate that the amphibole minerals present in the Duluth Complex are highly likely to be non-asbestiform.

Table 1. Listing of minerals identified in selected geologic formations in the NorthMet Deposit.

Information Source for Selected Geologic Formations	Duluth Complex	Expected Habit (Asbestiform or Non-asbestiform)
NorthMet Deposit [1]	***Rod Mill Feed***	
	Major mineral = Plagioclase feldspar	Non-asbestiform
	Minor mineral components:	
	Pyroxene	Non-asbestiform
	Olivine	Non-asbestiform
	Scavenger Tails:	
	Major mineral = Plagioclase feldspar	Non-asbestiform
	Minor mineral components:	
	Pyroxene	Non-asbestiform
	Olivine	Non-asbestiform
	Serpentine	Non-asbestiform
	Concentrate:	
	Major mineral assemblage = chalcopyrite	Non-asbestiform
	Moderate quantity = Pyrrhotite	Non-asbestiform
	Minor components:	
	Plagioclase feldspar	Non-asbestiform
	Pentlandite	Non-asbestiform
	Cubanite	Non-asbestiform
	Pyrite	Non-asbestiform
	Trace amounts:	
	Covellite	Non-asbestiform
	Bornite	Non-asbestiform
	Violarite	Non-asbestiform
	Galena	Non-asbestiform
	Sphalerite	Non-asbestiform

[1] Data obtained from SGS Lakefield Research Limited (Lakefield Research, Ontario, Canada) for rod mill feed and scavenger tails. SGS Lakefield Research Limited, Flotation Pilot Plant Products, Environmental Investigation and Air Testing, from NorthMet Samples. Prepared for PolyMet Mining Corporation, LR10054-003 Progress Report No. 6. June 2004.

Qualitative x-ray diffraction results show that scavenger tails and rod mill feed were dominated by silicate minerals, with only minor amounts of sulfides and trace amounts of carbonate minerals present. The major mineral in the concentrate was chalcopyrite.

While acknowledging the available data from the Regional Copper-Nickel Study, and specifically the work of Stevenson (1978) and the fibers data available for the NorthMet deposit itself prior to 2005, Minnesota State Agencies requested that additional fibers related data be provided by PolyMet. Pilot studies of the flotation and hydrometallurgical processes in mid- to late 2005 provided PolyMet with an opportunity to collect and report this additional data (Section 3).

3.0 FLOTATION PILOT STUDY RESULTS

PolyMet conducted flotation pilot testing in July and August 2005. Samples of the feed material to the flotation process (head feed; ore), tailings (material rejected from the flotation process), and flotation process water were collected and submitted to Braun Intertec for fibers analysis according to methodologies identified in Addendum 1 to Section 3.2 of the Environmental SAP (Appendix A). These collected samples are considered to be representative of the head feed, tailings, and flotation process water to be associated with processing ore from the NorthMet deposit. The results of the fibers analysis are reported and discussed below.

3.1 Types of Fibers Analyses

Nine samples each of ore (head feed), tailings, and flotation process water were submitted to Braun Intertec for fibers analysis. Each sample type is discussed separately below.

Ore (Head Feed)

The 9 ore samples are considered to be “bulk materials”. Subsamples from each of the 9 samples were analyzed by two microscopy methods: by Polarized Light Microscopy (PLM) following EPA’s method for the analysis of bulk materials (EPA/600/R-93-116), and by Transmission Electron Microscopy (TEM). For the TEM analysis, the MDH fiber identification and counting rules were used as described in MDH Method 851.

Tailings

The 9 tailings samples were also considered to be “bulk materials”. Subsamples from each of the 9 samples were analyzed by two microscopy methods: by PLM following EPA’s method for the analysis of bulk materials (EPA/600/R-93-116), and by TEM. For the TEM analysis, the MDH fiber identification and counting rules were used as described in MDH Method 851.

Flotation Process Water

The process water samples were only analyzed by TEM. Applicable methods were EPA 100.2 (also EPA/600/4-83-043; Asbestos structures in water) and MDH Method 851.

3.2 Polarized Light Microscopy Results

Ore (Head Feed)

A small amount of material (a subsample) from each of the 9 ore samples was analyzed essentially "as submitted". Scanning with PLM allows an analyst to view the entire amount of the sample material present on the filter. Fibrous material was identified by PLM in one of the 9 ore samples. Based on refractive indices the material was determined to meet the definition of actinolite asbestos. The asbestos content in the sample (sample P3O-B) was estimated to be less than 1%. PLM analysis results are provided in Appendix B.

Identification of asbestiform fibers is complicated in that not any one method by itself may be able to positively distinguish between amphibole asbestos and non-asbestos amphibole particles. It is important to recognize that asbestos "fibers" identified by light microscopy that meet a 3:1 or 5:1 length to width aspect ratio may in fact not be asbestos fibers. The EPA PLM method was developed for evaluation of fibers in workplaces where commercial asbestos was a component of building materials. It was not considered important to discriminate between asbestos and non-asbestos fibers. Cleavage fragments may have a similar microscopic appearance to that of "true" asbestos fibers. Therefore, methods other than light microscopy should be employed (size, optical extinction characteristics, and morphology) to be able to distinguish the asbestos from the non-asbestos particles (Van Orden et al., 2005).

Due to the limitations of the PLM analysis, TEM analysis of the ore samples was also conducted and these results are discussed in Section 3.3.

Tailings

The 9 tailings samples were submitted as "sludge-like" material. A subsample of material from each sample was first dried under a heat lamp and then reduced to a powder by mortar and pestle before analysis. As discussed with Braun Intertec staff, this additional grinding does not affect the identification of asbestos minerals or asbestiform fibers. The asbestiform fibers have high tensile strength and flexibility and the grinding does not destroy these types of fibers.

Fibrous material was not identified in the tailings samples when scanned by PLM (EPA Method: EPA/600/R-93-116).

3.3 Transmission Electron Microscopy Results

A small amount of material from each ore, tailing, and process water sample (a subsample) was prepared for analysis by TEM. In order to conduct the TEM analysis, additional grinding of the ore and tailings samples with mortar and pestle was conducted in the laboratory to produce a very fine powder. Stevenson (1978) identified that the finer a material is ground, the higher the number of "fibers" that are identified using the MDH counting rules (Method 851 or Method 852). This additional grinding in the laboratory only affects the fiber counts because more breakage of particles along mineral cleavage planes occurs. The mortar and pestle grinding does not affect the identification of asbestiform fibers since asbestiform fibers have high tensile strength and flexibility and the additional grinding is not expected to break or shorten the asbestiform fibers or decrease their width (personal communication, Mr. Steve Felton, Braun InterTec, Inc., December 2005).

When compared to the PLM analysis, the TEM analysis looks at a much smaller area of the material to be assessed, with the filter being gridded, and grids being selected for analysis according to specific criteria (MDH Method 852). The TEM analysis characterizes the fibers with regard to length, width, and mineral species. Table 2 provides a summary of the fibers analysis for the ore (head feed), tailings, and process water samples. Appendix C provides the detailed fiber identification and counting results from the individual samples.

- The TEM analysis did not confirm the presence of the fibrous material in Sample P3O-B that had been identified with PLM.
- The majority of fibers found in the samples are non-amphibole (503 out of 553; 91%).
- Amphibole fibers are approximately 9% of the fibers identified in the ore, tailings, and process water samples (50 out of 553).
    - The majority of the amphibole fibers were either Cummingtonite-grunerite (29 of 50 fibers; 58%) or actinolite (18 of 50 fibers; 36%). Two hornblende fibers (2 of 50; 4%), and one "other amphibole fiber" (1 of 50; 2%) were also identified.
- Chrysotile fibers were not identified in any of the samples.

Table 2. Summary fibers data[1] related to the processing of ore from the NorthMet deposit.

(NorthMet Project Flotation Pilot Study, 2005)

Information on:	**Ore (Head Feed)**	**Tailings**	**Flotation Process Water**	**TOTAL**
# of samples analyzed	9	9	9	
Fibrous Material Identified with Polarized Light Microscopy (PLM)? (EPA/600/R-93-116)	Yes. 1 sample contained fibrous material identified as actinolite asbestos; < 1%.	No.	Not applicable.	
Transmission Electron Microscopy (TEM) identifies asbestos fibers?	No. Amphibole minerals were identified (cummingtonite -grunerite and actinolite) but asbestos fibers were <u>not</u> identified.	No.	No. (EPA Method 100.2; EPA/600/4-83-043)	
Total Fiber Counts and Speciation (TEM Analysis; Counts Follow MDH Method 851)				
Total MN-Fibers Identified (includes amphiboles)	202 Length: range = 0.5 – 16.0 µm mean = 1.54 µm Aspect ratio (length:width) range = 3:1 to 27:1 mean = 4.8	217 Length: range = 0.5 – 10.1 µm mean = 1.59 µm Aspect ratio (length:width) range = 3:1 to 25:1 mean = 5.3	134 Length: range = 0.4 – 3.5 µm mean = 0.93 µm Aspect ratio (length:width) range = 3:1 to 14:1 mean = 5.3	553
Amphibole Minerals and Fibers Present?	Yes Present in 5 of 9 samples.	Yes Present in 8 of 9 samples.	Yes Present in 6 of 9 samples.	Yes (19 of 27)
Characteristics of Amphibole Fibers	11 fibers (5% of total fibers) Length: range = 0.75 – 4.5 µm mean = 1.6 µm Aspect ratio (Length:width): range = 3.0 – 20.65 mean = 6.49	20 fibers (9% of total fibers) Length: range = 0.75 – 10.1 µm mean = 2.36 µm Aspect ratio (Length:width): range = 3.0 – 20.83 mean = 5.54	19 fibers (14% of total fibers) Length: range = 0.4 – 1.7 µm mean = 0.91 µm Aspect ratio (Length:width): range = 2.67 – 14.17 mean = 5.07	50 (9%)
Chrysotile Fibers Present?	No; none identified	No; none identified	No; none identified	0
Fiber Count Summary				
Total	202	217	134	553
# of "MDH Fibers"(MN-fibers) Identified (aspect ratios of 3:1 or greater)	195	213	133	541
# of "Occupational Fibers" Identified (length of 5 micrometers or longer <u>and</u> aspect ratios of 3:1 or greater) [# of amphibole fibers identified as "Occupational Fibers"]	4 [0]	4 [2]	0 [0]	8 [2]
# of "Asbestos Fibers" Identified (<u>Solids</u>: length of 5 µm or longer <u>and</u> aspect ratios of 20:1 or greater. <u>Water</u>: length of 10 µm or longer <u>and</u> aspect ratios of 20:1 or greater.) [# of amphibole fibers identified as "Asbestos Fibers"]	1 [0]	0 [0]	0 [0]	1 [0]
# of "MN-Fibers" Identified Having Less than 3:1 Aspect Ratio	2	0	1	3

[1] Data are for fibers identified on subsections of filters prepared for each sample and analyzed by Braun Intertec. The fiber counts do not represent estimates for the entire filter or for the entire sample submitted for analysis.

With regard to the TEM analysis and the MDH Methods 851 and 852 fiber identification and counting criteria, the *"…method is unable to distinguish, on a fiber-by-fiber basis, between asbestiform fibers and cleavage fragments of the same mineral. …"* (MDH, Method 851 and 852). The presence of amphibole minerals alone does not mean that they are in the asbestiform habit. As stated in MDH Method 851 and 852, "… *Size distributions which are generated by the fiber count can help place the particulate sample in the cleavage fragment to asbestiform fiber continuum. …*".

Figure 3 shows the length versus the width of all fibers (amphibole, non-amphibole) found in the samples associated with processing ore from the NorthMet deposit (ore, tailings, flotation process water). The amphibole fibers tend to be short, lengths less than 5 µm, and blocky with aspect ratios ranging from 3:1 to 10:1, but are typically less than 5:1 (Figure 3). This is in contrast to asbestiform amphibole fibers which are characterized as being long and thin, with length-to-width aspect ratios of 20:1 or greater.

The TEM results also indicate the following for the fiber classifications to be reported to the Minnesota State Agencies per the approved Environmental Sampling and Analysis Plan (Appendix A) (all comparisons to 553 total fibers):

- 541 fibers (98%) can be classified as "MDH fibers" (i.e., MN-fiber; aspect ratios of 3:1 or greater) (Table 2).
- 8 fibers (1.4%) can be classified as an "occupational fiber" (length of 5 µm or longer <u>and</u> a length to diameter aspect ratio of at least 3:1) (Table 2); 2 of the 8 fibers are amphibole.
- One fiber (0.2%) meets the definition of an "asbestos fiber" using the EPA classification method (greater than 5 µm in length <u>and</u> an aspect ratio of 20:1 or greater), but this fiber is a non-amphibole fiber (Figure 3).
- 3 fibers (0.5%) were identified in the samples that do not meet the minimum criteria of having a 3:1 aspect ratio (Table 2).

In Figure 3, data points to the right of the 20:1 line can be considered to represent non-asbestiform fibers based on the EPA definition of an asbestos fiber (greater than 5 microns in length and an aspect ratio of 20:1 or greater. Based on Figure 3, the amphibole fibers in samples associated with the processing of ore from the NorthMet deposit can be considered non-asbestiform. Appendix C contains the detailed mineral and fiber information in the MDH requested format for each ore sample analyzed by TEM.

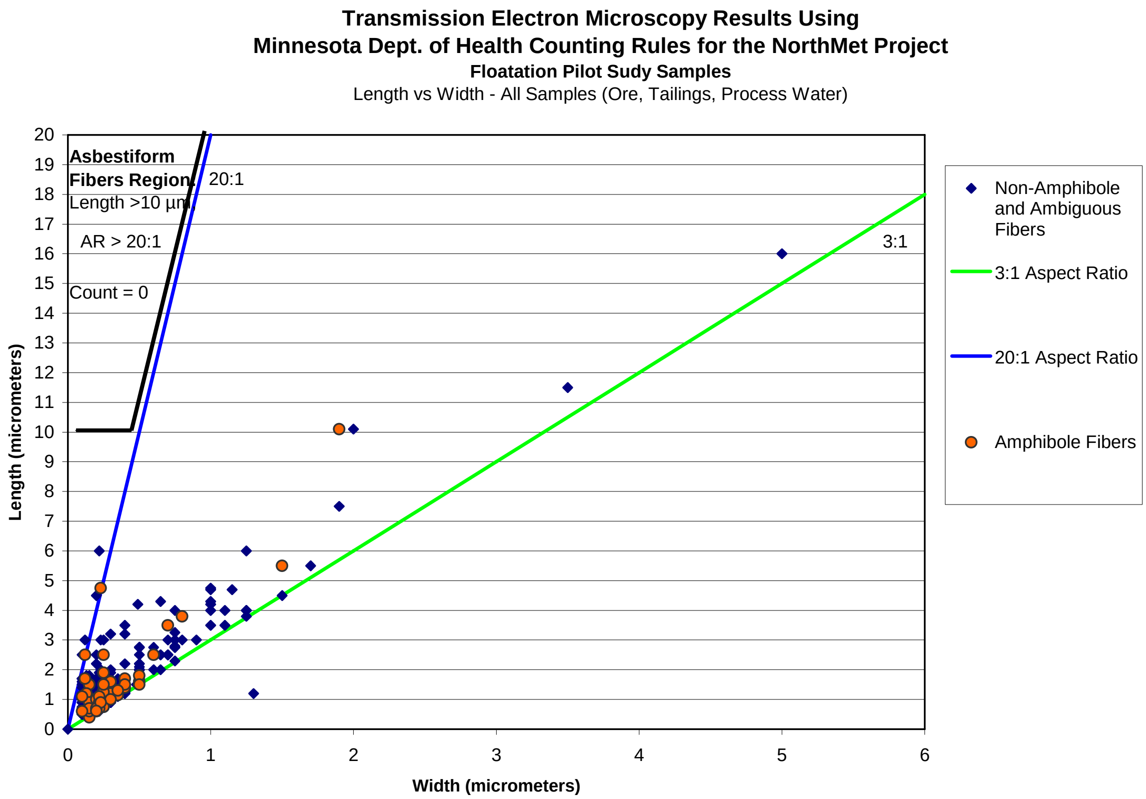


Figure 3. Plot of length versus width for 553 fibers identified in samples (ore, tailings, flotation process water) associated with the processing of ore from the NorthMet deposit.

A second method to assess whether the amphiboles are present as asbestiform fibers is based on Wylie (1978) and Stevenson (1978). A "fibrosity index" was calculated for the amphibole fibers found in the ore, tailings, and process water samples. This "fibrosity index" is based on a regression equation and follows the work of Wylie (1978), as applied by Stevenson (1978).

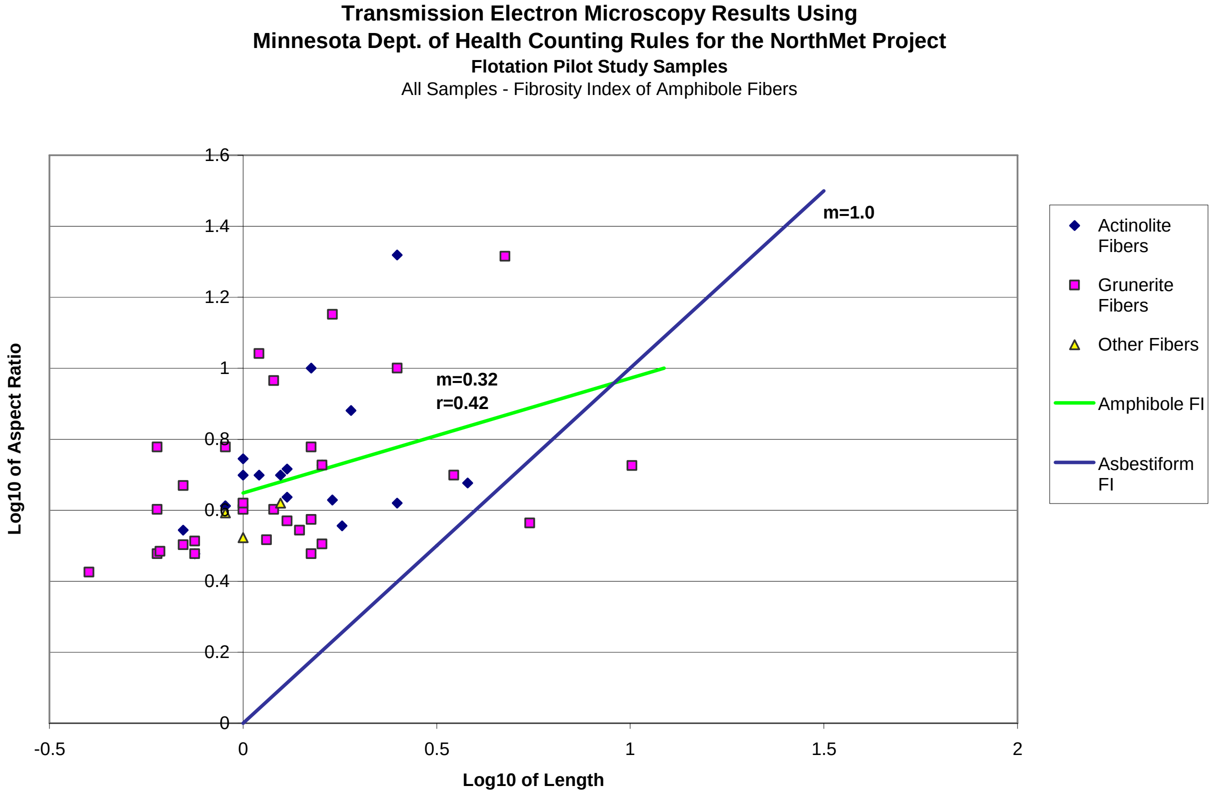
The regression equation is as follows: $\log10\ A.R. = M\ \log10 L + B$

Where: A.R. = aspect ratio (log10); M is the slope; L = length (log10); B is the zero intercept

Wylie (1978) proposed that the slope of the regression line (M) be considered a "fibrosity index". Wylie's incremental method identified slopes of approximately 0.8 to 1.0 for known asbestiform fibers (amosite, crocidolite, short fiber and long fiber chrysotile). Based on the work of Wylie (1978), a regression equation for amphibole fibers having a slope (M) of approximately 1.0 would be an indicator of asbestiform fibers. As identified by Stevenson (1978) via the work of Wylie (1978), a slope (M) less than 0.5 was found in preliminary results on a sample of non-asbestiform tremolite. Based on the findings from Wylie (1978), a regression slope of 0.5 or less would be considered an indication of non-asbestiform fibers.

Stevenson (1978) identified in his study that the slope and intercept of the regression equation for amphibole fibers "*… are not affected to any great extent by the increment method …*". Stevenson's (1978) log-log plots showed little difference in the slope whether fitting the regression line to all data or fitting the data to the increment method of Wylie (1978). For this analysis, the slope from fitting a regression line to all the data is provided.

Following the work of Stevenson (1978) and using the regression line as a "fibrosity index" as proposed by Wylie (1978), an assessment of the "fibrosity index" of the 50 amphibole fibers found in the samples associated with the processing of ore from the NorthMet deposit (ore, 11; tailings, 20; process water, 19) was conducted (Figure 4). The slope of the regression for the NorthMet amphibole fibers data, from all samples combined, is 0.32 (r-value = 0.42; significant at the 0.01 level). The slope value of 0.32 is less than Wylie's (1978) initial slope value of 0.5 for non-asbestiform tremolite. Based on the "fibrosity index" evaluation, the conclusion from Figure 4 is that the amphibole fibers identified in the samples associated with processing ore from the NorthMet deposit are most likely non-asbestiform. These findings are consistent with the findings from the Copper-Nickel Study (MEQB, 1979; Stevenson, 1978).



Slope (m) of 1.0 represents asbestiform fibers based on the work of Wylie (1978) and provides reference to the regression slope for the amphibole fibers identified in samples associated with the processing of ore from the NorthMet deposit. A second comparison is a slope (m) value of 0.5 for non-asbestiform tremolite (Wylie 1978).

Figure 4. Log-log plot of aspect ratio versus length and the associated regression slope for 50 amphibole fibers identified in samples associated with the processing of ore NorthMet deposit (ore = 11, tailings = 20, and flotation process water = 19).

To further confirm that the NorthMet amphibole fibers data indicates non-asbestiform fibers, an additional comparison of the amphibole fiber data associated with processing ore from the NorthMet deposit was made with the amphibole fibers data assessed by Stevenson (1978) that was associated with processing ore from the Duluth Complex (Table 3).

Table 3. Comparison of summary amphibole fibers data from Stevenson (1978) with amphibole fibers data associated with processing ore from the NorthMet deposit.
(data from Figures 21 and 22 from Stevenson, 1978)

Parameters	Stevenson (1978)	NorthMet Project
# of fibers identified in samples	155	50
Length (range; micrometers)	~ 0.3 – 5.5	0.4 – 10.1*
Widths (range; micrometers)	~ 0.02 – 0.6	0.1 – 1.9
Aspect Ratios (length:width)	3:1 – 60:1	2.7** – 21:1

*2 amphibole fibers greater than 5 µm; one fiber = 5.5 µm, the other = 10.1 µm. 48 of 50 fibers less than 5 µm long.
**one amphibole fiber identified and reported with a length of 0.4 µm and width of 0.15 µm.

Table 3 identifies that the NorthMet amphibole fibers data from the NorthMet pilot studies is similar to the fibers data generated for the Regional Copper-Nickel Study and assessed by Stevenson (1978); similar lengths and widths. This comparison is highlighted in Figure 5, overlaying the individual amphibole fibers data from the NorthMet project on the data from the Duluth Complex that was depicted in Figure 23 from Stevenson (1978). This comparison shows that the NorthMet amphibole fibers data are essentially a subset of the data assessed by Stevenson (1978). The range of amphibole fiber aspect ratios and lengths (log-log plots) of the NorthMet data are within the range of aspect ratios and lengths of the amphibole fibers assessed by Stevenson (1978) (Figure 5).

Stevenson (1978) determined through the application of Wylie's (1978) "fibrosity index" that the 155 amphibole fibers identified in samples associated with processing ore from the Duluth Complex were non-asbestiform (slope = 0.26; r = 0.29, significant at the 0.01 level) (Figure 5). As discussed previously, the slope of the regression for the NorthMet amphibole fibers data is 0.32 (r = 0.42) (Figure 4). Similar to the findings of Stevenson (1978) for other Duluth Complex amphibole fibers, the "fibrosity index" calculated for the NorthMet amphibole fibers indicates they are most likely non-asbestiform (Figure 4; Figure 5).

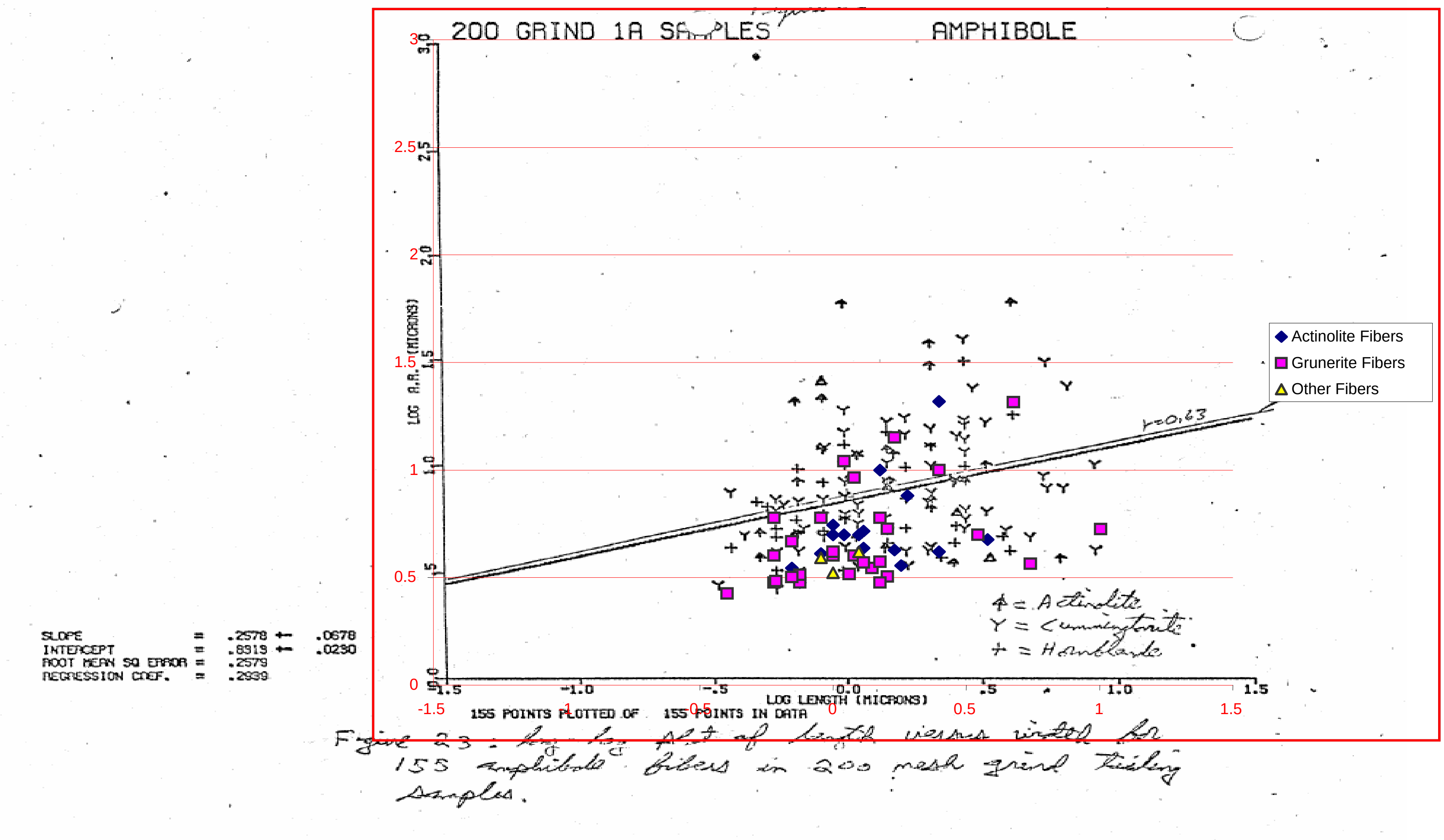
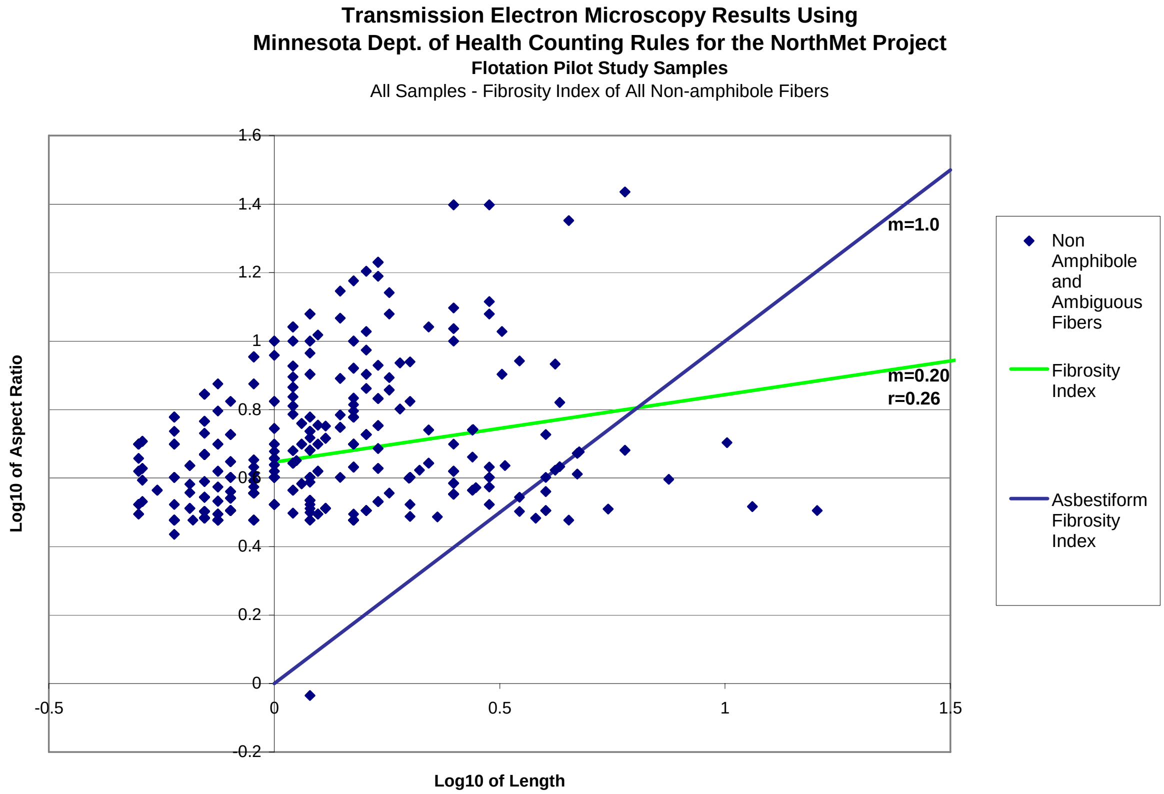


Figure 5. Overlay of the log-log plot of aspect ratio versus length for NorthMet Project amphibole fiber data (50 fibers; from Figure 4) on the log-log plot of aspect ratio versus length for 155 amphibole fibers identified in tailing samples from the Duluth Complex as reported in Figure 23 from Stevenson (1978).

Non-amphibole fibers from all samples (ore, tailings, flotation process water) associated with processing ore from the NorthMet deposit were also assessed by the "fibrosity index". The results for the 503 non-amphibole fibers are presented in Figure 6 below. The slope of the regression line is 0.20 (r = 0.26; significant at the 0.01 level). The slope value of 0.20 is less than Wylie's (1978) initial slope value of 0.5 for non-asbestiform tremolite. Based on the "fibrosity index" evaluation, the non-amphibole fibers identified in samples associated with processing ore from the NorthMet deposit are highly likely non-asbestiform fibers (Figure 6).

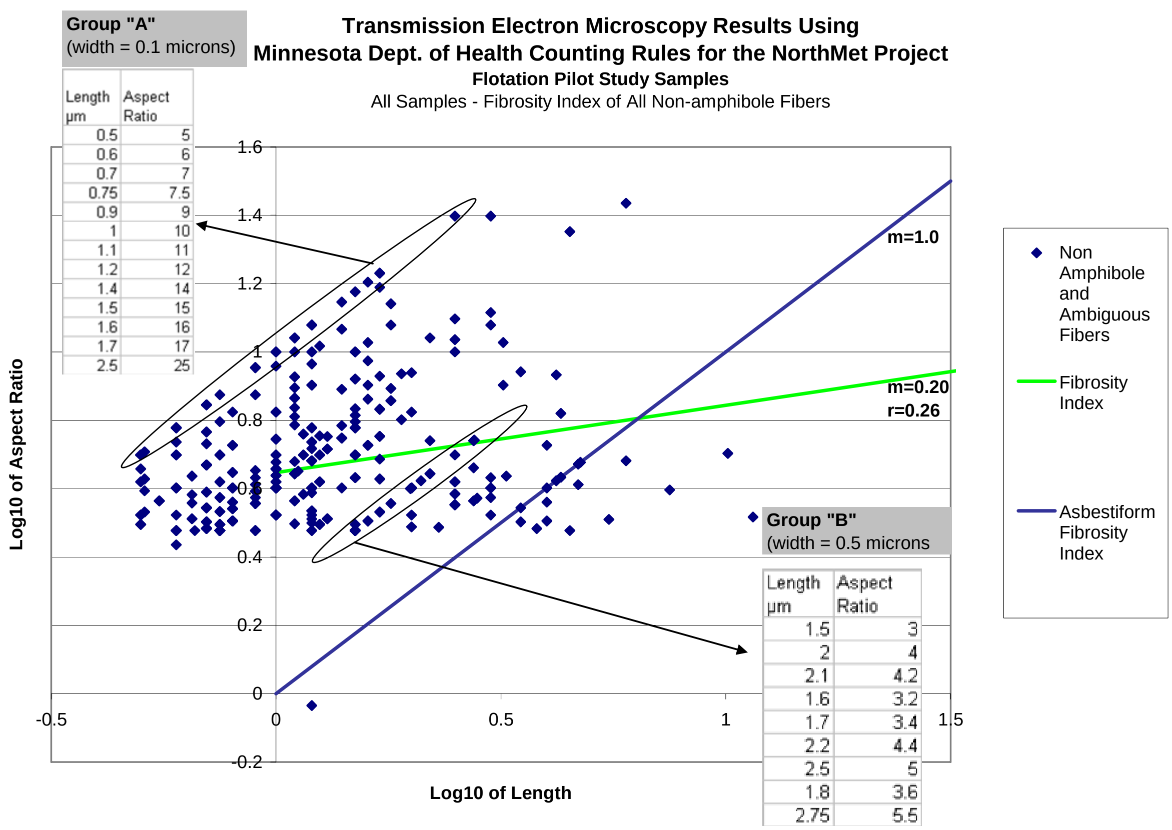


Slope (m) of 1.0 represents asbestiform fibers based on the work of Wylie (1978) and provides reference to the regression slope for the non-amphibole fibers identified in samples associated with the processing of ore from the NorthMet deposit. A second comparison is a slope (m) value of 0.5 for non-asbestiform tremolite (Wylie 1978).

The regression analysis used data from all samples: ore = 191, tailings = 197, flotation process water = 115; total = 503.

Figure 6. Log-log plot of aspect ratio versus length and the associated regression slope for 503 non-amphibole fibers identified in samples associated with the processing of ore from the NorthMet deposit.

The log:log non-amphibole fibers data plotted in Figure 6 show an unusual pattern of striations. The expectation is that the non-amphibole data should show more scatter as opposed to a discernible pattern. The non-amphibole fibers data were further investigated and it was confirmed that the data plotted in Figure 6 are the correct log-transformed data derived from the laboratory analytical results contained in Appendix C of this report. The investigation also identified that the striations in the data are associated with a uniform particle width for each data group. Figure 7 identifies that Group A data have a uniform width of 0.1 microns, while Group B data have a uniform width of 0.5 microns. The data in each group are from all sample types (ore, tailings, process water). The overall conclusion is that the striations in the plotted non-amphibole fibers data are related to the relatively uniform lengths and widths and generally prismatic/blocky structure of the particles themselves.



Group "A" (width = 0.1 microns)

Length µm	Aspect Ratio
0.5	5
0.6	6
0.7	7
0.75	7.5
0.9	9
1	10
1.1	11
1.2	12
1.4	14
1.5	15
1.6	16
1.7	17
2.5	25

Group "B" (width = 0.5 microns

Length µm	Aspect Ratio
1.5	3
2	4
2.1	4.2
1.6	3.2
1.7	3.4
2.2	4.4
2.5	5
1.8	3.6
2.75	5.5

(Log:log data in Figure 7 are the same data shown in Figure 6; untransformed data shown for Group A and Group B.)

The Fibrosity Index of the entire non-amphibole fibers dataset (503 samples) = 0.20

Figure 7. Additional investigation of the log:log plot of aspect ratio versus length for non-amphibole fibers data associated with the processing of ore from the NorthMet deposit.

3.4 Data Summary

Major findings from the analysis of ore, tailings, and flotation process water samples associated with processing ore from the NorthMet deposit are as follows:

1. A total of 27 samples were submitted to Braun Intertec for fibers analysis: 9 ore (head feed) samples; 9 tailings samples; 9 process water samples.

2. The ore (head feed) and tailings samples were analyzed by Polarized Light Microscopy (PLM) according to EPA's method for bulk materials (EPA/600/R-93-116).

    a. The PLM analysis identified fibrous actinolite in one of 9 ore samples; the concentration of the fibrous material was estimated to be less than 1%.

    b. Asbestos minerals were not identified in the 9 tailings samples.

3. The ore (head feed), tailings, and process water samples were also analyzed by Transmission Electron Microscopy (TEM).

    a. The TEM analysis did not identify asbestiform fibers in the ore, tailings, or process water samples.

    b. The TEM analysis did not identify chrysotile fibers (asbestiform subgroup of serpentine mineral) as being present in ore, tailings, or process water samples.

    c. The majority of fibers identified in the ore, tailings, and process water samples were non-amphibole (91%).

    d. Amphibole fibers were found to make up a small percentage (~ 9%) of total fibers identified in the ore, tailings, and process water samples.

    e. Based on the length versus width plot of the TEM results in Figure 3, the "fibrosity index" evaluation in Figure 4, and the comparison to Stevenson's (1978) data and analysis in Figure 5, it is likely that the amphibole fibers identified in samples associated with the processing of ore from the NorthMet deposit are non-asbestiform.

4. The fibers data from PolyMet's flotation pilot study are consistent with earlier findings and predictions for the Duluth Complex (Stevenson, 1978; MEQB, 1979).

5. As summarized by the MEQB (1979) regarding processing ore from the Duluth Complex, *"… The major issue here of potential environmental concern thus does not appear to be the possible release to the air and water of naturally-occurring asbestiform fibers as a result of mining, but rather the possible release of mineral fibers mechanically created as cleavage fragments from the non-asbestiform amphibole present in the mineralized Duluth Gabbro. …"*.

4.0 PROPOSED OPERATIONS AND ENVIRONMENTAL CONTROLS RELATED TO FIBERS

4.1 Controlling Plant Site Particulate Air Emissions

4.1.1 Coarse Particulate Matter

Data from the Flotation Pilot Study indicates that MN-fibers are likely to be associated with the processing of ore from the NorthMet deposit. The available TEM data presented in Section 3.3 indicates that most (~ 99.6%) of the MN-fibers are less than 10 microns in size (Figure 3). If these fibers were emitted to air, they would be classified as PM_{10} (i.e., small particles with an aerodynamic diameter less than 10 µm in size).

The potential sources of PM_{10} emissions at the Plant Site are discussed below.

- Crushing/grinding operations (existing): Particulate emissions associated with the crushing/grinding operations are currently controlled with several different types of air pollution control equipment.
    - Primary crushing: particle emissions controlled by fabric filters (99%+ control efficiency).
    - Secondary crushing: particle emissions from the pan feeders are currently controlled by Type W rotoclones (average control efficiency of 97% for emission calculation purposes; vendor information indicates 98.8% control efficiency).
    - Ore storage: emissions from the coarse ore storage bin are controlled by 2 Type W rotoclones and 2 fabric filters (assumed average control efficiency of 98% for emission calculation purposes).
    - Tertiary and quaternary crushing; feeders, conveyors, transfer points: particle emissions currently controlled by Type W rotoclones (97% control efficiency for emission calculation purposes).
    - Fine Ore Storage: Particle emissions from the North and South bins are currently controlled by Type W rotoclones (97% control efficiency for emission calculation purposes).

- Fine ore feeders (feed ore to the milling lines): particle emissions currently controlled by Type W rotoclones (97% control efficiency for emission calculation purposes).

- Milling and Flotation (existing): Amphibole fibers are not expected to be emitted to air from this process since it is a wet process.

- Concentrate Drying: PolyMet is now planning to have the option to dry the concentrate and then ship the dried concentrate by rail to off-site buyers instead of sending concentrate to the Hydrometallurgical Plant. Final details of the concentrate shipping are not yet available. Drying the concentrate can produce a small amount of particulate emissions from the drying process itself as well as from the loading of concentrate into railcars for off-site shipment. The potential particle emissions from the concentrate dryers and loading the concentrate into railcars is expected to be vented to wet scrubbers that have a removal efficiency of 99%+.

- Hydrometallurgical Plant (new): Concentrate will be input to the Hydrometallurgical Plant. A three-stage particulate removal system is planned for the equipment associated with the Hydrometallurgical Plant.

    - Each autoclave and flash vessel is proposed to have a dedicated venturi-type scrubber to remove entrained particulate matter and acid gases; raw water is to be used as the scrubbing liquor.

    - Steam condensation in a heat exchanger, which is designed to remove additional particulate and acid gases.

    - Remaining gases routed to the main scrubber, which will be of packed bed design, also with water as the scrubbing liquor.

    - Total system removal efficiency is estimated to be 99%+ for emission calculation purposes.

Because of ongoing public and regulatory agency concerns regarding potential releases of amphibole MN-fibers from the NorthMet Project, PolyMet will improve the technology to control potential particulate emissions. A summary of the proposed improvements follows.

Improvements in Air Emission Control Technology

PolyMet will be using existing LTVSMC equipment and the crushing/grinding circuits. In general, PolyMet proposes to replace outdated emission control equipment, and to utilize existing modern emission controls installed in the late 1990s. PolyMet is proposing to use primarily wet scrubbers for particulate controls in the crushing process because, in most cases, the existing systems were designed for wet scrubbers.

Ore grinding and crushing sources of particulate emissions can be enclosed for collection and control of particulate emissions. Baghouses, wet scrubbers, and ESP's are all capable of controlling crushing and grinding emissions. Cyclones were not evaluated in this analysis as they have lower control efficiencies than the other particulate control devices examined. Information and data used in this analysis are from RS58.

Ore crushing sources at the NorthMet project have exhaust flow rates ranging from 10,000 actual cubic feet per minute (acfm) to 100,000 acfm. Particulate control equipments costs are directly related to the flow rate of the air being treated. For this analysis, three material handling sources with representative flow rates (low, medium, and high) were evaluated for control costs using baghouses, scrubbers, and ESP's. These evaluations showed that all control systems were economically feasible. High and medium flow PM_{10} control costs were in the \$150/ton to \$350/ton PM_{10} removed. Costs for the low flow cases were approximately \$1,500/ton PM_{10} removed. Costs for the medium flow case are shown in Table 4 below.

Dry controls (baghouses and dry ESP's) have slightly better control efficiency than wet controls (wet scrubbers and wet ESP's) in these conditions (Table 4). Wet and dry controls are expected to have similar control efficiencies for filterable particulate matter. However, the use of wet control devices can potentially increase the amount of condensable particulate matter as determined by EPA Method 202. The non-ferrous metallic ore is higher in sulfide content than taconite ore. As a result, it is possible that dissolved solids in the scrubbing water may be an increased source of condensable particulate matter in the control device exhaust as compared to the dissolved solids that may have been associated with the previous taconite ore processing.

Table 4. Evaluation of the most effective PM10 control technologies for crushing related sources at the proposed NorthMet Plant Site using the medium air flow case

(from PolyMet EIS Document RS58)

Control Technology	Outlet Concentration (gr/dscf)*	Estimated Controlled Emissions (Tons/yr)	Emission Reduction (Tons/yr)**	Installed Capital Cost ($)	Annualized Operating Cost ($/yr)	Pollution Control Cost ($/ton)	Incremental Control Cost ($/ton)
Wet scrubber	0.006	7.4	2,376	$536,224	$369,185	$155	NA
Dry electrostatic Precipitator (ESP)	0.005	6.2	2,377	$3,150,708	$564,113	$237	$157,338
Baghouse	0.005	6.2	2,377	$1,239,148	$453,573	$191	$68,115
Wet wall electrostatic precipitator (WWESP)	0.006	7.4	2,376	$3,563,301	$627,420	$264	NA

gr/dscf = particle loading rate expressed as grains per dry standard cubic foot of air
NA = not applicable

*Total PM as measured by EPA Methods 5 (filterable) and 202 (condensable). Dry scrubbing such as ESPs and baghouses do not have a condensable fraction.

*** Emission reductions are based on comparison of potential emissions from the upgraded technology versus potential uncontrolled emissions of 2,383 tons/yr from the crushing/grinding source(s) at the proposed NorthMet Plant Site. In this comparison, dry scrubbing provides one (1) ton/yr more reduction than does wet scrubbing.

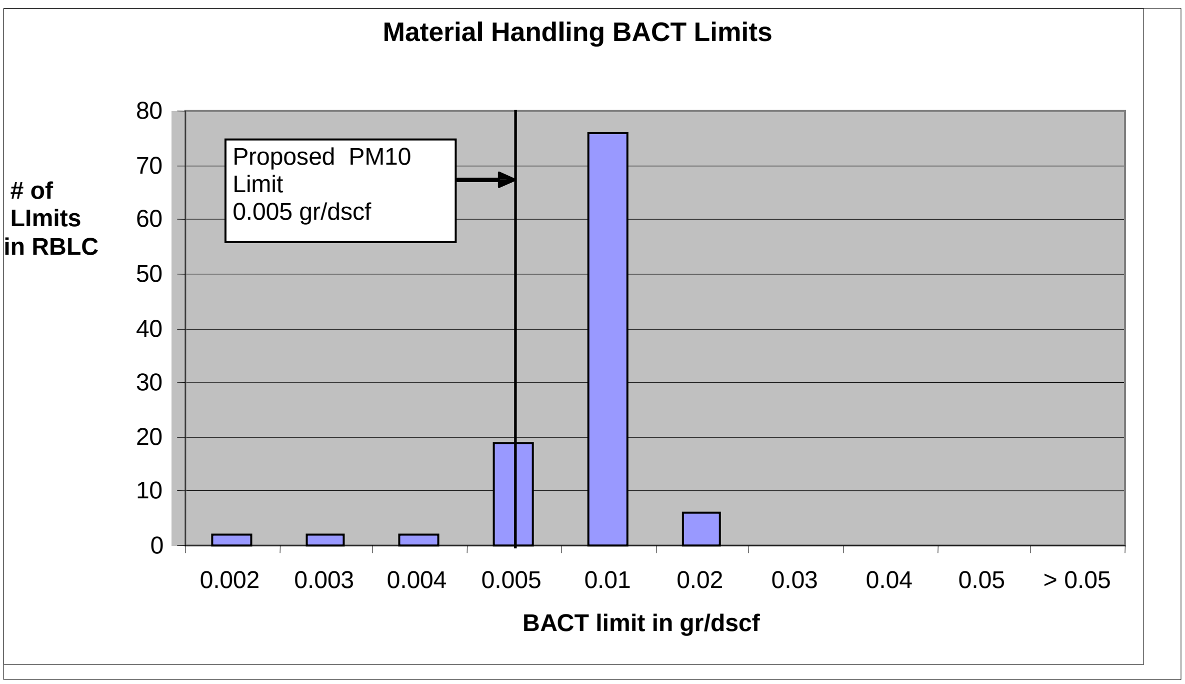
A value of 0.001 grains per dry standard cubic foot (gr/dscf) was used to estimate the potential contribution of scrubber water dissolved solids to the total particulate emissions rate, based on results from taconite ore processing, with a margin of safety to account for the different chemical properties of the ore to be processed for the NorthMet project.

For the 60" gyratory coarse crushers, PolyMet proposes to replace or upgrade the existing baghouse systems with baghouse controls to obtain a performance limit of 0.005 gr/dscf. Baghouses have the highest level of particulate control in this application. A performance limit of 0.005 gr/dscf is consistent with recent BACT limit determinations for material handling sources. Table 5 and Figure 8 summarize the RACT-BACT-LAER Clearinghouse (RBLC) data for material handling sources.

Table 5. Summary of the PM10 Emission Limits Contained in the RACT-BACT-LAER Clearinghouse
(from PolyMet EIS Document RS58)

RBLC PM10 BACT Limits Summary		
BACT-PSD PM10 gr/dscf Emission Limits		
MINIMUM	0.0025	gr/dscf
MAXIMUM	0.020	gr/dscf
MEDIAN	0.010	gr/dscf
COUNT	105	CASES

RBLC = RACT-BACT-LAER Clearinghouse; USEPA information database.



gr/dscf = grains per dry standard cubic foot.
RBLC = RACT-BACT-LAER Clearinghouse; USEPA information database.
Taconite MACT Limit for material handling sources = 0.005 gr/dscf.

Figure 8. PolyMet's Proposed PM10 Emission Limit for Material Handling Sources Compared to Recent BACT Limits Documented in the RACT-BACT-LAER Clearinghouse.

The lowest material handling BACT limits for PM identified in the RBLC search are for Northshore Mining Company (RBLC ID MN 0064) at 0.0025 gr/dscf. The facility's permit indicates that these limits were imposed to demonstrate modeled compliance with PSD increments (40 CFR 52.21(k)), and thus are considered to be more stringent limits than BACT. The Northshore Mining facility permit also includes a BACT limit (40 CFR 52.21 (j)) of 0.005 gr/dscf for material handling sources vented through stacks.

As shown in Figure 8, PolyMet's proposed PM/PM_{10} limit of 0.005 gr/dscf for the 60" coarse crushers is consistent with the vast majority of recent BACT determinations, and is lower than the median of recent BACT determinations. The proposed PM_{10} limit is also consistent with the taconite MACT standard for new ore and pellet handling sources (0.005 gr/dscf, as measured by EPA Method 5).

For the 36" gyratory coarse crushers and fine ore crushing equipment (except EU 017), PolyMet proposes wet scrubber controls with a performance limit of 0.006 gr/dscf of total particulate matter as measured by EPA Methods 5 and 202 (EIS Document RS58). The proposed limit is consistent with recent BACT determinations as noted above. It also provides a small allowance for condensable particulates. New wet scrubbing equipment will be installed to replace outdated emission controls. The existing crushing equipment was designed with wet scrubbers. Therefore, the crushing system already has the infrastructure in place to support wet scrubbing systems. In addition, floor space in the crushing building is limited. New wet scrubbing equipment will be able to fit within the existing space. Installing larger dry control systems like baghouses would require additional floor space, which may not be available.

For the fine ore storage bins, the fine ore feeders to milling and fine ore crushing East 3 (EU 017), PolyMet proposes to use existing pollution control equipment. PolyMet proposes a performance limit of 97% control efficiency or 0.008gr/dscf of total particulate matter as measured by EPA Methods 5 and 202. LTVSMC installed dynamic wet scrubbers (type W rotoclones) in the late 1990's on the fine ore storage bins and fine ore feeders. This control equipment has a high control efficiency, and replacement with new control equipment would provide minimal benefit with regard to reduced particulate emissions at a high cost as shown in Table 6 .

The scrubber for fine ore crushing East 3 (CE 121) is also new, installed just prior to the LTVSMC shutdown in 2001 CE 121 was designed to meet the existing source standard for the Taconite MACT. Therefore, installation of new controls would seem to provide little benefit with regard to reduced emissions, and the incremental control cost (new vs. existing) would be similar to those shown in Table 6.

Table 6. Evaluation of the Most Effective PM/PM10 Control Technologies for Fine Ore Storage Bins and Feeders at the Proposed NorthMet Plant Site; New Control Equipment Versus Existing Control With Type W Rotoclones.

Control Technology	Outlet Concentration*	Emission Reduction (Tons/yr)	Installed Capital Cost ($)	Annualized Operating Cost ($/yr)	Pollution Control Cost ($/ton)
Wet scrubber	0.006 gr/dscf (99% control) vs. 0.014 gr/dscf (97% control) **	1	$292,245	$300,731	$273,858
Dry electrostatic precipitator (ESP)	0.005 gr/dscf (99% control) vs. 0.014 gr/dscf (97% control) **	1	$1,717,151	$343,821	$313,097
Baghouse	0.005 gr/dscf (99% control) vs. 0.014 gr/dscf (97% control) **	1	$675,342	$351,018	$319,651
Wet wall electrostatic precipitator (WWESP)	0.006 gr/dscf (99% control) vs. 0.014 gr/dscf (97% control) **	1	$1,942,017	$377,352	$343,632

gr/dscf = particle loading rate expressed in grains per dry standard cubic foot of air.

*Total PM as measured by EPA Methods 5 (filterable) and 202 (condensable). Dry scrubbing such as a dry ESP or a baghouse do not have a condensable fraction.

**Type W Rotoclones are estimated to have a control efficiency of approximately 97% for emission calculation purposes. Vendor information indicates approximately 98.8% control efficiency.

Table 6 indicates that dry particulate controls provide only a slight reduction in emissions over wet controls, and the incremental cost of dry controls would seem to far exceed the benefits. For the medium flow case (Table 4), dry controls reduce emissions by only 1 ton per year more than wet controls, and the incremental cost of dry controls is $68,000 to $157,000 per additional ton of particulate matter removed. Typically a cost of $10,000 per additional ton of pollutant captured is used as a threshold for determining the economic feasibility of a control technology.

Final discussions and decisions regarding the pollution control equipment for the crushing/grinding operation are ongoing between PolyMet and the MPCA.

4.1.2 Fine Particulate Matter

The available TEM data presented in Section 3.3 indicates that most of the MN-fibers are less than 2.5 microns in size (Figure 3). If these MN-fibers were emitted to air, they would be classified as $PM_{2.5}$ (i.e., fine particles with an aerodynamic diameter less than 2.5 µm in size).

Because crushing and grinding operations are the most likely air emission source of MN-fibers at the Plant Site, this analysis will focus on $PM_{2.5}$ controls for the crushing and grinding sources. Sources of $PM_{2.5}$ in the crushing section of the plant include crushers, screens, vibrating pan feeders, and material drops from conveyors. All crushing and screening equipment and conveyor transfer points will be enclosed and ventilated to dust control equipment. Each train of crude and fine ore crushers, screens, pan feeders, and conveyors will be routed to a particulate matter control system for that processing train. Fines collected by dust control equipment will be re-processed in the milling operations.

Potential control technologies for particulate emissions, PM_{10} and $PM_{2.5,}$, are identified in Table 7. Information in Table 7 indicates that the controls reviewed in the PM_{10} analysis for the NorthMet project (PolyMet Document RS58) are the same controls that are applicable for $PM_{2.5}$ particles. Therefore, the control equipment selection for PM_{10} also represents an appropriate level of control for $PM_{2.5}$. In summary, the control equipment analysis for PM_{10} is considered to be representative of the control equipment analysis for $PM_{2.5}$.

The U.S. EPA report entitled *"Stationary Source Control Techniques Document for Fine Particulate Matter (EPA-452/R-97-001)"* has comparisons of control efficiencies of PM_{10} vs. $PM_{2.5}$.for various particulate matter control devices (see http://www.epa.gov/ttn/catc/products.html#aptecrpts). Table 8 shows that emissions control efficiencies for the fine particles ($PM_{2.5}$) are similar to control efficiencies for PM_{10} even though $PM_{2.5}$ particles are harder to capture than PM_{10} particles due to the smaller mass and aerodynamic diameter of $PM_{2.5}$ particles. Overall, $PM_{2.5}$ control efficiencies are slightly lower than PM_{10} control efficiencies (Table 8). The $PM_{2.5}$ control efficiency for wet scrubbing was slightly lower than for dry controls (3.3% less for wet scrubbing versus 1.0% less for ESP's and 0.2% less for baghouses). Based on the information in Table 8, there does not appear to be a significant difference between ESP's, baghouses and wet scrubbers in controlling $PM_{2.5}$ emissions.

Table 7. $PM_{2.5}$ / PM_{10} Emission Control Technologies for Crushing and Grinding Sources [1]

Technology	Description	Feasible? Yes or No	Control Efficiency
Fabric filter (baghouse)	A fabric filter, or baghouse, consists of a number of fabric bags placed inside an enclosure. Particulate matter is collected on the surface of the bags as the gas stream passes through them. The particulate is periodically removed from the bags and collected in hoppers located beneath the bags.	Yes	98% - 99+% or 0.005 gr/dscf*
Wet scrubber	Wet scrubbers remove particles from waste gas by capturing the particles in liquid droplets (usually water) and separating the droplets from the gas stream. The droplets transport the particulate out of the gas stream.	Yes	98% - 99+% or 0.005 gr/dscf*
Electrostatic precipitator	An electrostatic precipitator applies electrical forces to separate particles from the flue gas stream. Particles are given an electrical charge. The charged particles are attracted to and collected on oppositely charged collector plates. Particles on the collector plates are released by rapping and fall into hoppers for collection and removal.	Yes	98% - 99+% or 0.006 gr/dscf*
Wet electrostatic precipitator	A Wet ESP operates on the same collection principles as a dry ESP, and uses a water spray to remove particulate matter from the collection plates.	Yes	98% - 99+% or 0.006 gr/dscf*
Centrifugal separation (e.g. cyclones)	Cyclone separators are designed to remove particles by causing the exhaust gas stream to flow in a spiral pattern inside of a tube. Owing to centrifugal forces, the larger particles slide down the wall and drop to the bottom of the cyclone where they are removed. The cleaned gas flows out of the top the cyclone.	Yes	50% - 80%
Good design methods & operating practices	Minimize emissions through operating methods, procedures, and selection of raw materials. This includes installation of total enclosures and collection hoods where feasible	Yes	NA

[1] Source: U.S. EPA. Stationary Source Control Techniques Document for Fine Particulate Matter (EPA-452/R-97-001).

Table 8. Comparison of Control Efficiencies for PM_{10} vs. $PM_{2.5}$ from Stationary Source Control Techniques Document for Fine Particulate Matter [1]

	ESP's			Baghouse			Wet Scrubber [2]		
Source Type	**PM_{10}**	**$PM_{2.5}$**	**% Diff**	**PM_{10}**	**$PM_{2.5}$**	**% Diff**	**PM_{10}**	**$PM_{2.5}$**	**% Diff**
Coal fired Boilers									
Dry Bottom (bituminous)	97.7	96.0	1.7%	99.2	98.3	0.9%	81.7	50.0	NA [3]
Spreader Stoker (bituminous)	99.4	97.7	1.7%	99.9	99.3	0.6%			
Spreader Stoker (anthracite)	98.4	98.5	-0.1%	99.4	98.4	1.0%			
Residual Oil							91.5	88.8	3.0%
Wood and Bark							93.3	92.1	1.3%
Bark							85.1	83.8	1.5%
Coke Production									
Coal Preheating (venturi)							92.9	89.0	4.2%
Coke Pushing							95.2	89.0	6.5%
Primary Copper Production									
Multiple Hearth Roaster	99.0	99.1	-0.1%						
Reverberatory Smelter	97.1	97.4	-0.3%						
Ferroalloy Electric Arc Furnaces									
Iron silicates				97.0	97.6	-0.6%			
Iron manganese				98.3	98.7	-0.4%			
Silica				96.3	96.9	-0.6%			
Iron and Steel Production									
Open Hearth Furnace	99.2	99.2	0.0%						
Sinter Oven	94.0	90.0	4.3%						
Desulfurization				96.7	96.8	-0.1%			
Gray Iron Cupolas				93.9	93.4	0.5%			
Average			**1.0%**			**0.2%**			**3.3%**

[1] Control efficiency information obtained from U.S. EPA, Stationary Source Control Techniques Document for Fine Particulate Matter (EPA-452/R-97-001).

[2] Control efficiencies estimated for wet scrubbers to be installed on crushing/grinding sources at the Plant Site for the NorthMet project will have higher efficiencies (99%+) than those described here to achieve a particle loading rate of 0.005 grains per dry standard cubic foot (gr/dscf) as required for compliance with the Taconite MACT standard.

[3] This case, dry bottom (bituminous), is not representative of high efficiency wet scrubber performance; it was not included in calculating the Average difference between PM_{10} and $PM_{2.5}$ control efficiency.

In reviewing the information in Table 8, the reader should keep in mind that the control efficiency of any particulate control device is dependant upon the amount of particulates entering the control device and the nature of the physical properties of particulate matter being controlled. Table 8 contains information from several different source types; therefore, some of the variability in control efficiency is due to source type. Also note that the scrubber efficiencies in Table 8 are lower than the efficiency of the scrubbers PolyMet plans to install and operate on crushing/grinding sources at the Plant Site. Wet scrubbers can control particulate concentrations down to 0.006 gr/dscf versus a typical exhaust concentration of 0.005 gr/dscf for baghouses and dry ESP's. While some recent BACT determinations have resulted in emission limits of 0.0025 gr/dscf for baghouses, the control efficiency of wet scrubbers at NorthMet crushing sources will be essentially the same as the control efficiency for baghouses and ESP's.

4.1.3 Summary of Particulate Matter Emission Controls

The discussion on particulate matter emission controls for crushing/grinding operations at the Plant Site include the following:

- PolyMet will replace outdated particulate emission controls on existing equipment with new controls. Specifically, PolyMet proposes to upgrade outdated pollution control technology to wet scrubbers (except in the Coarse Crusher where existing baghouses will be upgraded) , resulting in an increased control efficiency to 99%+.

- For Prevention of Significant Deterioration (PSD) air permitting, wet scrubbing has typically been considered as BACT for particulate emissions (Table 4).

- The EPA report *"Stationary Source Control Techniques Document for Fine Particulate Matter"* contains information which shows particulate emission control equipment has nearly the same control efficiency for $PM_{2.5}$ as for PM_{10}.

- PolyMet's planned control technology upgrades to wet scrubbing result in emission reductions that are similar to the reductions expected to be achieved with dry scrubbing (Table 4, Table 6).

- Table 8 identifies that the control equipment is similarly efficient for PM_{10} and $PM_{2.5}$ (Table 8) and it is likely that the planned control technology upgrade reduces $PM_{2.5}$ emissions by almost the same amount as PM_{10} emissions.

Based on the Flotation Pilot Study data presented in Section 3.0, MN-fibers are expected to be associated with the PM_{10} emissions from the Plant Site crushing/grinding operations. Almost all of the MN-fibers are expected to be in PM10 size fraction, with a majority in the PM2.5 size fraction. Upgrading the pollution control technology on selected portions of the crushing/grinding operations is expected to result in lower MN-fiber air emissions than if no upgrade in pollution control equipment occurred. Unfortunately, data are not currently available to quantitatively estimate the potential decrease in MN-fibers associated with PolyMet's planned upgrades in pollution control equipment.

4.2 Controlling Releases from the Tailings Basin

4.2.1 Control of Wastewater Discharges

Wastewater discharges from the Plant Site processing operations could include amphibole MN-fibers in suspension. Pilot tests conducted on tailings slurries from the processing of Duluth Complex ore for the Regional Copper-Nickel Study showed that fragments longer than 2 um would settle-out of the water column within 48 hours (Stevenson 1978). Smaller mineral fibers remained in suspension, but with the aid of a chemical flocculant the concentration of the smaller mineral fibers could be reduced by 4 to 5 orders of magnitude (Stevenson 1978). Settling of fibers in the tailings basin prior to discharge, with a flocculant if necessary, was considered by Stevenson (1978) to be the most likely method to control the release of non-asbestiform fibers to waters of the State at that time.

The operating design for the facility includes a recycle/re-use management plan for the tailings basin water which is expected to eliminate a direct discharge from the tailings basin. Process water and storm water from the Plant Site will be routed to the tailings basin and Mine Site water is also planned to be pumped to the tailings basin. Tailings basin seepage water will be collected and routed back to the basin. The tailings basin will be the major source of the plant make-up water. The recycle/re-use management of the tailings basin water has been discussed with the MPCA and MDNR and will be an important part of the State Disposal System (SDS)) permitting that is required for the proposed facility.

4.2.2 Control of Tailings Basin Fugitive Dust Emissions

The fibers data presented in Section 3.0 indicates that a relatively small amount of amphibole MN-fibers are likely to be associated with tailings sent to the tailings basin. Exposed tailings in the basin, often referred to as beach areas, have the potential to contribute to fugitive dust emissions related to wind erosion acting on the beach areas and entraining particles up into the air.

The recycle/re-use management of the tailings basin is expected to result in higher water levels in the basin than had been occurring during the operations of LTVSMC. These higher water levels during active operations are expected to cover more of the tailings, with less beach area available for potential generation of fugitive dust emissions.

For the exposed beach areas that will occur in the tailings basin, PolyMet will be required to follow a Fugitive Dust Plan to minimize the generation of fugitive particle emissions. Minimizing fugitive particle emissions in the tailings basin will also minimize the potential for MN-fibers being emitted to air.

4.3 Air Dispersion Modeling Results for Plant Site PM_{10} Emissions

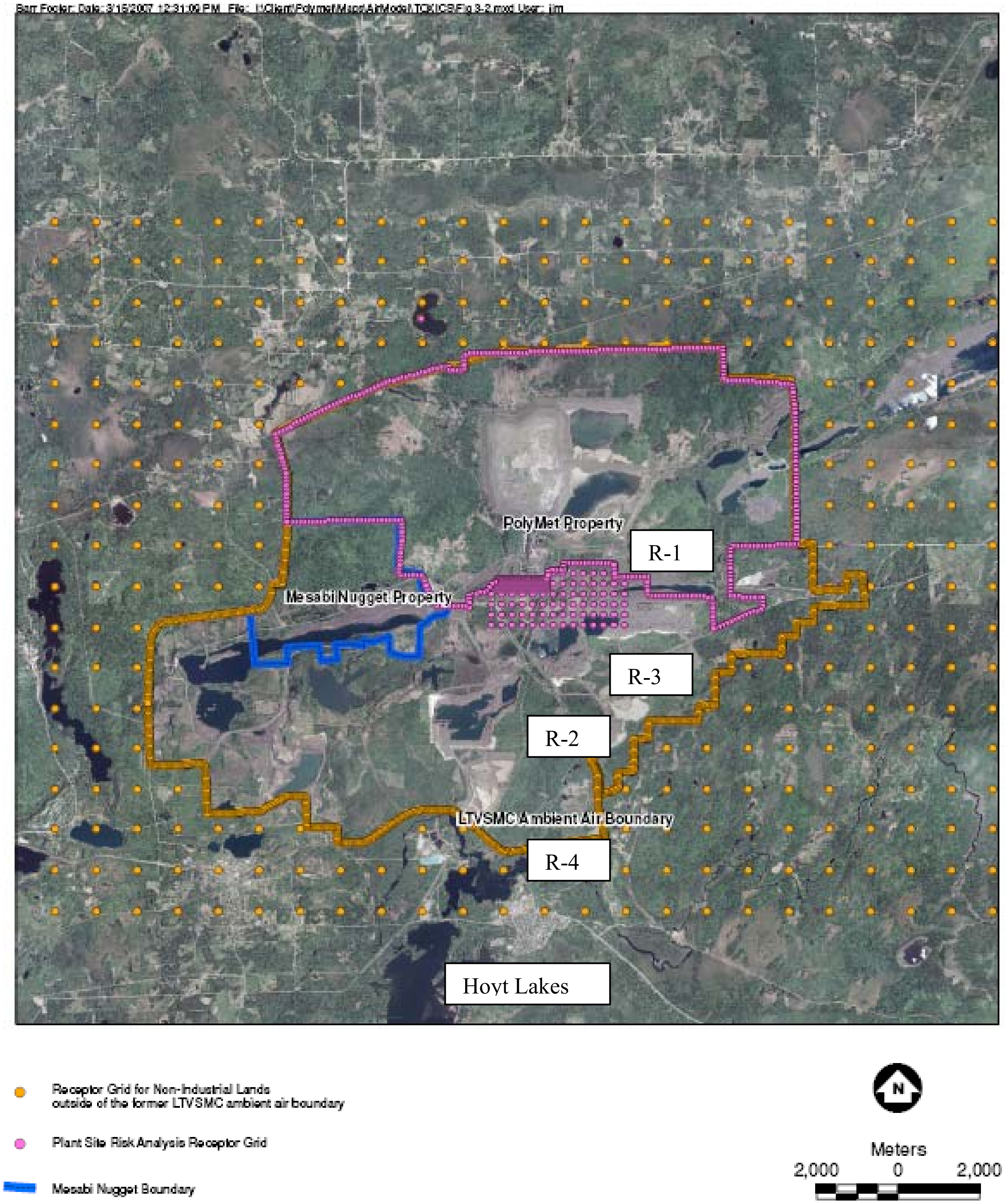
Air dispersion modeling was conducted to evaluate the potential change in air concentrations associated with different PM_{10} emission control strategies for the Crushing Plant sources. Three specific particle control scenarios were evaluated for the Crushing Plant and they are as follows:

1. PolyMet's proposed wet scrubbing upgrades on Crushing Plant sources to achieve a performance limit of 0.005 gr/dscf for filterable particulate.

2. PolyMet's proposed wet scrubbing upgrades on Crushing Plant sources to achieve a performance limit of 0.005 gr/dscf for filterable particulate <u>and</u> an upgrade to the existing baghouse on the primary crushing to meet a performance limit of 0.0025 gr/dscf.

3. Applying baghouse technology to all Crushing Plant sources to achieve a performance limit of 0.0025 gr/dscf.

The modeling included the tailings basin (fugitive dust) and Hydrometallurgical Plant, as well as the Crushing Plant. Control of fugitive dust emissions at the tailings basin includes limiting exposed beach areas (no control efficiency applied), while control on the Hydrometallurgical stacks was assumed to be 99% or higher. These other sources of particulate emissions were included in the analysis to provide information on their contribution to modeled air concentrations in relation to the Crushing Plant sources. The receptor grid and the areas of maximum modeled locations are presented in Figure 8.



R-1 = Plant Site operating boundary; R-2 = main gate guardhouse; R-3 = southeast portion of the LTVSMC ambient air boundary; R-4 = southern portion of the LTVSMC ambient air boundary just north of Hoyt Lakes.

Figure 8. Receptor grid and areas of maximum modeled PM10 air concentrations for Plant Site sources; NorthMet project.

Modeling results for the four receptor areas are presented in Table 9 and summarized as follows:

- “Total, all modeled sources” (tailings basin + Hydrometallurgical plant + Crushing plant),
    - Maximum modeled annual PM_{10} air concentrations potentially associated with Process Plant and Tailings basin (fugitive dust) emissions are low, ranging from approximately 6 $\mu g/m^3$ at the Plant Site operating boundary to less than one $\mu g/m^3$ at the former LTVSMC ambient air boundary.
    - There is only a slight change of one to 0.1 $\mu g/m^3$ in the maximum modeled air concentration at each receptor location associated with the change in emission control scenarios for the Crushing Plant sources.
- Crushing Plant Sources:
    - Table 9 identifies that the modeled air concentration at the Plant Site operating boundary potentially associated with only Crushing Plant sources is approximately one $\mu g/m^3$, but the modeled air concentration at the other locations is less than one $\mu g/m^3$. A one $\mu g/m^3$ contribution from a modeled source is typically considered significant for regulatory purposes. The overall conclusion is that the Crushing Plant is not expected to be a significant contributor to particles in ambient air.
    - The relative change in air concentrations due to the different emission control scenarios is small at each receptor, ranging from a 0.5 $\mu g/m^3$ difference at the Plant Site operating boundary to 0.04 $\mu g/m^3$ difference at the southern portion of the former LTVSMC ambient air boundary (i.e., that portion of the former LTVSMC ambient air boundary just north of Hoyt Lakes; Figure 8, Table 9). These potential changes in air concentrations are likely not measurable given the existing background annual concentration of particles (approximately 16 $\mu g/m^3$) and today’s monitoring capabilities.

Table 9. Air dispersion modeling results for estimated PM10 emissions from the proposed Plant Site; NorthMet project.

Modeled Receptor Location	Crushing Plant Emission Control Scenario	Maximum Modeled Annual Air Concentration [1] [2] ($\mu g/m^3$)			
		Total [3] (all modeled sources)	Tailings Basin Only	Hydromet Plant Only	Crushing Plant Only
Plant Site Operating Boundary (south/southeast)	1) Proposed Upgrade in Controls by PolyMet (wet scrubbing)	6	5	3	1
	2) Proposed Upgrade in Controls by PolyMet + Upgrade primary crushing control to baghouse @ 0.0025 gr/dscf	6	5	3	1
	3) Upgrade crushing sources to all baghouses @ 0.0025 gr/dscf	5	5	3	0.5
Main Guard Gate	1) Proposed Upgrade in Controls by PolyMet (wet scrubbing)	0.5	0.04	0.2	0.2
	2) Proposed Upgrade in Controls by PolyMet + Upgrade primary crushing control to baghouse @ 0.0025 gr/dscf	0.4	0.04	0.2	0.2
	3) Upgrade crushing sources to all baghouses @ 0.0025 gr/dscf	0.3	0.04	0.2	0.1
Former LTVSMC Air Boundary: southeast portion [4]	1) Proposed Upgrade in Controls by PolyMet (wet scrubbing)	1	0.8	0.1	0.1
	2) Proposed Upgrade in Controls by PolyMet + Upgrade primary crushing control to baghouse @ 0.0025 gr/dscf	1	0.8	0.1	0.1
	3) Upgrade crushing sources to all baghouses @ 0.0025 gr/dscf	1	0.8	0.1	0.05
Former LTVSMC Air Boundary: south portion [4]	1) Proposed Upgrade in Controls by PolyMet (wet scrubbing)	0.2	0.06	0.05	0.06
	2) Proposed Upgrade in Controls by PolyMet + Upgrade primary crushing control to baghouse @ 0.0025 gr/dscf	0.2	0.06	0.05	0.06
	3) Upgrade crushing sources to all baghouses @ 0.0025 gr/dscf	0.1	0.06	0.05	0.02

[1] Modeled air concentrations rounded to one significant figure.
[2] $PM_{2.5}$ annual standard = 15 $\mu g/m^3$. The Minnesota PM_{10} annual standard = 50 $\mu g/m^3$. Modeled air concentrations are well below both of these standards.
[3] Modeled sources = tailings basin, Hydrometallurgical plant, and Crushing plant. Modeling did not include fugitive emissions from road dust, process consumable material handling, etc.
[4] The general location of the maximum modeled air concentrations is identified in Figure 8.

Conclusions

Conclusions regarding the modeled PM_{10} air concentrations presented in Table 9 in regard to potential exposure to MN-fibers in ambient air include the following:

- Modeled air concentrations of particles potentially associated with the Plant Site operations, including fugitive dust from the tailings basin, are estimated to be low at the Plant Site operating boundary and one $\mu g/m^3$ or less at the locations where the general public could potentially be present (main gate guardhouse and the former LTVSMC ambient air boundary).

- The maximum modeled air concentrations potentially associated with only Crushing Plant sources is small, ranging from approximately one $\mu g/m^3$ at the Plant Site operating boundary for emission control scenarios 1 and 2, to less than 0.02 $\mu g/m^3$ at the former LTVSMC ambient air boundary for control scenario 3. Using a contribution of one $\mu g/m^3$ as a threshold for significance, the Crushing Plant sources are not expected to be significant contributors to modeled air concentrations at the locations where the general public could potentially be present (main gate guardhouse and the former LTVSMC ambient air boundary).

- The modeled PM_{10} air concentrations from the Plant Site operations are below the $PM_{2.5}$ ambient air standard of 15 $\mu g/m^3$ and the Minnesota PM_{10} annual standard of 50 $\mu g/m^3$ at all locations. Modeled air concentrations to the areas where the general public has access (main gate guardhouse, former LTVSMC ambient air boundary) are one $\mu g/m^3$ or less and modeled concentrations from only Crushing Plant sources are all less than one $\mu g/m^3$. The amphibole MN-fibers potentially associated with the Crushing Plant sources are a relatively small percent of the material to be processed and are primarily in the $PM_{2.5}$ size fraction (Figure 2). Based on the maximum modeled air concentrations presented in Table 9 for Crushing Plant sources and the relatively small amount of amphibole minerals in the ore from the NorthMet deposit, the potential exposure of the general public to amphibole MN-fibers is expected to be low.

- Upgrading control equipment on the Crushing Plant sources to baghouses to achieve a limit of 0.0025 gr/dscf does not result in a significant change in modeled air concentrations. When the current background air concentration of approximately 16 $\mu g/m^3$ is taken into account and today's monitoring capabilities, the potential change in air concentrations associated with this pollution control equipment upgrade on the Crushing Plant sources is likely not measurable. In addition, this upgrade in pollution control equipment likely does not result in any measurable change in the potential exposure to the general public because of the modeled low ambient air concentrations of particles associated with the overall Plant Site operations, the modeled low ambient air concentrations of particles potentially associated with only Crushing Plant sources, and the small amount of amphibole minerals in the ore from the NorthMet deposit.

In summary, the potential upgrade to baghouses on Crushing Plant sources to achieve a limit of 0.0025 gr/dscf for filterable particulate is not warranted at this time because the modeling results indicate there is likely no measurable change in particle air concentrations, and likely no measurable change in potential exposure to amphibole MN-fibers, associated with this change.

4.4 Air Monitoring Related to Plant Site Operations

PolyMet will initiate ambient air monitoring for fibers in 2007, prior to start-up of the facility. The proposed location for the fibers monitoring is the main gate guardhouse which is the nearest point to the Plant Site where the general public has access and where power for operating the monitor is available. Monitoring is also planned to be conducted for a period of time after the facility is in operation to provide data for pre- and post-construction comparisons. Final details of the fibers monitoring will be worked out with the Minnesota State Agencies in the summer of 2007.

4.5 Controlling Mine Site Particulate Air Emissions

Activities at the Mine Site are expected to generate fugitive particulate air emissions. The activities expected to generate fugitive dust emissions are overburden removal, blasting, truck hauling of waste rock, lean ore and ore, fugitive emissions from the stockpiles, and loading ore into railcars for transport to the Plant Site. The largest source of particulate emissions at the Mine Site is expected to be associated with the haul trucks (PolyMet Document RS57B).

Section 2.3 identified that serpentine minerals are likely to be associated with the waste rock and lean ore. Section 2.3 also identified that amphibole minerals are likely to be associated with the ore. MN-fibers may be associated with the breaking of the larger rock chunks during blasting and during loading onto trucks. However, the mining activities are not expected to generate much in the way of serpentine or amphibole MN-fibers because there are no plans to crush or grind ore at the Mine Site. Roads at the Mine Site are likely to be constructed of a mixture of materials such as overburden or waste rock, that are expected to have very little serpentine or amphibole MN-fibers associated with them.

When compared to other potential emission sources, the Mine Site is expected to be a minor source of particulate air emissions (RS57B). PolyMet will be required to prepare and implement a Fugitive Dust

Control Plan for the Mine site. The Control Plan is expected to focus on the fugitive dust emissions associated with the haul trucks.

The Mine Site is located approximately 6 miles to the east of the Plant Site. Fugitive emissions at the Mine Site are unlikely to have a significant impact at the Plant Site because these fugitive emissions tend to be made up of larger particles that deposit closer to the emission source. The distance separating the Plant Site and Mine Site makes it highly unlikely that there would be significant contributions from one site to the other site.

In summary, the relatively low concentrations of serpentine and amphibole minerals in the NorthMet deposit and the activities at the Mine Site indicates that it is unlikely for the Mine Site to be an important source of amphibole MN-fibers air emissions. Controlling fugitive dust emissions at the Mine Site will further reduce the potential for amphibole MN-fibers to become airborne.

5.0 HUMAN HEALTH EFFECTS

Since the 1960s, asbestos has been recognized as a potent carcinogen and serious health hazard. Inhalation of airborne asbestos fibers has been established as the cause of:

- Asbestosis (thickening and scarring of lung tissue).
- Mesothelioma (a highly lethal tumor of the pleura, which is a membranous lining of the upper body cavity and covering for the lungs. The pleura is a two-layered structure: the parietal pleura lines the walls of the chest cage and covers the upper surface of the diaphragm, and the pulmonary pleura, or visceral layer, tightly covers the surface of the lungs).
    - The mesothelium is a protective membrane made of mesothelial cells which forms a sac of lubricating fluid around most organs, allowing the organs to move and function properly. The mesothelium is given different names, depending on where it is, *e.g.,* the heart (*pericardium*), abdomen (*peritoneum*), lungs (*pleura*), or other organ.
    - Malignant mesothelioma is a rare tumor arising from the lining of the pleural or peritoneal cavity.
- Cancers of the lung, intestines, and liver.

In 1972, the Occupational Safety and Health Administration began regulating asbestos and strengthening work safety standards.

Some confusion has arisen over the definition of amphibole asbestos which has led to the impression that both forms of the amphiboles are the same and equally hazardous. It is now recognized that the prismatic mineral forms and the asbestos forms, even of the same amphibole, are mineralogically distinct, fracture in critically different ways, and the dusts formed by breakage have different effects on health (Langer et al., 1991; Ilgren et al., 1998; Davis et al., 1991; Beard, 1992; ATSDR, 2002; Berman, 2003; Duke, 2000; Mossman, 2003; Janssen et al., 1994, 1997; Zanella et al., 1996, 1999).

The available geology and mineralogy data for the Duluth Complex, and the NorthMet deposit in particular, indicates that the ore body does contain amphibole minerals. Based on data from Stevenson (1978) and PolyMet's Flotation Pilot Study, processing of the ore from the NorthMet deposit may create cleavage fragments that are by Minnesota State Agency definition a fiber (3:1 aspect ratio). These cleavage fragments are expected to be primarily non-amphibole cleavage fragments, but a small percent may be amphibole cleavage fragments. The discussions below highlight the difference between "fibrous" amphiboles and amphibole cleavage fragments in relation to the induction of mesothelioma since this disease is of great concern in the region and to Minnesota State Agencies.

For Minnesota State Agencies the differentiation between asbestiform fibers and cleavage fragments is not important on a regulatory basis because the definition of a fiber (i.e., 3:1 aspect ratio, no minimum length) encompasses both types. However, the available literature indicates that fiber characteristics (e.g., chemistry, length, width) can play an important role in the potential for health effects. Sections 5.1 and 5.2 provide health related information from peer-reviewed journals and available government report reports and summaries. The discussion on health effects is not limited to Minnesota State Agency fibers and therefore the terms "cleavage fragment" and "fiber" are used in this discussion as they were used in the referenced literature. The information presented in Sections 5.1 and 5.2 is then referenced in Section 5.3, along with the NorthMet project fibers data presented in Section 3.3, to provide additional perspective on the potential health effects from amphibole fibers that may be associated with the proposed project.

5.1 Inhalation Health Effects

The following discussion provides information on asbestos related health effects and the relationship of fiber chemistry and fiber dimensions (length, width, aspect ratio) that distinguish asbestos fibers from amphibole cleavage fragments in regard to potential asbestos-related health effects.

Fiber Chemistry and Reactivity

- Direct mechanisms of asbestos fiber carcinogenesis include genotoxic and nongenotoxic pathways. It has been hypothesized that long asbestos fibers that are partially phagocytized by macrophages trigger persistent production of reactive oxygen species (ROS). Reactive oxygen species have been linked to cell injury, inflammation, mutagenesis, and the development of many cancers, (Mossman, 2003; Shukla et al. 2003). Because of the high surface content of redox-reactive iron, asbestos fibers can generate additional radicals which could be generated in the vicinity of any target cells. The reactive radicals can damage DNA or form adducts. If the DNA is not repaired mutations or deletions could occur. Long asbestos fibers have also been shown to interfere with the mitotic spindle, chromosomal alteration (NAP, 2006).

- The mechanisms of particle-induced cytotoxicity are complex. A critical part of this process appears to be the ability of particles and fibers to bind to and damage cellular membranes. The disruption of the membranes can result in hemolysza, which is the leakage of hemoglobin from the red blood cells (RBCs). Hemolysis can be quantified spectrophotometrically and often is used to define mechanisms of membrane damage by particles. The hemolytic activity of fibers relates to physicochemical properties such as size, magnesium content, crystallinity, and surface charge (NAP, 1984).

- Surface charge of asbestiform and non-asbestiform amphiboles differ (Zoltai, 1979; Schott et al., 1981; Palekar et al., 1979). This difference is important since asbestos induced cell damage appears to be initiated by a reaction of the plasma membrane that results either in cell lysis or in phagocytosis of the material. The degree of cytotoxic reactivity, as measured by a variety of *in vitro* techniques, including hemolysis and decrease in cell viability, is apparently dependent initially on the surface charge of the fiber. The surface charge on fibers is directly related to the fibers hemolytic activity (NAP, 1984). Surface charge is also related to cationic exchange and particle absorption potential which affect their biological activity (NAP, 1984).

Fiber Physical Properties – Length, Width, Aspect Ratio

The physical properties of asbestiform fibers play an important role in the mechanism of the induction of health effects. Various factors influence the transport and deposition of inhaled particles in the respiratory tract. One clearly important factor is respirability, which is dependent upon the dimensional characteristics of fibers. Dimensional characteristics of fibers determine where they will be deposited in the respiratory tract and how a cell will respond to them.

The characteristics of asbestiform amphibole fibers (e.g., high fibrosity, fiber shape and size, and easy separability) appear to be biologically relevant in producing a rare tumor of the lining of the pleural or peritoneal cavity (mesothelioma). Some of the important characteristics related to fibers and asbestos-related health effects are as follows:.

- The flexibility of the asbestiform fibers that enables them to bend without breaking may facilitate their passage through the respiratory tract. For fibers less than 5 µm in length the information available on particle deposition and longer fibers suggests that fiber diameter likely has the greatest influence on deposition patterns (Lippmann 1990).
- The surface area of asbestiform fibers per unit volume is very large.
    - Asbestiform fibers may undergo alteration after inhalation due to their physicochemical properties. Asbestiform fibers tend to fragment longitudinally (along a horizontal plane) into thinner fibrils as opposed to cleavage fragments, which cannot do so (Wylie, 1999;

Paoletti, Schiller et al., 1981; NRC 1984). Coffin et al (1982) observed this same longitudinal splitting of long fibers (greater than 8 microns in length). Cook et al. (1982) provide alternative data that suggests short ferroactinolite fibers less than 8 microns in length fragment longitudinally to produce thinner and more numerous short fibers.

  - Fiber fragmentation and splitting results in an increase in the number of fibers and fiber surface area. Since direct cell contact appears to be essential to asbestiform fiber induced diseases, the greater the surface area, the greater the likely pathogenic potential of a fiber The decrease in fiber diameter through fiber splitting may also play a role in the pathogenicity of asbestiform fibers.

- The number of fibers inhaled and their durability rather than their mass appear to be significant factors in the pathogenicity of asbestiform fibers. Many asbestiform fibers survive in biological systems for long periods.

  - OSHA (1992) concluded that fiber dimension is certainly a significant determinant of biological function and that tumor probability increases with the number of long and thin durable particles.
  - Clearance of fibers deposited in the lung is an important physiological defense mechanism that influences the risk associated with fiber exposure. The role of fiber length in pathogenicity has been the subject of considerable study and has recently been reviewed (Middendorf et al. 2007). Evidence from *in vitro* and *in vivo* studies in rodents indicate that fibers with a length equal to or greater than the diameter of rodent lung macrophages (about 15 μm) are most closely linked to biological effects observed in the lung. Alveolar macrophages appear to be capable of phagocytizing and removing fibers shorter than approximately 15 μm in length, either by transport to the mucociliary system or to local lymph channels. Above this length, the alveolar macrophage appears to be ineffective at physical removal, although there is some evidence that longer fibers are partially engulfed by one or more macrophages, resulting in differential removal rates for fibers of different lengths. While fiber lengths greater than 15 μm appear to be associated with toxicity in experimental studies, a “critical” length for toxicity in humans has been shown to be probably greater than 15 μm (Middendorf et al., 2007).

- The cleavage fragments of the amphiboles are positioned radially rather than along a horizontal plane as found in asbestiform fibers. The critical length for fiber clearance approximates the diameter of an alveolar macrophage. The critical length cut-off has been measured to range from

10 to 24 μm (Ilgren, 2004). Fiber fragmentation of the amphibole mineral results in shorter fibers, typically less than 10 μm, which are more readily cleared from the airway and may therefore present a lower long-term toxicity.

    - Fibers with diameters greater than about 3 μm would be very unlikely to reach the alveoli.
    - An analysis conducted by Lippmann (1988, 1990) found that fiber retention drops rapidly as fiber diameter increases from 0.8 to 2.0 μm.

- Short fibers may be enclosed by scavenger cells (called macrophages in the immune system, which exist to absorb foreign particles or bacteria in the body) and thus be substantially prevented from interaction with other cell types. Longer, thinner fibers appear to be more pathogenic than shorter, thicker fibers, probably because such fibers cannot be engulfed or inactivated by cells such as macrophages (NAS 1984).
    - In a study with isolated alveolar macrophages (AMs) from rodents, release of ROS, superoxide, was measured after addition of crocidolite and riebeckite (non-asbestiform analog of crocidolite) to these cells, as well as non-asbestiform mordenite (all particle diameters and/or fiber lengths were measured by scanning electron microscopy), the non-asbestiform particles were taken up, i.e., phagocytized, by cells, but were much less bioreactive than crocidolite at comparable concentrations (Hill, 1995; Mossman, 2003).
    - Studies with non-asbestiform riebeckite and antigorite preparations in hamster tracheal epithelial cells (HTE) cells, rat lung epithelial cells (RLE) and isolates of normal rat pleural mesothelial cells (RPM) as non-asbestiform control have consistently revealed that these non-asbestiform minerals are inactive, regardless of endpoint. Moreover, they are incapable, in contrast to asbestos fibers, of causing alterations in cell proliferation or death in RPM cells (Mossman, 2003; Goldberg et *al.* 1997). Nonfibrous mineral analogs of riebeckite (similar in chemistry to crocidolite) and antigorite (similar in chemistry to chrysotile) failed to induce squamous metaplasia, and increased DNA synthesis at a range of concentrations and exposure times. Though a number of these riebeckite and antigorite particles were elongated, they were thick, short single crystal cleavage fragments. These studies highlight the importance of fibrous geometry, crystal growth and aspect ratio in bioreactivity (Mossman, 2003).

- OSHA further concluded that longer, thinner fibers are likely to be more pathogenic (OSHA, 1992).

- Asbestiform fibers are also known to induce inflammation with associated cell proliferation, which is potentially important for the clonal expansion of genetically altered initiated cells. Persistence of cell proliferation and inflammation appears to be the key to assessing the pathogenic potential of inhaled fibrous particulates.

- Nonfibrous particles generally do not induce mesotheliomas in animals (NAS, 1984).

It is also recognized that fiber size and cancer risk are related. An analysis conducted by Lippmann (1988, 1990) identified that no lung cancer was found to be associated with fiber length less than 5 µm. The lung cancers observed were associated with fibers having a diameter of 0.3 to 0.8 µm and a length of greater than 10 µm.

For mesothelioma risk, fibers with a dimension of <0.25 µm in diameter and >8 µm long (aspect ratios >30:1) appear to present the greatest risk (Stanton, et al., 1981) with almost no risk presented by short fibers (Brown et al. 1986). Similarly, lung cancer risk also depends on fiber dimensions. Based on asbestos inhalation studies, Berman et al (1995, 2003) found that potency for lung cancer rested with fibers that were longer than 10 µm and less than 0.3 µm in diameter (aspect ratios >30:1). Their model found that fibers that were <10 µm long and had widths from 0.3-5.0 µm (aspect ratios < 30:1 to 2:1) were not associated with a lung cancer risk.

The Berman and Crump index assigns zero risk to fibers less than 5 um in length. Fibers between 5 and 10 um are assigned a risk that is one three-hundredth of the risk assigned to fibers longer that 10 um (EPA 2003). In a 2006 review of the Berman and Crump index by an expert panel, panelists agreed that there is considerably greater risk for lung cancer for fibers longer than 10 um (ERG 2006).However, the panel was uncertain as to the exact cut size for length and the magnitude of the relative potency. The panelists agreed that the available data suggest that the risk for fibers less than 5 um in length is very low and could be zero (ERG, 2006) . The optimal exposure index that best reconciles the published literature assigns equal potency to fibers longer than 10 µm and thinner than 0.4 µm and assigns no potency to fibers of other dimensions (EPA, 2003).

In contrast to the above information, Dodson et al..(2003) conducted a review of experimental models that have been used to assess the response to various lengths of asbestos fibers in animal models in addition to data obtained from studies of human materials and stated that "… *the data presented argue that asbestos fibers of all lengths induce pathological responses and that caution should be exerted when attempting to* *exclude any population of inhaled fibers, based on their length, from being contributors to the potential for development of asbestos-related diseases ….*" Regulatory agencies such as U.S. EPA Region 9 and the MDH have expressed similar concerns regarding potential adverse impacts from short fibers. These concerns have focused on the inability of previous studies to specifically identify the fiber size range producing the specific effect. For protection of public health these government agencies rely on a conservative approach that there is the potential for short fibers to have health effects and they strive to reduce any potential exposure to particle emissions that may have short fibers associated with them.

Animal as well as *in-vitro* studies have demonstrated that cleavage fragments are not carcinogenic (Chisholm et al., 1995; Smith et al., 1979, 1981; Davis et al., 1985; 1991; Wagner et al., 1982; Pott et al., 1974, 1989; McConnell et al., 1983; Timbrell et al., 1971; Coffin et al., 1977; Hansen et al., 1987; Wylie et al., 1997; Marsh et al., 1988; Woodworth, et al., 1983; Palekar et al., 1979). The effects of asbestos fibers and non-asbestiform cleavage fragments on animals have been assessed in the same studies to compare their carcinogenic potential. Some of the "… most compelling evidence that their effects are very different comes from animal studies. …" (Ilgren, 2004). All such studies have used either intrapleural injection, intrapleural implantation, or intraperitoneal injection. Each delivers massive doses directly to the mesothelium. This can only be accomplished by artificial exposure methods that bypass host defense mechanisms that normally prevent all but a small fraction of fibers from reaching the mesothelium following inhalation. Despite the extreme sensitivity of these injection test methods and the massive doses employed, cleavage fragments still fail to produce any tumors or a tumor response exceeding background. By contrast, asbestos fibers in these injection studies produce high tumor rates not infrequently reaching 100%. The negative carcinogenic responses noted with cleavage fragments therefore provide very strong evidence that cleavage fragments are not likely carcinogenic to humans, particularly when the sensitivity of the assay and the large doses used are taken into consideration (Ilgren, 2004).

The work by Ilgren (2004) and others supports earlier conclusions by OSHA (1992) in that animal studies strongly suggest qualitative differences in the carcinogenic potential of asbestos and cleavage fragments. *In vitro* studies conducted with cell types of lung and pleural origin as well as non-respiratory cells have shown that non-asbestiform minerals are less potent than asbestos fibers (Marsh et al, 1988; Sesko et al, 1989; Mossman et al 1990; Hansen et al 1987). Recent *in vitro* studies as reported by Mossman (Mossman, 2003) with HTE (hamster tracheal epithelial cells), RLE (rat lung epithelial cells) and RPM cells (rat pleural mesothelial) showed that the non-asbestiform minerals tested were inactive, regardless of endpoint (Janssen et al. 1994, 1997; Zanella et al. 1996, 1999). In addition, non-asbestiform minerals were found to be incapable, in contrast to asbestos fibers, of causing alterations in cell proliferation or death in RPM cells (Goldberg et al. 1997 as quoted by Mossman et al. 2003). In summary, in most of these studies the cleavage fragments or non-fibrous minerals were shown to be virtually inactive (Mossman et al. 2003)

The cell culture studies of Donaldson et al. (1989, 1991, and 1992) Brown et al. (1986) and Hill et al. (1995) have generally confirmed the impression that fibers shorter than 5 µm, and indeed possibly less than 10 µm, have little pathologic effect other than what might be expected from a general respirable silicate mineral dust (Addison et al, 2003). Nonpathogenic fibers, such as cleavage fragments, do stimulate some pleural inflammation and cell proliferation when inhaled in very high concentrations, but the effects are transitory with cessation of exposure. Where the possible health effects from exposure to prismatic amphiboles (i.e., cleavage fragments) have been studied, results indicate that health effects have been slight (Ilgren, 2004). *In vitro* studies conducted with cell types of lung and pleural origin as well as non-respiratory cells have shown that cleavage fragments or non-fibrous minerals are virtually inactive regardless of endpoint and were incapable, in contrast to asbestos fibers, of causing alterations in cell proliferation or death in rat pleural mesothelial cells (Mossman et al. 2003).

Epidemiological studies in the mining and related industries indicate that exposure to short fibers (<5 microns in length) are unlikely to cause cancer in humans (Gamble et al., 2005; Steenland et al.,1995; McDonald et al., 1978; Gillam et al., 1976; Brown et al., 1986; Kusiak et al., 1991; Higgins et al., 1983; Cooper et al., 1992; Honda et al., 2002; Oestenstad et al., 2002; Morgan, 1981; Thomas et al., 1987; Wergeland et al., 1990; Rubino et al., 1976; Wegman et al., 1982; Selevan et al., 1979; Wik et al., 2001; McDonald et al., 1988). The Minnesota Department of Health in a presentation entitled "*Exposure to commercial Asbestos in Northeastern Minnesota Iron Miners who Developed Mesothelioma*" at an international conference on asbestos held in 2003, concluded that the most plausible explanation consistent with these findings is that commercial asbestos exposure, rather than taconite dust, is the most likely cause for the occurrence of mesothelioma in men employed in the mining industry in northern Minnesota. This MDH (2003) study used job histories of iron miners who developed mesothelioma to determine if their jobs, inside or outside of the mining industry, could have involved exposure to commercial asbestos. Seventeen individuals diagnosed with mesothelioma in Minnesota between 1988 and 1996 were found to have worked in the iron mining industry. For two of the 17 individuals who developed mesothelioma, a potential source of exposure could not be determined. Fourteen of the 15 had potential exposure to commercial asbestos; with 4 of the 14 employed in the mining industry only, 4 of the 14 having held non-mining jobs only, and 6 of the 14 were employed in both mining and non-mining industries. Recent findings of an additional 35 cases of mesothelioma in that group of mine workers has not changed the MDH findings from 2003 that exposure to commercial asbestos is the most likely cause of the disease, although further investigation of these additional cases are planned (MDH News Release, March 28, 2007).

The information presented in this section indicates that a relatively large body of research has been conducted on fibers and that the research findings have been interpreted to mean that exposure to long and thin fibers typically greater than 8 to 10 microns and aspect ratios greater than 20:1 are associated with health effects and that potential risks from short fibers are not expected to be as significant as from long fibers or that short fibers have minimal or no cancer risks associated with them. Two government review panels have reached similar conclusions (ATSDR 2003; EPA 2006). However, the interpretation of *in-vitro*, *in-vivo* and epidemiological studies remains controversial. It is true that many of these studies suffer from the various kinds of limitations that commonly plague similar studies typically associated with true asbestos, including primarily the inadequate manner in which the relevant exposures have been characterized in many studies. Some researchers believe that these types of limitations prevent any conclusions from being made regarding potential effects from short fibers (Dodson et al 2003). However the differences in the carcinogenicity of amphibole asbestos and non-amphibole asbestos are sufficiently large to be clearly discernable even with the study limitations. Together with later studies on these and related minerals, there is strong evidence of a much lower hazard associated with the shorter, thicker fibers of the non-asbestos amphiboles, than is found for the asbestos analogues of the same mineral (Mossman, 2003)

It is however recognized that protecting public health requires a conservative approach and that precautions need to be taken with regard to assessing potential impacts. In many cases a weight-of-evidence approach is used to assess the potential impacts. Taken as a whole, the evidence from the available literature is strongly suggestive either that cleavage fragments (structure for structure) are less potent than true asbestiform structures or that particle populations composed primarily of cleavage fragments contain fewer structures within the size range that induces biological activity than populations containing substantial fractions of asbestiform material (Mossman, 2003).

5.2 Ingestion Health Effects

There has been great public concern about the adverse health effects resulting from the presence of asbestos fibers in municipal drinking water supplies. In 1992, the U.S. EPA set a drinking water standard of 7,000,000 asbestos fibers per liter of water; fibers longer than 10 microns. There is no drinking water standard for amphibole MN-fibers.

Asbestos is not known to cause any health problems when people are exposed to it at levels above the drinking water standard for relatively short periods of time (USEPA 2006). Asbestos has the potential to cause lung disease and cancer from a lifetime exposure at levels above the drinking water standard (USEPA 2006). The following summarizes the current findings in the available literature:

- A review of 11 published papers that have evaluated the carcinogenic potential of asbestos following its ingestion failed to produce any definite, reproducible, organ specific carcinogenic effect after long-term, high-level ingestion of various types of asbestos fibers (Condie, 1983).

- Lange (Lange et al., 2004) concluded that asbestos in drinking water did not cause mesothelioma

- The National Toxicology Program (NTP) conducted lifetime carcinogenesis studies of amosite asbestos in laboratory animals (hamsters) administered in food. Under the conditions of these studies, the ingestion of amosite asbestos at a level of 1 percent in the diet for a lifetime was not toxic and did not cause a carcinogenic response. The NTP concluded that the level of evidence of carcinogenicity was negative (NTP, 1983).

- A lifetime (including exposure to the dams and gavage during the neonatal period) oral ingestion study (1% in the diet) in rats of 'blocky' tremolite did not to show evidence of carcinogenic activity (NTP 1990, McConnell et al. 1983).

- Other studies conducted with rats where chrysotile and a mixture of chrysotile and crocidolite was administered to rats in food showed that ingestion of high doses of asbestos fibers had no toxic effects and no carcinogenic effects were observed (McConnell, 2002; Truhaut et al., 1989). No consistent association between asbestos exposure and colon cancer was observed in population based case-control studies.

- Long-term ingestion studies show no evidence of an increased incidence of colon cancer in animals and do not provide biological plausibility for a causal association between asbestos exposure and colon cancer (Gamble, 1994).

- In a powerful case-control study conducted in the Puget Sound area, which included data on individual exposures based on length of residence and water source, there was no consistent evidence of a cancer risk due to the ingestion of asbestos in drinking-water. The World Health Organization (WHO) concluded that studies conducted to date provide little convincing evidence of an association between asbestos in public water supplies and cancer induction (WHO, 1986).

- The ATSDR (2001) concluded that inhalation is the principal route of exposure for a general population (ATSDR 2001).

In summary, the available body of research suggests that potential health effects related to the ingestion of asbestos fibers are not expected when asbestos fiber concentrations are at or below the EPA standard of 7,000,000 asbestos fibers/liter

For amphibole MN-fibers, the MDH has concluded that the available information indicates they have some carcinogenic potency (MDH 2005). The MDH further concludes that ingested amphibole MN-fibers are bioavailable and can exert a toxic effect if present in high enough numbers (MDH 2005). However, a threshold concentration for amphibole MN-fibers has not been identified.

5.3 Potential For Health Effects to be Associated with the Proposed Facility

Asbestiform Fibers

The TEM data from PolyMet's flotation pilot study identified the presence of amphibole MN-fibers, but amphibole asbestos was not identified. Chrysotile fibers were not identified in any of the samples.

As presented in Figure 3, the lengths of the amphibole fibers are predominately less than 10 µm; mean length is approximately 1.6 µm (Table 2). Only one of 50 amphibole fibers is greater than 10 µm long; length of 10.1 µm, width of approximately 2.0 µm, aspect ratio of 5:1 (Figure 3). Aspect ratios for the amphibole fibers range from less than 3 to 20.8, with a mean of 5.7. The fibrosity index for the amphibole fibers is 0.32 (Figure 4), as compared to 1.0 for asbestos fibers. The one amphibole fiber with an aspect ratio of greater than 20:1 is a short fiber; length of ~ 5 µm. Based on the data presented in Section 3.0 in Table 2, Figure 3 and Figure 4, the amphibole fibers identified by TEM analysis are most likely non-asbestiform. These findings are consistent with earlier findings from the Regional Copper-Nickel Study (MEQB 1979; Stevenson 1978) regarding the presence of non-asbestiform amphibole fibers associated with the processing of ore from the Duluth Complex.

Overall the presence of asbestiform fibers in the Duluth Complex is considered rare (MEQB 1979). The overall percentage of asbestiform material potentially in ore from the NorthMet deposit is expected to be very small based on the NorthMet data presented in Section 3.3 (Table 2; Figure 3) and the data from Stevenson (1978).

In summary, asbestiform fibers were not identified in the ore, tailings, or flotation process water samples from the NorthMet pilot studies (Figure 3, Figure 4). Based on the detailed TEM results, the probability of asbestiform fibers being associated with processing ore from the NorthMet deposit is low. Therefore, potential inhalation health effects from asbestiform fibers are not likely to be associated with the processing of ore from the NorthMet deposit.

Non-Asbestiform Amphibole Fibers

Inhalation

Consistent with the findings from Stevenson (1978) for samples associated with processing ore from the Duluth Complex, the available TEM data from the flotation pilot study indicates that the MN-fibers to be associated with the processing of ore from the NorthMet deposit are most likely non-asbestiform (Figure 3; Figure 4; Figure 5). These non-asbestiform fibers are predominantly non-amphibole (91% of fibers identified), with 9% of the identified fibers being amphibole (Table 2). MN-fibers are most likely to be associated with particulate emissions from the crushing/grinding operations. Particulate emissions will be controlled to meet ambient air quality standards and other regulatory requirements.

As discussed in Section 5.1, a considerable body of evidence, gathered over the last 30 years, suggests that amphibole cleavage fragments do not show the same toxicity as their asbestiform analogues (Mossman, 2003; ERG, 2006; ATSDR, 2003; Berman et al., 2003; Ilgren 2004; Donaldson et al,1989, 1991, and 1992; Brown et al.,1986; Hill et al. 1995). Researchers have identified that long and thin amphibole fibers are of most concern in relation to the induction of asbestos related diseases (Berman and Crump 2003), while fibers with lengths less than 5 microns, widths greater than 0.25 microns, and aspect ratios less than 30:1 are not likely to have any risk for mesothelioma or lung cancer (Brown et al. 1986; Lippmann 1988; Oehlert 1991; OSHA 1992; Berman et al. 1995, 2003; ATSDR, 2003). “The Berman and Crump index assigns zero risk to fibers less than 5 um in length. Fibers between 5 and 10 μm are assigned a risk that is one three-hundredth of the risk assigned to fibers longer that 10 μm. Panelists attending a Peer Consultation Workshop convened by EPA in 2006 (ERG, 2006) agreed that there is considerably greater risk for lung cancer for fibers longer than 10 μm. However, the panel was uncertain as to the exact cut size for length and the magnitude of the relative potency. The panelists also agreed that the available data suggest that the risk for fibers less than 5 μm in length is very low and could be zero (ERG 2006).

While the results of numerous epidemiologic, animal, and *in vitro* studies, have led scientists to conclude that short fibers (< 5 microns in length) are inactive or much less active biologically than long, thin asbestos fibers (ATSDR, 2003; Health Effects Institute-Asbestos Research, 1991; Mossman, 2003;

OSHA, 1992), the interpretation of the role of amphibole cleavage fragments with regard to potential health effects remains uncertain (Dodson et al. 2003). Due to this uncertainty the Minnesota State Agencies are treating amphibole cleavage fragments as though they have the potential for the toxicity and potency of amphibole asbestos. The role of amphibole cleavage fragments in the induction of asbestos-related health effects and chronic diseases is the subject of ongoing evaluation by Minnesota state agencies. However, in the absence of amphibole minerals, the Minnesota State Agencies have indicated that asbestos-related health effects are not expected.

The following information indicates that potential exposure to air-borne non-asbestiform amphibole fibers is expected to be low from the proposed facility:

- As estimated by Stevenson (1978), the Duluth Complex contains minor amounts of amphibole minerals and in general has approximately 66% less amphiboles than are present in the Biwabik Iron Formation.
- As presented in Table 2, more than 90% of the fibers identified in samples associated with processing ore from the NorthMet deposit are non-amphibole and only a relatively small percent were amphibole.
- Particulate air emissions will be controlled.
    - Crushing/grinding operations at the Plant Site may have non-asbestiform amphibole MN-fibers associated with them and these emissions will be controlled to meet specific air quality and control technology standards. PolyMet has proposed to upgrade the pollution control equipment on Crushing Plant sources to comply with a limit of 0.005 gr/dscf filterable particulate.
    - Potential fugitive dust emissions from the tailings basin beaches will be controlled as required by the Fugitive Dust Control Plan.
    - Mine Site activities are expected to generate fugitive dust emissions that are also to be controlled according to the Fugitive Dust Control Plan.
- Air dispersion modeling of particulate emissions indicates that maximum annual air concentrations at the Plant Site operating boundary are low (~ 6 µg/m^3) and are one µg/m^3 or less at the main gate guardhouse and the former LTVSMC ambient air boundary where the general public has access. These modeled air concentrations are below the Minnesota annual PM_{10} standard (50 µg/m^3) and the current annual $PM_{2.5}$ standard (15 µg/m^3). These modeling results

indicate that the already low potential air concentrations decrease markedly as one moves away from the Plant Site. These low modeled air concentrations indicate that potential exposure to Plant Site particle emissions is expected to be low.

- Further reducing potential exposure to air-borne amphibole MN-fiber is the relatively remote location of the Plant Site in relation to the residents of Aurora and Hoyt Lakes. The Plant Site is approximately 5 miles northeast of the City of Aurora and also 5 miles north of the City of Hoyt Lakes (the intersection of County Roads 666 and 110), approximately 4 miles from residences/cabins on the far eastern portion of Colby Lake that are located just to the north of Hoyt Lakes and just to the south of the former LTVSMC ambient air boundary, approximately 3.8 miles west of residents on the western operating boundary, and 3.5 miles southeast of residents on and near Heikkilla Lake. The Mine Site is more remote than the Plant Site, being located approximately 8 miles to the east of the Plant Site along the Dunka Road.

- The Air Emissions Risk Analysis (AERA) conducted for the proposed facility took into account non-asbestiform amphibole fiber chemistry in deriving particle-based emission estimates. Inhalation and multimedia risk results did not exceed the MDH thresholds of concern (May 2005 and March 2007 AERA submittals).

Ingestion (drinking water)

Asbestiform fibers (amphibole, chrysotile) were not identified in the ore, tailings, or process water samples from the Flotation Pilot Study. The TEM data from the flotation pilot study also indicate that MN-fibers associated with the flotation process (tailings, process water) will most likely be non-asbestiform fibers (i.e., cleavage fragments). The tailings and process water will be routed to the tailings basin.

The Minnesota State Agencies consider the potential human health effects related to ingestion of non-asbestiform amphibole MN-fibers to be uncertain. The potential exposure to water-borne non-asbestiform amphibole MN-fibers associated with the processing of ore from the NorthMet deposit is expected to be low given the low concentration of amphibole minerals in the ore, the potential settling of particles in the tailings basin, and the tailings basin being operated under a re-use/recycle management plan that is expected to eliminate a direct discharge from the basin.

Because contact water (water that has come into contact with ore, waste rock or the pit walls and floor) at the mine will be pumped to the tailings basin, the mine area is not expected to have a direct discharge.

In summary, due to the re-use/recycle management of the tailings basin the potential exposure to amphibole MN-fibers associated with tailings basin water through ingestion is very low, if not highly unlikely.

6.0 CONCLUSIONS

Main conclusions regarding the data obtained from the NorthMet Project Flotation Pilot Study are as follows:

- Section 2 – Mineralogy of the NorthMet Deposit
    - Amphibole and serpentine minerals are expected to be present in the Duluth Complex in small quantities(MEQB 1979).
    - Serpentine minerals are expected to be present at low concentrations in the NorthMet deposit and be primarily associated with waste rock and lean ore based on available data. To date, serpentine has been identified only at trace levels in the mineralized (sulfide-bearing rock) areas of the NorthMet deposit (PolyMet petrographic analysis).
    - Amphibole minerals are expected to be present in low concentrations in the ore from the NorthMet deposit. Stevenson (1978) estimated that the amphiboles in the Duluth Complex are present at one-third of the levels identified in the Biwabik Iron Formation.
- Section 3 – Flotation Pilot Study Results
    - Amphibole asbestos has not been identified by detailed microscopy (TEM) in samples associated with the processing of ore from the NorthMet deposit or from the Duluth Complex (Stevenson 1978).
    - Chrysotile fibers, the asbestos form of serpentine, were not identified by TEM analysis in samples associated with processing ore from the NorthMet deposit. Based on the available data it is unlikely that chrysotile fibers will be associated with processing ore from the NorthMet deposit.
    - A relatively small amount of amphibole MN-fibers are likely to be associated with the processing of ore from the NorthMet deposit (crushing/ grinding of ore, tailings, flotation process water). However, the majority of the MN-fibers are expected to be non-amphibole. Crushing/grinding operations at the Plant Site are expected to be the most likely source of amphibole MN-fiber emissions to air.

- Section 4 – Particle Emission Control and Modeling Results
    - PolyMet has proposed to upgrade the particle emission controls on Crushing Plant sources to meet a limit of 0.005 gr/dscf filterable particulate. The MPCA has indicated their preference for a limit of 0.0025 gr/dscf filterable particulate.
        - For a limit of 0.005 gr/dscf filterable particulate, modeled maximum annual air concentrations for at the Plant Site operating boundary are approximately 6 $\mu g/m^3$ and are one $\mu g/m^3$ or less at the former LTVSMC ambient air boundary. Maximum modeled annual air concentrations for only Crushing Plant sources are one $\mu g/m^3$ or less.
        - There is only a slight decrease in modeled air concentrations when a lower limit of 0.0025 gr/dscf filterable particulate is applied to Crushing Plant sources. This decrease is likely not measurable given the background annual PM10 air concentration of 16 $\mu g/m^3$ and currently available monitoring equipment. Therefore, it is unlikely that a lower limit of 0.0025 gr/dscf filterable particulate provides any real reduction in potential exposure to PM10 or PM2.5 emissions from the Crushing Plant sources.
    - The tailings basin will be operated according to a re-use/recycle management plan and this is expected to eliminate the direct discharge from the basin. Therefore, amphibole MN-fibers are not expected to be discharged from the basin.
- Section 5 – Potential for Human Health Effects
    - While the results of numerous epidemiologic, animal, and *in vitro* studies, have led scientists to conclude that short fibers (< 5 microns in length) are inactive or much less active biologically than long, thin asbestos fibers (ATSDR, 2003; Health Effects Institute-Asbestos Research, 1991; Mossman, 2003; OSHA, 1992), the interpretation of the role of amphibole cleavage fragments with regard to potential health effects remains uncertain. The Minnesota State Agencies consider the role of amphibole cleavage fragments (i.e., MN-fibers) in the induction of asbestos-related health effects to be uncertain at this time and they assume that amphibole MN-fibers have the potential for the toxicity and potency of amphibole asbestos. In addition, the Minnesota State Agencies consider the potential human health effects related to ingestion of amphibole MN-fibers to be uncertain.

- Based on the available data it is unlikely that amphibole asbestos will be associated with processing ore from the NorthMet deposit at levels of concern. Therefore, the potential risk for asbestos-related diseases such as asbestosis (a disease characterized by scarring of the air-exchange regions of the lungs), lung cancer, and malignant mesothelioma (cancer of the tissue lining the chest or abdomen) due to inhalation and ingestion of non-asbestiform amphibole MN-fibers potentially generated by the proposed facility is expected to be low, if any.

- Potential inhalation exposure to amphibole MN-fibers potentially associated with processing ore from the NorthMet deposit is expected to be low given the minor amounts of amphibole in the NorthMet deposit and the control of particulate air emissions. PolyMet has proposed to upgrade the control equipment on the Crushing Plant sources to meet an emission limit of 0.005 gr/dscf filterable particulate. Modeled maximum annual particulate air concentrations are low at all locations. The majority of the amphibole MN-fibers are in the fine fraction, 2.5 microns or smaller. Modeled maximum annual air concentrations the Plant Site operating boundary are approximately 6 $\mu g/m^3$ and are one $\mu g/m^3$ or less at the former LTVSMC ambient air boundary. In comparison, the Minnesota annual PM_{10} standard is 50 $\mu g/m^3$ and the current annual $PM_{2.5}$ standard is 15 $\mu g/m^3$. Therefore, potential exposure to amphibole MN-fibers is expected to be low.

- Potential ingestion of amphibole MN-fibers through drinking water is also expected to be low given the minor amounts of amphibole in the NorthMet deposit, pumping Mine Site water to the tailings basin, settling of particles in the tailings basin and operating the tailings basin under a re-use/recycle management plan that is expected to eliminate the need for a direct discharge from the basin.

In summary, while amphibole MN-fibers are expected to be associated with the NorthMet project, potential exposure to these MN-fibers is expected to be low due to the small amount of amphibole minerals present in the NorthMet deposit, PolyMet's proposed upgrade in air emission controls Crushing Plant sources, and the operation of the tailings basin under a re-use/recycle management plan.

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APPENDICES

A. **Addendum 1 to Section 3.2 of the Environmental Sampling and Analysis Plan (SAP) (for the NorthMet Project Flotation Pilot Studies)**

B. **Polarized Light Microscopy Results for NorthMet Project Ore (Head Feed) and Tailings Samples**

C. **Transmission Electron Microscopy Results for NorthMet Project Ore (Head Feed), Tailings, and Flotation Process Water Samples: Fiber Count and Speciation Reporting Table (per Table 2 in Addendum 1 to Section 3.2 of the SAP)**

Appendix A

Addendum 1 to Section 3.2 of the Environmental Sampling and Analysis Plan (NorthMet Project Flotation Pilot Studies)

(September 16, 2005)

NorthMet Project

Addendum 1 to Section 3.2

Appendix
Environmental Sampling and Analysis Plan
Pilot Test – NorthMet Deposit

Section 3.2

Previous analysis of representative ore samples from the NorthMet deposit show that the ore body is dominated by crystalline silicate minerals – calcic plagioclase feldspar, pyroxene, olivine, biotite, chlorite, serpentine, and amphibole. Plagioclase feldspar (the predominant mineral accounting for approximately 55 – 60 percent of the ore body) is <u>not</u> known to be carcinogenic.

The NorthMet deposit contains minor amounts of amphibole minerals, the minerals generally associated with asbestos. The analytical results that are currently available show that the amphibole minerals in the Duluth Complex in general (Stevenson, 1978; MEQB, 1979), and the NorthMet deposit in particular, are in the non-asbestiform habit. Stevenson (1978) identified that "…*The dominant … fiber found in the study is not truly asbestiform but rather an acicular crystal fragment or a cleavage fragment"*.

PolyMet's processing of these amphibole minerals that are part of the ore may release non-asbestiform amphiboles, commonly referred to as "cleavage fragments". As identified by the Mine Safety and Health Administration (MSHA), *"… Cleavage fragments may be formed when nonfibrous amphibole minerals are crushed, as may occur in mining or milling operations. Cleavage fragments are not asbestiform and do not fall within our definition of asbestos. …"* (MSHA, 2005).

The release of asbestiform fibers or "long fibers" (i.e., fibers greater than 5 micrometers in length with aspect ratios of 20:1 or greater, or 10 micrometers or greater in length in water per national water quality standard) is <u>not</u> expected to occur from the proposed facility based on the analytical and mineralogical data available for the Duluth Complex minerals (Stevenson, 1978; MEQB, 1979).

This addendum has been prepared to respond to state agency and public comments and questions regarding the project's potential formation of cleavage fragments and the potential to release long fibers to the environment, and to provide consistency with other available data for mining operations. The fiber sampling and analysis for the Pilot Testing will provide data for the different definitions of "fiber" that are currently used by state and federal agencies. Sampling focuses on the flotation process.

1) The head feed material is considered to be a surrogate for the crushing and grinding operations. The crushing/grinding of ore is expected to be the most significant source of potential cleavage fragment and/or fiber releases to air. For the Pilot Testing, air samples could not be collected from the crushing/grinding of the bulk sample. However, the head feed material should contain cleavage fragments and/or fibers if they are present. Therefore, the head feed material can be used as an indicator of potential cleavage fragment and/or fiber air emissions that could be associated with the proposed PolyMet facility.

2) Tailings and water produced from the flotation process provides information on the cleavage fragments and/or fibers potentially to be sent to the Tailings Basin.

The Sampling and Analysis Plan for the pilot testing initially submitted to the Minnesota state agencies in mid-June 2005 identified the collection of head feed and tailings samples for fibers analysis from the flotation process. Continued discussions with the state agencies regarding the fibers analysis identified the need to collect and archive head feed, tailings, and flotation process water for additional analysis per the direction from the state agencies. The discussion below reflects the initial sampling and analysis for fibers, as well as the additional analyses to be conducted on the archived samples.

1. Analysis of Head Feed and Tailings Samples

   Initial Samples

   Samples of the head feed are to be collected and composited from each ore parcel, with each ore parcel identified by the degree of copper mineralization. Nine (9) representative samples (3 from each ore parcel) will then be obtained from the composited material. Samples of the tailings material will be collected at periodic intervals during the flotation process. These materials are to be submitted to an accredited laboratory for fibers analysis according to EPA methods for bulk materials (EPA Method: EPA/600/R-93-116).

   Additional Samples

   As mentioned above, head feed and tailings are to be archived so that an additional 9 samples (3 from each ore parcel) from each material can be obtained. A total of 18 samples of the head feed, and 18 samples of the tailings, will be submitted to an accredited laboratory to conduct the additional fibers analyses.

   The Minnesota Pollution Control Agency (MPCA) and the Minnesota Department of Health (MDH) have stated that the samples must be analyzed by Transmission Electron Microscopy (TEM). Analysis by TEM requires that the additional head feed and tailings samples be ground in the laboratory to a finer consistency. The tailings material collected from the pilot study is already considered to be a finely ground material and passes 200 mesh sieve. It is PolyMet's preference that samples be analyzed "as submitted" and that no additional grinding of the collected samples be conducted because Stevenson (1978) identified that the degree of grinding has a significant influence on the number of fibers being found in samples (fibers as identified using the MDH identification and counting method). The more grinding that occurs, the finer the material, the more fibers identified in the sample (Stevenson, 1978). Additional grinding of the submitted samples makes the relationship between fiber counts for each sample and PolyMet's proposed process uncertain. This is particularly true for the fiber counting method used by the MDH (Method 851 and 852).

   Another complicating factor is that the samples to be submitted for fibers analysis are considered to be "bulk samples". The methodologies that have been recommended to be used for fibers analysis (MDH Method 852 and NIOSH 7400) are for air samples. These methods cannot be applied directly to the head feed and tailings samples that are to be submitted for analysis. However, the fiber counting, documentation, and information reporting specified in the respective air methods will be used in describing the results of the TEM analysis.

   The approach for the fibers analysis of the head feed and tailings samples is as follows:

   a. Initial Characterization:

      i. Qualitative description of samples as received by the laboratory with regard to particle size and other general characteristics of interest in regards to fibers analysis.

b. Fibers Identification (including Cleavage Fragment): Counts and Speciation

i. Initial Scan by polarized light microscopy (EPA/600/R-93-116):

Per this EPA method for bulk materials, an initial scan of the samples will be conducted with polarized light microscopy (PLM).

ii. Detailed Scan.

Fibers identification and mineralogical speciation will be conducted using Transmission Electron Microscopy (TEM). Analysis of the head feed and tailings samples by TEM requires that the samples be ground to a finer consistency at the laboratory. After grinding, a small amount of the ground sample will be transferred to an appropriate medium for TEM analysis (according to discussion in MDH Method 852).

"Fibers" associated with the head feed and tailings samples will be identified according to the following criteria and specifications:

- "MDH Fiber" (per fiber identification and counting described in MDH Method 852): A "fiber" is identified as those particles with length-to-width ratios (referred to as aspect ratio) of 3:1 or greater. No minimum length is used in fibers identification; cleavage fragments are identified as "fibers". In applying the MDH Method 852 fiber identification and counting criteria, this method is unable to distinguish, on a fiber by fiber basis, between asbestiform fibers and cleavage fragments of the same mineral (MDH, Method 852). Size distributions which are generated by the fiber count, if enough fibers can be counted, can help place the particular sample in the cleavage fragment to asbestiform fiber continuum (MDH, Method 852).

- "Occupational Fiber" (per fiber identification and counting described in NIOSH 7400 method): A "fiber" is identified as those particles that are 5 micrometers in length or longer, <u>and</u> have a length to diameter aspect ratio of at least 3:1.

- Asbestos Fiber (per fiber identification and counting described in EPA/600/R-93-116): Asbestos minerals, if present, will be identified. Fibers having a length of 5 micrometers or longer <u>and</u> with length to diameter aspect ratios of 20:1 or greater will be identified and reported.

iii. Fibers speciation will be also be conducted with TEM. Mineralogy information is to be provided for the following groups as described in MDH Method 852:

- Amphibole: these fibers give positive amphibole diffraction patterns. In most cases, parallel rows of spots that are perpendicular to the long axis of the fiber will be observed. MDH Method 852 specifies that the amphiboles be reported by mineral chemistry:

  - Cummingtonite-grunerite
  - Actinolite
  - Tremolite

- Hornblende
- Other
- Total Amphibole

- Chrysotile: this mineral has a pattern distinguished by a streaky set of spots at specific locations. Its scroll-like morphology causes the streaking of spots under high (90,000x) magnifications.

- Non-amphibole – Non-chrysotile: these are minerals whose diffraction pattern spacings are definitely not amphibole or chrysotile.

- Ambiguous: a category where fibers have a diffraction pattern that is not easily recognizable as amphibole, chrysotile, or non-amphibole.

2. Analysis of Water Samples from the Flotation Process

Samples of the flotation process water will be obtained from archived water that was collected during the flotation pilot study the week of August 12, 2005. Nine (9) samples (3 from each ore parcel) will be collected from this archived process water to be analyzed by the MDH method and the EPA method; total number of samples = 18.

Samples of the process water may require special preparation such as one or more filterings to produce an appropriate sample for analysis. The sample preparation is to follow the specific methodology identified below and is not discussed in detail here.

a. Minnesota Department of Health Method 851

Fiber count and mineralogy information is to be provided per Minnesota Department of Health's (MDH) Method 851. As specified by MDH Method 851, the samples are analyzed in a series of steps. First, a known volume of the sample is filtered onto a polycarbonate membrane filter. That filter is then processed to make it appropriate for fiber counting by TEM.

A "fiber" is identified as those particles with length-to-width ratios of 3:1 or greater. There is no minimum length applied to a fiber. The MDH methodology identifies cleavage fragments as "fibers". This method is unable to distinguish, on a fiber by fiber basis, between asbestiform fibers and cleavage fragments of the same mineral (MDH Method 851). Size distributions which are generated by the fiber count, if enough fibers are counted, may help place the particular sample in the cleavage fragment to asbestiform fiber continuum (MDH Method 851).

Once counted, fibers are characterized as:

- Amphibole: these fibers give positive amphibole diffraction patterns. In most cases, parallel rows of spots that are perpendicular to the long axis of the fiber will be observed. MDH Method 852 specifies that the amphiboles be reported by mineral chemistry:

  - Cummingtonite-grunerite

- Actinolite
- Tremolite
- Hornblende
- Other
- Total Amphibole

- Chrysotile: this mineral has a pattern distinguished by a streaky set of spots at specific locations. Its scroll-like morphology causes the streaking of spots under high (90,000x) magnifications.

- Non-amphibole – non-chrysotile: these are minerals whose diffraction pattern spacings are definitely not amphibole or chrysotile.

- Ambiguous: a category where fibers have a diffraction pattern that is not easily recognizable as amphibole chrysotile, or non-amphibole.

b. U.S. Environmental Protection Agency

Water samples will also be analyzed according to EPA Method 100.2 (Determination of asbestos structures over 10 µm in length in drinking water; asbestos in water by TEM) for asbestos fibers greater than 10 micrometers in length and reported as fibers per liter (f/L).

3. Summary Table of Fibers Analyses

Table 1 below summarizes the samples to be collected from the Pilot Testing for fibers analysis and the analytical methods to be used.

Table 1. Summary of proposed sampling for fibers analysis from PolyMet's Pilot Testing.

Type of Sample	# of Samples	Type of Analysis	Analytical Tool	Analytical Method	Reporting [1]
Head Feed	9	Mineralogy	TEM	follows MDH Method 852	Speciation by mineral groups as specified in MDH Method 852
		Fibers	PLM	EPA/600/R-93-116	Presence/absence of asbestos minerals; asbestos fibers count.
			TEM	Not applicable	Fiber counts by speciated mineral group according to the following definition of fibers: "MDH fiber" identified as particles with length to width ratios of 3:1 or greater "Occupational fiber" identified as particles that are longer than 5 micrometers with aspect ratios of 3:1 or greater. Asbestos fiber (per EPA/600/R-93-116) identified as particles that are longer than 5 micrometers with aspect ratios of 20:1 or greater.
Tailings	9	Mineralogy	TEM	MDH, 852	Speciation by mineral groups as specified in MDH Method 852
		Fibers	PLM	EPA/600/R-93-116	Presence/absence of asbestos minerals; asbestos fibers count.
			TEM	MDH, 852	Fiber counts by speciated mineral group according to the following definition of fibers: "MDH fiber" identified as particles with length to width ratios of 3:1 or greater "Occupational fiber" identified as particles that are longer than 5 micrometers with aspect ratios of 3:1 or greater. Asbestos fiber (per EPA/600/R-93-116) identified as particles that are longer than 5 micrometers with aspect ratios of 20:1 or greater.
Water from Flotation	9	Mineralogy	TEM	MDH, 851	
		Fibers	TEM	MDH, 851	
	9	Fibers	TEM	EPA Method 100.2 (EPA/600R-94/134)	

[1] MDH staff have stated that they would like to review the data generated from PolyMet's contract laboratory for consistency with MDH's fiber counting and speciation requirements as outlined in MDH Method 851 (water) and 852 (air). The level of effort by MDH staff in conducting this review, and the time frame for this review, is not yet known.

EPA = U.S. Environmental Protection Agency
MDH = Minnesota Dept. of Health
PLM = Polarized light microscopy
TEM = Transmission electron microscopy

Table 2. Summary of Fibers Data Reporting [1]

Sample Number:	
Lab ID Number	
Sampling (field) ID (location and/or Field No.):	
Date of Collection:	
Volume filtered:	

	MDH Fiber [2]			**Occupational Fiber [2]**			**Asbestos Fiber [2]**		
Mineral Type	**Fiber Count**	**Concen tration**	**Confidence Intervals**	**Fiber Count**	**Concen tration**	**Confidence Intervals**	**Fiber Count**	**Concen tration**	**Confidence Intervals**
Amphibole									
Chrysotile									
Non-Amphibole, non-chrysotile									
Ambiguous									
Total Concentration									

Amphibole Information

	MDH Fiber [2]		**Occupational Fiber [2]**		**Asbestos Fiber [2]**		
Amphibole Mineral Chemistry	**Fiber Count**	**% of Total Amphibole**	**Fiber Count**	**% of Total Amphibole**	**Fiber Count**	**% of Total Amphibole**	**Comments**
Cummingtonite-grunerite							
Actinolite							
Tremolite							
Hornblende							
Other							
Total Amphibole							

Fiber Information

	MDH Fiber [2]				**Occupational Fiber [2]**				**Asbestos Fiber [2]**			
Mineral Type / Chemistry	Fiber #	Length	Width	Aspect Ratio (L/W)	Fiber #	Length	Width	Aspect Ratio (L/W)	Fiber #	Length	Width	Aspect Ratio (L/W)
Grid Opening #												
Amphibole												
Chrysotile												
Non-Amphibole, non-chrysotile												
Ambiguous												
Amphiboles:												
Cummingtonite-grunerite												
Actinolite												
Tremolite												
Hornblende												
Other												

[1] MDH staff have stated that they would like to review the data generated from PolyMet's contract laboratory for consistency with MDH's fiber counting and speciation requirements as outlined in MDH Method 851 (water) and 852 (air). The level of effort by MDH staff in conducting this review, and the time frame for this review, is not yet known.

[2] MDH fiber: 3:1 aspect ratio or greater; no minimum length.
Occupational fiber: 3:1 aspect ratio or greater and longer than 5 micrometers.
Asbestos fiber: aspect ratio of 20:1 or greater and longer than 10 micrometers.

Definitions

Asbestiform: mineral crystals that form long, thread-like fibers. When pressure is applied to an asbestos fiber, it bends much like a wire, rather than breaks. Fibers can separate into "fibrils" of a smaller diameter (often less than 0.5 µm; referred to as "polyfilamentous") and is viewed as one of the most important characteristics of asbestos (MSHA, 2005). As described in Appendix A of the Environmental Protection Agency's "Method for the Determination of Asbestos in Bulk Building Materials", asbestiform is defined as:

> With the light microscope, the asbestiform habit is generally recognized by the following characteristics:
>
> - Mean aspect (length to width) ratios ranging from 20:1 to 100:1 or higher for fibers longer than 5 micrometers. Aspect ratios should be determined for fibers, not bundles.
> - Very thin fibrils, usually less than 0.5 micrometers in width, and two or more of the following:
>   - Parallel fibers occurring in bundles,
>   - Fiber bundles displaying splayed ends,
>   - Matted masses of individual fibers, and/or
>   - Fibers showing curvature.

Nonasbestiform / cleavage fragments: As identified by MSHA (2005): *"… In the nonasbestiform habit, mineral crystals do not grow in long thin fibers. They grow in a more massive habit. … When pressure is applied, the nonasbestiform crystals fracture easily into prismatic particles, which are called cleavage fragments because they result from the particle's breaking or cleavage, rather than the crystal's formation or growth. Some particles are acicular (needle shaped), and stair-step cleavage along the edges of some particles is common.*

Cleavage fragments may be formed when nonfibrous amphibole minerals are crushed, as may occur in mining and milling operations. Cleavage fragments are not asbestiform and do not fall within the regulatory definition of asbestos. …".

Micrometer: unit of measure denoted as "µm".

References

Minnesota Environmental Quality Board (MEQB), 1979. Regional Copper-Nickel Study, 1976 – 1979. Volume 3, Chapters, 1, 2, and 3.

Mine Safety and Health Administration (MSHA). 2005. Asbestos exposure limits; Proposed Rule. 30 CRF Parts 56, 57, and 71. Federal Register, Vol. 70, No. 145: 43950-43989. Friday, July 29, 2005.

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Appendix B

B-1. Polarized Light Microscopy Results for NorthMet Project Ore (Head Feed) Samples

B-2. Polarized Light Microscopy Results for NorthMet Project Tailings Samples

B-1. Polarized Light Microscopy Results for NorthMet Project Ore (Head Feed) Samples

Client:	**Barr Engineering Company**	Laboratory:	**Braun Intertec Corporation**	Date Reported:	10/5/2005
Log-In:	08/31/05	Lab Contact:	Kevin R. Osborn	**Page 3 of 6**	
Client Reference:	23/69-862002003	PO Number:			

Sample No: 0504262-01 Client ID: P20-C

Macroscopic Description	No. of Layers and Layer Designator	Percent of Total Sample	Non-Fibrous Components*	Other Fibrous Non-Asbestos Content Total or Layer %	Footnotes	Asbestos Content Total or Layer %	Footnotes	Analytical Date
Gray rock fragments	1	100	1,2,4	None Detected		None Detected		10/05/05

Sample No: 0504262-02 Client ID: P20-B

Macroscopic Description	No. of Layers and Layer Designator	Percent of Total Sample	Non-Fibrous Components*	Other Fibrous Non-Asbestos Content Total or Layer %	Footnotes	Asbestos Content Total or Layer %	Footnotes	Analytical Date
Gray rock fragments	1	100	1,2,4	None Detected		None Detected		10/05/05

Sample No: 0504262-03 Client ID: P10-B

Macroscopic Description	No. of Layers and Layer Designator	Percent of Total Sample	Non-Fibrous Components*	Other Fibrous Non-Asbestos Content Total or Layer %	Footnotes	Asbestos Content Total or Layer %	Footnotes	Analytical Date
Gray rock fragments	1	100	1,2,4	None Detected		None Detected		10/05/05

Sample No: 0504262-04 Client ID: P10-A

Macroscopic Description	No. of Layers and Layer Designator	Percent of Total Sample	Non-Fibrous Components*	Other Fibrous Non-Asbestos Content Total or Layer %	Footnotes	Asbestos Content Total or Layer %	Footnotes	Analytical Date
Gray rock fragments	1	100	1,2,4	None Detected		None Detected		10/05/05

Client: **Barr Engineering Company**
Log-In: 08/31/05
Client Reference: 23/69-862002003

Laboratory: **Braun Intertec Corporation**
Lab Contact: Kevin R. Osborn
PO Number:

Date Reported: 10/5/2005

Sample No: 0504262-05 Client ID: P10-C

Macroscopic Description	No. of Layers and Layer Designator	Percent of Total Sample	Non-Fibrous Components*	Other Fibrous Non-Asbestos Content Total or Layer %	Footnotes	Asbestos Content Total or Layer %	Footnotes	Analytical Date
Gray rock fragments	1	100	1,2,4	Cellulose <1		None Detected		10/05/05

Sample No: 0504262-06 Client ID: P20-A

Macroscopic Description	No. of Layers and Layer Designator	Percent of Total Sample	Non-Fibrous Components*	Other Fibrous Non-Asbestos Content Total or Layer %	Footnotes	Asbestos Content Total or Layer %	Footnotes	Analytical Date
Gray rock fragments	1	100	1,2,4	None Detected		None Detected		10/05/05

Sample No: 0504262-07 Client ID: P30-A

Macroscopic Description	No. of Layers and Layer Designator	Percent of Total Sample	Non-Fibrous Components*	Other Fibrous Non-Asbestos Content Total or Layer %	Footnotes	Asbestos Content Total or Layer %	Footnotes	Analytical Date
Gray rock fragments	1	100	1,2,4	Cellulose <1		None Detected		10/05/05

Sample No: 0504262-08 Client ID: P30-B

Macroscopic Description	No. of Layers and Layer Designator	Percent of Total Sample	Non-Fibrous Components*	Other Fibrous Non-Asbestos Content Total or Layer %	Footnotes	Asbestos Content Total or Layer %	Footnotes	Analytical Date
Gray rock fragments	1	100	1,2,4	None Detected		Actinolite <1		10/05/05

Sample No: 0504262-09 Client ID: P30-C

Macroscopic Description	No. of Layers and Layer Designator	Percent of Total Sample	Non-Fibrous Components*	Other Fibrous Non-Asbestos Content Total or Layer %	Footnotes	Asbestos Content Total or Layer %	Footnotes	Analytical Date
Gray rock fragments	1	100	1,2,4	None Detected		None Detected		10/05/05

Footnotes and Definitions

< Less Than

> Greater Than

*** Key to Non-Fibrous Components**

1 = Rock/Mineral fragments	5 = Diatoms	9 = Vinyl	13 = Spores/Pollen
2 = Mica/Vermiculite	6 = Perlite	10 = Foam/Rubber	14 = Foil
3 = Binders	7 = Adhesive/Mastic	11 = Paint	
4 = Opaques	8 = Tar	12 = Other	

B-2. Polarized Light Microscopy Results for NorthMet Project Tailings Samples

Client:	Barr Engineering Company	Laboratory:	Braun Intertec Corporation	Date Reported:	10/4/2005
Log-In:	08/31/05	Lab Contact:	Kevin R. Osborn	**Page 3 of 7**	
Client Reference:	23/69-862002003	PO Number:			

Sample No: 0504261-01 Client ID: P35-B

Macroscopic Description	No. of Layers and Layer Designator	Percent of Total Sample	Non-Fibrous Components*	Other Fibrous Non-Asbestos Content Total or Layer %	Footnotes	Asbestos Content Total or Layer %	Footnotes	Analytical Date
Gray sludge material	1	100	1,2,4	None Detected		None Detected		10/04/05

Sample No: 0504261-02 Client ID: P35-A

Macroscopic Description	No. of Layers and Layer Designator	Percent of Total Sample	Non-Fibrous Components*	Other Fibrous Non-Asbestos Content Total or Layer %	Footnotes	Asbestos Content Total or Layer %	Footnotes	Analytical Date
Gray sludge material	1	100	1,2,4	None Detected		None Detected		10/04/05

Sample No: 0504261-03 Client ID: P35-C

Macroscopic Description	No. of Layers and Layer Designator	Percent of Total Sample	Non-Fibrous Components*	Other Fibrous Non-Asbestos Content Total or Layer %	Footnotes	Asbestos Content Total or Layer %	Footnotes	Analytical Date
Gray sludge material	1	100	1,2,4	None Detected		None Detected		10/04/05

Sample No: 0504261-04 Client ID: P25-B

Macroscopic Description	No. of Layers and Layer Designator	Percent of Total Sample	Non-Fibrous Components*	Other Fibrous Non-Asbestos Content Total or Layer %	Footnotes	Asbestos Content Total or Layer %	Footnotes	Analytical Date
Gray sludge material	1	100	1,2,4	None Detected		None Detected		10/04/05

Client:	**Barr Engineering Company**	Laboratory:	**Braun Intertec Corporation**	Date Reported:	10/4/2005
Log-In:	08/31/05	Lab Contact:	Kevin R. Osborn	**Page 4 of 7**	
Client Reference: 23/69-862002003		PO Number:			

Sample No: 0504261-05 Client ID: P25-A

Macroscopic Description	No. of Layers and Layer Designator	Percent of Total Sample	Non-Fibrous Components*	Other Fibrous Non-Asbestos Content Total or Layer %	Footnotes	Asbestos Content Total or Layer %	Footnotes	Analytical Date
Gray sludge material	1	100	1,2,4	None Detected		None Detected		10/04/05

Sample No: 0504261-06 Client ID: P15-A

Macroscopic Description	No. of Layers and Layer Designator	Percent of Total Sample	Non-Fibrous Components*	Other Fibrous Non-Asbestos Content Total or Layer %	Footnotes	Asbestos Content Total or Layer %	Footnotes	Analytical Date
Gray sludge material	1	100	1,2,4	None Detected		None Detected		10/04/05

Sample No: 0504261-07 Client ID: P15-B

Macroscopic Description	No. of Layers and Layer Designator	Percent of Total Sample	Non-Fibrous Components*	Other Fibrous Non-Asbestos Content Total or Layer %	Footnotes	Asbestos Content Total or Layer %	Footnotes	Analytical Date
Gray sludge material	1	100	1,2,4	None Detected		None Detected		10/04/05

Sample No: 0504261-08 Client ID: P15-C

Macroscopic Description	No. of Layers and Layer Designator	Percent of Total Sample	Non-Fibrous Components*	Other Fibrous Non-Asbestos Content Total or Layer %	Footnotes	Asbestos Content Total or Layer %	Footnotes	Analytical Date
Gray sludge material	1	100	1,2,4	None Detected		None Detected		10/04/05

Sample No: 0504261-09 Client ID: P25-C

Macroscopic Description	No. of Layers and Layer Designator	Percent of Total Sample	Non-Fibrous Components*	Other Fibrous Non-Asbestos Content Total or Layer %	Footnotes	Asbestos Content Total or Layer %	Footnotes	Analytical Date
Gray sludge material	1	100	1,2,4	None Detected		None Detected		10/04/05

Footnotes and Definitions

<	Less Than
>	Greater Than

*** Key to Non-Fibrous Components**

1 = Rock/Mineral fragments	5 = Diatoms	9 = Vinyl	13 = Spores/Pollen
2 = Mica/Vermiculite	6 = Perlite	10 = Foam/Rubber	14 = Foil
3 = Binders	7 = Adhesive/Mastic	11 = Paint	
4 = Opaques	8 = Tar	12 = Other	

Case Narrative

The sludge material samples were dried under a heat lamp and reduced to a powder by mortar and pestle before analysis.

Appendix C

Transmission Electron Microscopy Results for NorthMet Project Ore (Head Feed), Tailings, and Flotation Process Water Samples: Fiber Count and Speciation Reporting Tables (per Table 2 in Addendum 1 to Section 3.2 of the SAP)

	Ore/Headfeed	Sludge/Tailings	Water/Floatation Process Water
Total number of samples analyzed:	9	9	9
Total number of samples with Amphiboles:	5	8	6
% of Samples with Amphiboles:	56%	89%	67%
Total number of fibers analyzed/assessed:	202	217	134
Total # of amphibole fibers identified:	11	20	19
% of Amphibole Fibers:	5%	9%	14%
% of Amphibole Fiber Types			
Cummingtonite-grunerite	73%	45%	63%
Actinolite	27%	50%	26%
Tremolite	0%	0%	0%
Hornblende	0%	0%	11%
Other Amphibole/Ambiguous	0%	5%	0%
Range of Fiber Lengths			
Maximum (um)	16.00	10.10	3.50
Minimum (um)	0.50	0.50	0.40
Average (um)	1.54	1.59	0.93
Aspect Ratio			

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Tailings Samples

Sample Information

Sample Number:	P3S-B
Lab ID Number:	05-01304-1
Sampling (field) ID (location and/or Field No.):	
Date of Collection:	8/30/2005
Media/Sample Type:	Sludge/Tailings
Volume Filtered [1]:	NA

Mineral Information

	Fiber Count	% of Total Amphibole	Conc. [1] MFL	95% Confidence Intervals [1]		Fiber Type			
				Lower Limit	Upper Limit	Other (AR<3:1)	MDH (AR >=3:1, no min. length)	OCC (AR >=3:1, length >5 um)	Asbestos (AR>=20:1, Length>10 um)
Amphibole	1	100					X		
Cummingtonite-grunerite	1	100					X		
Actinolite									
Tremolite									
Hornblende									
Other Amphibole/Ambiguous									
Chrysotile									
Non-Amphibole, non-chrysotile	24						X		
Ambiguous	1						X		
Totals	26	3.8							

[1] Water samples only

MFL Million Fibers per Liter

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Tailings Samples

Fiber Information

Grid Opening	Fiber Number	Length µm	Width µm	Aspect Ratio	Mineral Type				Amph Chem [1]	Fiber Type			
					Amphibole	Chrysotile	Non-Amphibole/Non-Chrysotile	Ambiguous		**Other** (AR<3:1)	**MDH** (AR >=3:1, no min. length)	**OCC** (AR >=3:1, length >5 um)	**Asbestos** (AR>=20:1, Length>5 um)
F7	1	1.00	0.25	4.00			X				X		
	2	0.80	0.20	4.00			X				X		
	3	1.70	0.50	3.40			X				X		
	4	1.00	0.25	4.00				X			X		
	5	0.80	0.15	5.33			X				X		
	6	0.90	0.25	3.60			X				X		
	7	4.70	1.15	4.09			X				X		
	8	1.70	0.30	5.67			X				X		
	9	0.80	0.25	3.20			X				X		
	10	1.30	0.40	3.25			X				X		
H4	11	1.00	0.22	4.55			X				X		
	12	1.60	0.30	5.33			X				X		
	13	3.50	0.70	5.00	X				G		X		
	14	1.50	0.25	6.00			X				X		
	15	0.70	0.20	3.50			X				X		
	16	3.00	0.90	3.33			X				X		
I3	17	0.70	0.10	7.00			X				X		
	18	1.50	0.15	10.00			X				X		
	19	2.50	0.65	3.85			X				X		
	20	1.50	0.30	5.00			X				X		
	21	4.30	1.00	4.30			X				X		
	22	0.90	0.30	3.00			X				X		
	23	0.70	0.15	4.67			X				X		
	24	1.20	0.25	4.80			X				X		
	25	0.80	0.23	3.48			X				X		
	26	1.70	0.40	4.25			X				X		

[1] *Amphibole Chemistry*

G Grunerite
A Actinolite
T Tremolite
H Hornblende
O Other

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Tailings Samples

Sample Information

Sample Number:	P3S-A
Lab ID Number:	05-01304-2
Sampling (field) ID (location and/or Field No.):	
Date of Collection:	8/30/2005
Media/Sample Type:	Sludge/Tailings
Volume Filtered [1]:	NA

Mineral Information

	Fiber Count	% of Total Amphibole	Conc. [1] MFL	95% Confidence Intervals [1]		Fiber Type			
				Lower Limit	Upper Limit	**Other** (AR<3:1)	**MDH** (AR >=3:1, no min. length)	**OCC** (AR >=3:1, length >5 um)	**Asbestos** (AR>=20:1, Length>10 um)
Amphibole	3	100					X	X	
Cummingtonite-grunerite	2	66.7						X	
Actinolite									
Tremolite									
Hornblende									
Other Amphibole/Ambiguous	1	33.3					X		
Chrysotile									
Non-Amphibole, non-chrysotile	18						X		
Ambiguous	2						X		
Totals	23	13.0							

[1] Water samples only

MFL Million Fibers per Liter

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Tailings Samples

Fiber Information

Grid Opening	Fiber Number	Length	Width	Aspect Ratio	Mineral Type				Amph Chem [1]	Fiber Type			
					Amphibole	Chrysotile	Non-Amphibole/Non-Chrysotile	Ambiguous		**Other** (AR<3:1)	**MDH** (AR >=3:1, no min. length)	**OCC** (AR >=3:1, length >5 um)	**Asbestos** (AR>=20:1, Length>5 um)
D8	1	1.10	0.25	4.40			X				X		
	2	0.90	0.30	3.00			X				X		
	3	1.20	0.30	4.00			X				X		
	4	2.50	0.60	4.17			X				X		
	5	3.50	1.00	3.50			X				X		
	6	10.10	1.90	5.32	X				G			X	
	7	1.25	0.22	5.68			X				X		
	8	1.50	0.50	3.00				X			X		
B8	9	1.60	0.30	5.33			X				X		
	10	1.30	0.40	3.25			X				X		
	11	0.50	0.10	5.00			X				X		
	12	0.66	0.22	3.00			X				X		
	13	1.25	0.30	4.17	X				O		X		
	14	1.20	0.10	12.00			X				X		
	15	0.80	0.23	3.48			X				X		
B3	16	0.75	0.25	3.00			X				X		
	17	5.50	1.50	3.67	X				G			X	
	18	0.75	0.24	3.13			X				X		
	19	0.60	0.12	5.00			X				X		
	20	1.40	0.25	5.60			X				X		
	21	1.25	0.12	10.42				X			X		
	22	3.00	0.25	12.00			X				X		
	23	2.50	0.70	3.57			X				X		

[1] *Amphibole Chemistry*
- G Grunerite
- A Actinolite
- T Tremolite
- H Hornblende
- O Other

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Tailings Samples

Sample Information

Sample Number:	P3S-C
Lab ID Number:	05-01304-3
Sampling (field) ID (location and/or Field No.):	
Date of Collection:	8/30/2005
Media/Sample Type:	Sludge/Tailings
Volume Filtered [1]:	NA

Mineral Information

	Fiber Count	**% of Total Amphibole**	**Conc. [1]** MFL	**95% Confidence Intervals [1]**		**Fiber Type**			
				Lower Limit	Upper Limit	**Other** (AR<3:1)	**MDH** (AR >=3:1, no min. length)	**OCC** (AR >=3:1, length >5 um)	**Asbestos** (AR>=20:1, Length>10 um)
Amphibole	4	100					X		
Cummingtonite-grunerite									
Actinolite	4	100					X		
Tremolite									
Hornblende									
Other Amphibole/Ambiguous									
Chrysotile									
Non-Amphibole, non-chrysotile	17						X		
Ambiguous	2						X		
Totals	23	17.4							

[1] Water samples only

MFL Million Fibers per Liter

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Tailings Samples

Fiber Information

Grid Opening	Fiber Number	Length	Width	Aspect Ratio	Mineral Type				Amph Chem [1]	Fiber Type			
					Amphibole	Chrysotile	Non-Amphibole/Non-Chrysotile	Ambiguous		**Other** (AR<3:1)	**MDH** (AR >=3:1, no min. length)	**OCC** (AR >=3:1, length >5 um)	**Asbestos** (AR>=20:1, Length>5 um)
D6	1	4.70	1.00	4.70			X				X		
	2	0.65	0.18	3.61			X				X		
	3	2.50	0.12	20.83	X				A		X		
	4	0.80	0.18	4.44			X				X		
	5	1.00	0.24	4.17			X				X		
	6	1.70	0.35	4.86			X				X		
	7	1.30	0.25	5.20	X				A		X		
	8	4.50	1.50	3.00			X				X		
	9	0.70	0.20	3.50			X				X		
	10	1.60	0.50	3.20			X				X		
	11	1.50	0.30	5.00			X				X		
	12	1.90	0.25	7.60	X				A		X		
	13	1.80	0.23	7.83			X				X		
F7	14	0.65	0.20	3.25			X				X		
	15	0.90	0.30	3.00			X				X		
	16	1.20	0.20	6.00			X				X		
	17	1.10	0.30	3.67			X				X		
	18	3.00	0.23	13.04				X			X		
	19	3.80	0.80	4.75	X				A		X		
	20	3.80	1.25	3.04			X				X		
	21	1.10	0.25	4.40				X			X		
	22	1.25	0.30	4.17			X				X		
	23	1.70	0.25	6.80			X				X		

[1] *Amphibole Chemistry*

G Grunerite
A Actinolite
T Tremolite
H Hornblende
O Other

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Tailings Samples

Sample Information

Sample Number:	P2S-B
Lab ID Number:	05-01304-4
Sampling (field) ID (location and/or Field No.):	
Date of Collection:	8/30/2005
Media/Sample Type:	Sludge/Tailings
Volume Filtered [1]:	NA

Mineral Information

	Fiber Count	% of Total Amphibole	Conc. [1] MFL	95% Confidence Intervals [1] Lower Limit	Upper Limit	Fiber Type: Other (AR<3:1)	MDH (AR >=3:1, no min. length)	OCC (AR >=3:1, length >5 um)	Asbestos (AR>=20:1, Length>10 um)
Amphibole									
Cummingtonite-grunerite									
Actinolite									
Tremolite									
Hornblende									
Other Amphibole/Ambiguous									
Chrysotile									
Non-Amphibole, non-chrysotile	19						X	X	
Ambiguous	2						X		
Totals	21	0.0							

[1] Water samples only

MFL Million Fibers per Liter

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Tailings Samples

Fiber Information

Grid Opening	Fiber Number	Length	Width	Aspect Ratio	Mineral Type				Amph Chem [1]	Fiber Type			
					Amphibole	Chrysotile	Non-Amphibole/Non-Chrysotile	Ambiguous		**Other** (AR<3:1)	**MDH** (AR >=3:1, no min. length)	**OCC** (AR >=3:1, length >5 um)	**Asbestos** (AR>=20:1, Length>5 um)
H4	1	2.00	0.30	6.67			X				X		
	2	3.20	0.30	10.67			X				X		
	3	1.20	0.31	3.87			X				X		
	4	0.51	0.12	4.25			X				X		
	5	1.60	0.30	5.33			X				X		
	6	1.10	0.30	3.67			X				X		
	7	1.80	0.25	7.20			X				X		
	8	0.75	0.25	3.00			X				X		
	9	1.10	0.35	3.14			X				X		
	10	0.75	0.25	3.00				X			X		
I6	11	1.25	0.30	4.17			X				X		
	12	1.50	0.15	10.00				X			X		
	13	1.00	0.23	4.35			X				X		
	14	0.70	0.23	3.04			X				X		
	15	10.10	2.00	5.05			X					X	
	16	1.40	0.25	5.60			X				X		
	17	1.50	0.50	3.00			X				X		
	18	0.90	0.30	3.00			X				X		
	19	3.00	0.12	25.00			X				X		
	20	0.90	0.25	3.60			X				X		
	21	2.00	0.23	8.70			X				X		

[1] *Amphibole Chemistry*

G Grunerite
A Actinolite
T Tremolite
H Hornblende
O Other

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Tailings Samples

Sample Information

Sample Number:	P2S-A
Lab ID Number:	05-01304-5
Sampling (field) ID (location and/or Field No.):	
Date of Collection:	8/30/2005
Media/Sample Type:	Sludge/Tailings
Volume Filtered [1]:	NA

Mineral Information

	Fiber Count	% of Total Amphibole	Conc. [1] MFL	95% Confidence Intervals [1] Lower Limit	Upper Limit	Fiber Type: Other (AR<3:1)	MDH (AR >=3:1, no min. length)	OCC (AR >=3:1, length >5 um)	Asbestos (AR>=20:1, Length>10 um)
Amphibole	2	100					X		
Cummingtonite-grunerite	1	50					X		
Actinolite	1	50					X		
Tremolite									
Hornblende									
Other Amphibole/Ambiguous									
Chrysotile									
Non-Amphibole, non-chrysotile	22						X	X	
Ambiguous									
Totals	24	8.3							

[1] Water samples only

MFL Million Fibers per Liter

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Tailings Samples

Fiber Information

Grid Opening	Fiber Number	Length	Width	Aspect Ratio	Mineral Type				Amph Chem [1]	Fiber Type			
					Amphibole	Chrysotile	Non-Amphibole/Non-Chrysotile	Ambiguous		**Other** (AR<3:1)	**MDH** (AR >=3:1, no min. length)	**OCC** (AR >=3:1, length >5 um)	**Asbestos** (AR>=20:1, Length>5 um)
F3	1	0.80	0.23	3.48			X				X		
	2	2.80	0.75	3.73			X				X		
	3	0.70	0.22	3.18			X				X		
	4	3.00	0.80	3.75			X				X		
	5	2.00	0.60	3.33			X				X		
	6	1.60	0.50	3.20			X				X		
	7	1.80	0.50	3.60			X				X		
	8	1.00	0.25	4.00	X				G		X		
H5	9	5.50	1.70	3.24			X					X	
	10	1.25	0.40	3.13			X				X		
	11	1.00	0.25	4.00			X				X		
	12	0.90	0.21	4.29			X				X		
	13	2.50	0.23	10.87			X				X		
	14	1.00	0.22	4.55			X				X		
	15	1.20	0.25	4.80			X				X		
	16	1.00	0.30	3.33			X				X		
	17	1.50	0.30	5.00			X				X		
	18	1.15	0.30	3.83			X				X		
	19	1.00	0.30	3.33			X				X		
	20	1.00	0.25	4.00			X				X		
	21	1.00	0.25	4.00			X				X		
	22	4.00	1.00	4.00			X				X		
	23	1.30	0.30	4.33	X				A		X		
	24	1.25	0.30	4.17			X				X		

[1] *Amphibole Chemistry*

- G Grunerite
- A Actinolite
- T Tremolite
- H Hornblende
- O Other

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Tailings Samples

Sample Information

Sample Number:	P1S-A
Lab ID Number:	05-01304-6
Sampling (field) ID (location and/or Field No.):	
Date of Collection:	8/30/2005
Media/Sample Type:	Sludge/Tailings
Volume Filtered [1]:	NA

Mineral Information

	Fiber Count	**% of Total Amphibole**	**Conc. [1]** MFL	**95% Confidence Intervals [1]**		**Fiber Type**			
				Lower Limit	Upper Limit	**Other** (AR<3:1)	**MDH** (AR >=3:1, no min. length)	**OCC** (AR >=3:1, length >5 um)	**Asbestos** (AR>=20:1, Length>10 um)
Amphibole	3	100					X		
Cummingtonite-grunerite	1	33.3					X		
Actinolite	2	66.7					X		
Tremolite									
Hornblende									
Other Amphibole/Ambiguous									
Chrysotile									
Non-Amphibole, non-chrysotile	17						X		
Ambiguous	5						X		
Totals	25	12.0							

[1] Water samples only

MFL Million Fibers per Liter

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Tailings Samples

Fiber Information

Grid Opening	Fiber Number	Length	Width	Aspect Ratio	Mineral Type				Amph Chem [1]	Fiber Type			
					Amphibole	Chrysotile	Non-Amphibole/Non-Chrysotile	Ambiguous		**Other** (AR<3:1)	**MDH** (AR >=3:1, no min. length)	**OCC** (AR >=3:1, length >5 um)	**Asbestos** (AR>=20:1, Length>5 um)
D7	1	1.10	0.16	6.88				X			X		
	2	1.25	0.25	5.00			X				X		
	3	0.80	0.15	5.33				X			X		
	4	1.60	0.20	8.00			X				X		
	5	0.75	0.22	3.41			X				X		
	6	0.80	0.12	6.67			X				X		
	7	0.50	0.10	5.00			X				X		
	8	1.20	0.30	4.00			X				X		
E4	9	1.20	0.35	3.43			X				X		
	10	1.10	0.17	6.47				X			X		
	11	1.60	0.50	3.20			X				X		
	12	1.60	0.50	3.20	X				G		X		
	13	1.20	0.36	3.33			X				X		
	14	1.10	0.25	4.40			X				X		
	15	1.70	0.40	4.25	X				A		X		
	16	1.20	0.12	10.00			X				X		
	17	0.75	0.25	3.00			X				X		
F7	18	1.00	0.20	5.00			X				X		
	19	1.60	0.50	3.20			X				X		
	20	1.20	0.10	12.00			X				X		
	21	1.20	0.25	4.80			X				X		
	22	0.75	0.25	3.00				X			X		
	23	1.50	0.50	3.00			X				X		
	24	1.80	0.50	3.60	X				A		X		
	25	1.20	0.13	9.23				X			X		

[1] *Amphibole Chemistry*

G Grunerite
A Actinolite
T Tremolite
H Hornblende
O Other

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Tailings Samples

Sample Information

Sample Number:	P1S-B
Lab ID Number:	05-01304-7
Sampling (field) ID (location and/or Field No.):	
Date of Collection:	8/30/2005
Media/Sample Type:	Sludge/Tailings
Volume Filtered [1]:	NA

Mineral Information

	Fiber Count	% of Total Amphibole	Conc. [1] MFL	95% Confidence Intervals [1] Lower Limit	95% Confidence Intervals [1] Upper Limit	Fiber Type: Other (AR<3:1)	Fiber Type: MDH (AR >=3:1, no min. length)	Fiber Type: OCC (AR >=3:1, length >5 um)	Fiber Type: Asbestos (AR>=20:1, Length>10 um)
Amphibole	3	100					X		
Cummingtonite-grunerite	2	66.7					X		
Actinolite	1	33.3					X		
Tremolite									
Hornblende									
Other Amphibole/Ambiguous									
Chrysotile									
Non-Amphibole, non-chrysotile	26						X		
Ambiguous									
Totals	29	10.3							

[1] Water samples only

MFL Million Fibers per Liter

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Tailings Samples

Fiber Information

Grid Opening	Fiber Number	Length	Width	Aspect Ratio	Mineral Type				Amph Chem [1]	Fiber Type			
					Amphibole	Chrysotile	Non-Amphibole/Non-Chrysotile	Ambiguous		**Other** (AR<3:1)	**MDH** (AR >=3:1, no min. length)	**OCC** (AR >=3:1, length >5 um)	**Asbestos** (AR>=20:1, Length>5 um)
D6	1	1.60	0.30	5.33			X				X		
	2	1.50	0.35	4.29			X				X		
	3	1.10	0.10	11.00			X				X		
	4	1.10	0.15	7.33			X				X		
	5	1.60	0.30	5.33	X				G		X		
	6	1.70	0.25	6.80			X				X		
	7	1.10	0.13	8.46			X				X		
	8	1.50	0.18	8.33			X				X		
	9	1.20	0.20	6.00			X				X		
	10	1.70	0.30	5.67			X				X		
	11	2.50	0.50	5.00			X				X		
	12	0.60	0.10	6.00			X				X		
	13	1.50	0.50	3.00			X				X		
	14	1.10	0.25	4.40			X				X		
	15	2.50	0.60	4.17	X				A		X		
	16	4.00	1.10	3.64			X				X		
	17	0.50	0.15	3.33			X				X		
	18	1.20	0.25	4.80			X				X		
F3	19	1.10	0.11	10.00			X				X		
	20	1.60	0.22	7.27			X				X		
	21	4.00	1.25	3.20			X				X		
	22	1.50	0.24	6.25			X				X		
	23	1.50	0.50	3.00			X				X		
	24	1.60	0.50	3.20			X				X		
	25	1.40	0.40	3.50	X				G		X		
	26	1.00	0.22	4.55			X				X		
	27	1.5	0.5	3.00			X				X		
	28	1.3	0.25	5.20			X				X		
	29	1.6	0.17	9.41			X				X		

[1] *Amphibole Chemistry*

G Grunerite
A Actinolite
T Tremolite
H Hornblende
O Other

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Tailings Samples

Sample Information

Sample Number:	P1S-C
Lab ID Number:	05-01304-8
Sampling (field) ID (location and/or Field No.):	
Date of Collection:	8/30/2005
Media/Sample Type:	Sludge/Tailings
Volume Filtered [1]:	NA

Mineral Information

	Fiber Count	% of Total Amphibole	Conc. [1] MFL	95% Confidence Intervals [1]		Fiber Type			
				Lower Limit	Upper Limit	**Other** (AR<3:1)	**MDH** (AR >=3:1, no min. length)	**OCC** (AR >=3:1, length >5 um)	**Asbestos** (AR>=20:1, Length>10 um)
Amphibole	1	100					X		
Cummingtonite-grunerite									
Actinolite	1	100					X		
Tremolite									
Hornblende									
Other Amphibole/Ambiguous									
Chrysotile									
Non-Amphibole, non-chrysotile	18						X		
Ambiguous	2						X		
Totals	21	4.8							

[1] Water samples only

MFL Million Fibers per Liter

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Tailings Samples

Fiber Information

Grid Opening	Fiber Number	Length	Width	Aspect Ratio	Mineral Type				Amph Chem [1]	Fiber Type			
					Amphibole	Chrysotile	Non-Amphibole/Non-Chrysotile	Ambiguous		Other (AR<3:1)	MDH (AR >=3:1, no min. length)	OCC (AR >=3:1, length >5 um)	Asbestos (AR>=20:1, Length>5 um)
E8	1	1.00	0.25	4.00			X				X		
	2	0.90	0.25	3.60			X				X		
	3	3.20	0.40	8.00			X				X		
	4	1.25	0.40	3.13			X				X		
	5	1.80	0.15	12.00			X				X		
	6	1.25	0.25	5.00			X				X		
G5	7	1.80	0.13	13.85			X				X		
	8	4.30	0.65	6.62			X				X		
	9	0.60	0.12	5.00			X				X		
	10	1.70	0.30	5.67			X				X		
	11	1.90	0.30	6.33			X				X		
	12	1.70	0.10	17.00				X			X		
	13	1.50	0.50	3.00			X				X		
I5	14	1.60	0.10	16.00			X				X		
	15	0.75	0.25	3.00			X				X		
	16	1.25	0.40	3.13			X				X		
	17	1.30	0.23	5.65			X				X		
	18	1.00	0.18	5.56	X				A		X		
	19	1.30	0.40	3.25				X			X		
	20	1.00	0.30	3.33			X				X		
	21	0.65	0.17	3.82			X				X		

[1] *Amphibole Chemistry*

G Grunerite
A Actinolite
T Tremolite
H Hornblende
O Other

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Tailings Samples

Sample Information

Sample Number:	P2S-C
Lab ID Number:	05-01304-9
Sampling (field) ID (location and/or Field No.):	
Date of Collection:	8/30/2005
Media/Sample Type:	Sludge/Tailings
Volume Filtered [1]:	NA

Mineral Information

	Fiber Count	% of Total Amphibole	Conc. [1] MFL	95% Confidence Intervals [1] Lower Limit	95% Confidence Intervals [1] Upper Limit	Fiber Type: Other (AR<3:1)	Fiber Type: MDH (AR >=3:1, no min. length)	Fiber Type: OCC (AR >=3:1, length >5 um)	Fiber Type: Asbestos (AR>=20:1, Length>10 um)
Amphibole	3	100					X		
Cummingtonite-grunerite	2	66.7					X		
Actinolite	1	33.3					X		
Tremolite									
Hornblende									
Other Amphibole/Ambiguous									
Chrysotile									
Non-Amphibole, non-chrysotile	20						X		
Ambiguous	2						X		
Totals	25	12.0							

[1] Water samples only

MFL Million Fibers per Liter

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Tailings Samples

Fiber Information

Grid Opening	Fiber Number	Length	Width	Aspect Ratio	Mineral Type: Amphibole	Mineral Type: Chrysotile	Mineral Type: Non-Amphibole/Non-Chrysotile	Mineral Type: Ambiguous	Amph Chem [1]	Fiber Type: Other (AR<3:1)	Fiber Type: MDH (AR >=3:1, no min. length)	Fiber Type: OCC (AR >=3:1, length >5 um)	Fiber Type: Asbestos (AR>=20:1, Length>5 um)
D6	1	1.70	0.10	17.00			X				X		
	2	2.50	0.60	4.17			X				X		
	3	0.90	0.25	3.60			X				X		
	4	1.10	0.14	7.86			X				X		
	5	2.20	0.20	11.00			X				X		
	6	1.70	0.50	3.40			X				X		
	7	0.75	0.25	3.00			X				X		
	8	1.15	0.35	3.29	X				G		X		
	9	0.90	0.23	3.91			X				X		
	10	2.75	0.50	5.50			X				X		
	11	1.00	0.25	4.00			X				X		
	12	1.20	0.30	4.00			X				X		
E4]	13	0.70	0.13	5.38			X				X		
	14	0.70	0.23	3.04			X				X		
	15	0.90	0.30	3.00			X				X		
	16	0.80	0.23	3.48				X			X		
	17	0.75	0.25	3.00				X			X		
	18	0.90	0.10	9.00			X				X		
	19	1.20	0.40	3.00			X				X		
	20	0.75	0.25	3.00	X				G		X		
	21	1.00	0.30	3.33			X				X		
	22	1.10	0.25	4.40			X				X		
	23	1.50	0.15	10.00	X				A		X		
	24	0.75	0.25	3.00			X				X		
	25	1.00	0.18	5.56			X				X		

[1] *Amphibole Chemistry*

- G Grunerite
- A Actinolite
- T Tremolite
- H Hornblende
- O Other

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Ore Samples

Sample Information

Sample Number:	P2O-C
Lab ID Number:	05-01304-10
Sampling (field) ID (location and/or Field No.):	
Date of Collection:	8/30/2005
Media/Sample Type:	Ore/Headfeed
Volume Filtered [1]:	NA

Mineral Information

	Fiber Count	% of Total Amphibole	Conc. [1] MFL	95% Confidence Intervals [1]		Fiber Type			
				Lower Limit	Upper Limit	**Other** (AR<3:1)	**MDH** (AR >=3:1, no min. length)	**OCC** (AR >=3:1, length >5 um)	**Asbestos** (AR>=20:1, Length>10 um)
Amphibole									
Cummingtonite-grunerite									
Actinolite									
Tremolite									
Hornblende									
Other Amphibole/Ambiguous									
Chrysotile									
Non-Amphibole, non-chrysotile	20						X	X	
Ambiguous	2						X		
Totals	22								

[1] Water samples only

MFL Million Fibers per Liter

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Ore Samples

Fiber Information

Grid Opening	Fiber Number	Length	Width	Aspect Ratio	Mineral Type				Amph Chem [1]	Fiber Type			
					Amphibole	Chrysotile	Non-Amphibole/Non-Chrysotile	Ambiguous		**Other** (AR<3:1)	**MDH** (AR >=3:1, no min. length)	**OCC** (AR >=3:1, length >5 um)	**Asbestos** (AR>=20:1, Length>5 um)
F7	1	1.50	0.50	3.00			X				X		
	2	1.00	0.30	3.33			X				X		
	3	11.50	3.50	3.29			X					X	
	4	1.40	0.18	7.78			X				X		
E8	5	0.70	0.23	3.04			X				X		
	6	0.51	0.13	3.92			X				X		
	7	3.25	0.75	4.33			X				X		
	8	0.75	0.12	6.25			X				X		
D6	9	0.75	0.25	3.00			X				X		
	10	1.50	0.50	3.00			X				X		
	11	7.50	1.90	3.95			X					X	
	12	1.20	0.25	4.80			X				X		
	13	0.80	0.25	3.20			X				X		
C5	14	1.00	0.11	9.09			X				X		
	15	4.20	1.00	4.20			X				X		
	16	0.75	0.25	3.00			X				X		
	17	0.70	0.23	3.04				X			X		
	18	1.10	0.30	3.67				X			X		
D3	19	1.20	0.40	3.00			X				X		
	20	1.50	0.25	6.00			X				X		
	21	1.20	0.38	3.16			X				X		
	22	0.75	0.25	3.00			X				X		

[1] *Amphibole Chemistry*

G Grunerite
A Actinolite
T Tremolite
H Hornblende
O Other

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Ore Samples

Sample Information

Sample Number:	P2O-B
Lab ID Number:	05-01304-11
Sampling (field) ID (location and/or Field No.):	
Date of Collection:	8/30/2005
Media/Sample Type:	Ore/Headfeed
Volume Filtered [1]:	NA

Mineral Information

	Fiber Count	**% of Total Amphibole**	**Conc. [1]** MFL	**95% Confidence Intervals [1]** Lower Limit	Upper Limit	**Fiber Type** **Other** (AR<3:1)	**MDH** (AR >=3:1, no min. length)	**OCC** (AR >=3:1, length >5 um)	**Asbestos** (AR>=20:1, Length>10 um)
Amphibole									
Cummingtonite-grunerite									
Actinolite									
Tremolite									
Hornblende									
Other Amphibole/Ambiguous									
Chrysotile									
Non-Amphibole, non-chrysotile	21						X		
Ambiguous									
Totals	21								

[1] Water samples only

MFL Million Fibers per Liter

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Ore Samples

Fiber Information

Grid Opening	Fiber Number	Length	Width	Aspect Ratio	Mineral Type				Amph Chem [1]	Fiber Type			
					Amphibole	Chrysotile	Non-Amphibole/Non-Chrysotile	Ambiguous		**Other** (AR<3:1)	**MDH** (AR >=3:1, no min. length)	**OCC** (AR >=3:1, length >5 um)	**Asbestos** (AR>=20:1, Length>5 um)
G8	1	1.00	0.25	4.00			X				X		
	2	0.60	0.18	3.33			X				X		
	3	1.10	0.25	4.40			X				X		
	4	2.50	0.70	3.57			X				X		
	5	1.10	0.23	4.78			X				X		
	6	4.50	0.20	22.50			X				X		
	7	1.40	0.25	5.60			X				X		
H6	8	0.90	0.25	3.60			X				X		
	9	4.00	0.75	5.33			X				X		
	10	0.70	0.18	3.89			X				X		
	11	1.60	0.50	3.20			X				X		
	12	0.75	0.25	3.00			X				X		
	13	1.15	0.20	5.75			X				X		
	14	1.15	0.20	5.75			X				X		
	15	0.75	0.25	3.00			X				X		
	16	1.50	0.48	3.13			X				X		
	17	1.50	0.30	5.00			X				X		
	18	2.75	0.75	3.67			X				X		
	19	2.50	0.60	4.17			X				X		
	20	1.20	0.22	5.45			X				X		
	21	1.20	1.30	0.92			X			X			

[1] *Amphibole Chemistry*

- G Grunerite
- A Actinolite
- T Tremolite
- H Hornblende
- O Other

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Ore Samples

Sample Information

Sample Number:	P1O-B
Lab ID Number:	05-01304-12
Sampling (field) ID (location and/or Field No.):	
Date of Collection:	8/30/2005
Media/Sample Type:	Ore/Headfeed
Volume Filtered [1]:	NA

Mineral Information

	Fiber Count	% of Total Amphibole	Conc. [1] MFL	95% Confidence Intervals [1]		Fiber Type			
				Lower Limit	Upper Limit	**Other** (AR<3:1)	**MDH** (AR >=3:1, no min. length)	**OCC** (AR >=3:1, length >5 um)	**Asbestos** (AR>=20:1, Length>10 um)
Amphibole	1	100					X		
Cummingtonite-grunerite	1	100					X		
Actinolite									
Tremolite									
Hornblende									
Other Amphibole/Ambiguous									
Chrysotile									
Non-Amphibole, non-chrysotile	22						X		
Ambiguous									
Totals	23	4.3							

[1] Water samples only

MFL Million Fibers per Liter

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Ore Samples

Fiber Information

Grid Opening	Fiber Number	Length	Width	Aspect Ratio	Mineral Type: Amphibole	Mineral Type: Chrysotile	Mineral Type: Non-Amphibole/Non-Chrysotile	Mineral Type: Ambiguous	Amph Chem [1]	Fiber Type: **Other** (AR<3:1)	Fiber Type: **MDH** (AR >=3:1, no min. length)	Fiber Type: **OCC** (AR >=3:1, length >5 um)	Fiber Type: **Asbestos** (AR>=20:1, Length>5 um)
D6	1	1.50	0.50	3.00			X				X		
	2	0.75	0.25	3.00			X				X		
	3	1.00	0.30	3.33			X				X		
	4	0.90	0.25	3.60			X				X		
	5	0.75	0.10	7.50			X				X		
	6	0.60	0.20	3.00			X				X		
	7	0.50	0.10	5.00			X				X		
	8	1.00	0.30	3.33			X				X		
	9	2.50	0.25	10.00	X				G		X		
	10	1.00	0.15	6.67			X				X		
	11	0.90	0.25	3.60			X				X		
	12	0.75	0.15	5.00			X				X		
	13	0.65	0.15	4.33			X				X		
D3	14	1.50	0.35	4.29			X				X		
	15	0.90	0.25	3.60			X				X		
	16	1.40	0.23	6.09			X				X		
	17	0.70	0.23	3.04			X				X		
	18	0.90	0.25	3.60			X				X		
	19	1.20	0.23	5.22			X				X		
	20	1.00	0.25	4.00			X				X		
	21	4.00	1.25	3.20			X				X		
	22	1.20	0.25	4.80			X				X		
	23	0.75	0.20	3.75			X				X		

[1] *Amphibole Chemistry*

G Grunerite
A Actinolite
T Tremolite
H Hornblende
O Other

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Ore Samples

Sample Information

Sample Number:	P1O-A
Lab ID Number:	05-01304-13
Sampling (field) ID (location and/or Field No.):	
Date of Collection:	8/30/2005
Media/Sample Type:	Ore/Headfeed
Volume Filtered [1]:	NA

Mineral Information

	Fiber Count	**% of Total Amphibole**	**Conc. [1]** MFL	**95% Confidence Intervals [1]**		**Fiber Type**			
				Lower Limit	Upper Limit	**Other** (AR<3:1)	**MDH** (AR >=3:1, no min. length)	**OCC** (AR >=3:1, length >5 um)	**Asbestos** (AR>=20:1, Length>10 um)
Amphibole									
Cummingtonite-grunerite									
Actinolite									
Tremolite									
Hornblende									
Other Amphibole/Ambiguous									
Chrysotile									
Non-Amphibole, non-chrysotile	20						X	X	
Ambiguous	3						X		
Totals	23								

[1] Water samples only

MFL Million Fibers per Liter

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Ore Samples

Fiber Information

Grid Opening	Fiber Number	Length	Width	Aspect Ratio	Mineral Type				Amph Chem [1]	Fiber Type			
					Amphibole	Chrysotile	Non-Amphibole/Non-Chrysotile	Ambiguous		**Other** (AR<3:1)	**MDH** (AR >=3:1, no min. length)	**OCC** (AR >=3:1, length >5 um)	**Asbestos** (AR>=20:1, Length>5 um)
D8	1	2.75	0.75	3.67			X				X		
	2	0.75	0.18	4.17			X				X		
	3	0.75	0.25	3.00			X				X		
	4	6.00	1.25	4.80			X					X	
	5	0.75	0.25	3.00			X				X		
	6	1.70	0.40	4.25			X				X		
	7	0.50	0.12	4.17			X				X		
	8	1.40	0.35	4.00			X				X		
	9	1.00	0.15	6.67				X			X		
	10	1.00	0.25	4.00				X			X		
	11	0.75	0.24	3.13			X				X		
	12	4.20	0.49	8.57			X				X		
	13	1.00	0.24	4.17			X				X		
	14	1.00	0.30	3.33			X				X		
H5	15	0.75	0.24	3.13			X				X		
	16	1.00	0.30	3.33			X				X		
	17	1.00	0.22	4.55			X				X		
	18	0.70	0.23	3.04				X			X		
	19	1.50	0.15	10.00			X				X		
	20	0.75	0.15	5.00			X				X		
	21	1.80	0.25	7.20			X				X		
	22	0.90	0.12	7.50			X				X		
	23	0.60	0.20	3.00			X				X		

[1] *Amphibole Chemistry*

G Grunerite
A Actinolite
T Tremolite
H Hornblende
O Other

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Ore Samples

Sample Information

Sample Number:	P1O-C
Lab ID Number:	05-01304-14
Sampling (field) ID (location and/or Field No.):	
Date of Collection:	8/30/2005
Media/Sample Type:	Ore/Headfeed
Volume Filtered [1]:	NA

Mineral Information

	Fiber Count	% of Total Amphibole	Conc. [1] MFL	95% Confidence Intervals [1]		Fiber Type			
				Lower Limit	Upper Limit	**Other** (AR<3:1)	**MDH** (AR >=3:1, no min. length)	**OCC** (AR >=3:1, length >5 um)	**Asbestos** (AR>=20:1, Length>10 um)
Amphibole									
Cummingtonite-grunerite									
Actinolite									
Tremolite									
Hornblende									
Other Amphibole/Ambiguous									
Chrysotile									
Non-Amphibole, non-chrysotile	23						X		
Ambiguous									
Totals	23								

[1] Water samples only

MFL Million Fibers per Liter

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Ore Samples

Fiber Information

Grid Opening	Fiber Number	Length	Width	Aspect Ratio	Mineral Type				Amph Chem [1]	Fiber Type			
					Amphibole	Chrysotile	Non-Amphibole/Non-Chrysotile	Ambiguous		**Other** (AR<3:1)	**MDH** (AR >=3:1, no min. length)	**OCC** (AR >=3:1, length >5 um)	**Asbestos** (AR>=20:1, Length>5 um)
	1	2.00	0.50	4.00			X				X		
	2	2.00	0.50	4.00			X				X		
	3	0.75	0.25	3.00			X				X		
	4	2.00	0.50	4.00			X				X		
	5	1.00	0.30	3.33			X				X		
	6	1.50	0.50	3.00			X				X		
	7	1.50	0.25	6.00			X				X		
	8	1.12	0.25	4.48			X				X		
	9	1.00	0.25	4.00			X				X		
	10	1.00	0.20	5.00			X				X		
	11	0.80	0.20	4.00			X				X		
	12	0.80	0.18	4.44			X				X		
	13	0.80	0.25	3.20			X				X		
	14	0.75	0.24	3.13			X				X		
	15	2.75	0.50	5.50			X				X		
	16	1.10	0.18	6.11			X				X		
	17	0.51	0.12	4.25			X				X		
	18	2.00	0.65	3.08			X				X		
	19	1.00	0.30	3.33			X				X		
	20	2.75	0.60	4.58			X				X		
	21	0.75	0.22	3.41			X				X		
	22	1.50	0.50	3.00			X				X		
	23	0.75	0.25	3.00			X				X		

[1] *Amphibole Chemistry*

G Grunerite
A Actinolite
T Tremolite
H Hornblende
O Other

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Ore Samples

Sample Information

Sample Number:	P2O-A
Lab ID Number:	05-01304-15
Sampling (field) ID (location and/or Field No.):	
Date of Collection:	8/30/2005
Media/Sample Type:	Ore/Headfeed
Volume Filtered [1]:	NA

Mineral Information

	Fiber Count	% of Total Amphibole	Conc. [1] MFL	95% Confidence Intervals [1]		Fiber Type			
				Lower Limit	Upper Limit	**Other** (AR<3:1)	**MDH** (AR >=3:1, no min. length)	**OCC** (AR >=3:1, length >5 um)	**Asbestos** (AR>=20:1, Length>10 um)
Amphibole	1	100					X		
Cummingtonite-grunerite	1	100					X		
Actinolite									
Tremolite									
Hornblende									
Other Amphibole/Ambiguous									
Chrysotile									
Non-Amphibole, non-chrysotile	23						X		
Ambiguous	1						X		
Totals	25	4.0							

[1] Water samples only

MFL Million Fibers per Liter

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Ore Samples

Fiber Information

Grid Opening	Fiber Number	Length	Width	Aspect Ratio	Mineral Type				Amph Chem [1]	Fiber Type			
					Amphibole	Chrysotile	Non-Amphibole/Non-Chrysotile	Ambiguous		**Other** (AR<3:1)	**MDH** (AR >=3:1, no min. length)	**OCC** (AR >=3:1, length >5 um)	**Asbestos** (AR>=20:1, Length>5 um)
E8	1	1.50	0.50	3.00			X				X		
	2	2.10	0.50	4.20			X				X		
	3	0.51	0.15	3.40			X				X		
	4	3.00	0.75	4.00			X				X		
	5	1.50	0.25	6.00			X				X		
	6	0.80	0.25	3.20			X				X		
	7	1.20	0.30	4.00			X				X		
	8	2.76	0.50	5.52			X				X		
	9	0.70	0.23	3.04			X				X		
	10	1.00	0.23	4.35			X				X		
C8	11	1.00	0.21	4.76			X				X		
	12	1.00	0.25	4.00			X				X		
	13	0.80	0.25	3.20			X				X		
	14	0.80	0.25	3.20			X				X		
	15	2.50	0.10	25.00			X				X		
	16	1.50	0.50	3.00			X				X		
	17	0.70	0.20	3.50			X				X		
H4	18	0.80	0.25	3.20			X				X		
	19	0.75	0.18	4.17			X				X		
	20	1.50	0.40	3.75	X				G		X		
	21	1.50	0.50	3.00			X				X		
	22	1.20	0.25	4.80			X				X		
	23	0.80	0.20	4.00				X			X		
	24	2.50	0.25	10.00			X				X		
	25	0.75	0.25	3.00			X				X		

[1] *Amphibole Chemistry*

G Grunerite

A Actinolite

T Tremolite

H Hornblende

O Other

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Ore Samples

Sample Information

Sample Number:	PO0-A
Lab ID Number:	05-01304-16
Sampling (field) ID (location and/or Field No.):	
Date of Collection:	8/30/2005
Media/Sample Type:	Ore/Headfeed
Volume Filtered [1]:	NA

Mineral Information

	Fiber Count	% of Total Amphibole	Conc. [1] MFL	95% Confidence Intervals [1]		Fiber Type			
				Lower Limit	Upper Limit	Other (AR<3:1)	MDH (AR >=3:1, no min. length)	OCC (AR >=3:1, length >5 um)	Asbestos (AR>=20:1, Length>10 um)
Amphibole	5	100					X		
Cummingtonite-grunerite	5	100					X		
Actinolite									
Tremolite									
Hornblende									
Other Amphibole/Ambiguous									
Chrysotile									
Non-Amphibole, non-chrysotile	13						X		
Ambiguous	2						X		
Totals	20	25.0							

[1] Water samples only

MFL Million Fibers per Liter

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Ore Samples

Fiber Information

Grid Opening	Fiber Number	Length	Width	Aspect Ratio	Mineral Type				Amph Chem [1]	Fiber Type			
					Amphibole	Chrysotile	Non-Amphibole/Non-Chrysotile	Ambiguous		**Other** (AR<3:1)	**MDH** (AR >=3:1, no min. length)	**OCC** (AR >=3:1, length >5 um)	**Asbestos** (AR>=20:1, Length>5 um)
B8	1	1.20	0.30	4.00			X				X		
	2	1.20	0.13	9.23	X				G		X		
	3	1.15	0.30	3.83			X				X		
	4	1.50	0.50	3.00	X				G		X		
	5	1.00	0.10	10.00				X			X		
	6	1.20	0.35	3.43			X				X		
	7	1.40	0.10	14.00				X			X		
G7	8	2.50	0.70	3.57			X				X		
	9	1.50	0.25	6.00			X				X		
	10	0.75	0.15	5.00			X				X		
	11	1.20	0.30	4.00	X				G		X		
	12	1.15	0.23	5.00			X				X		
	13	1.50	0.25	6.00			X				X		
	14	3.00	0.75	4.00			X				X		
	15	1.50	0.50	3.00			X				X		
	16	0.75	0.23	3.26	X				G		X		
	17	1.20	0.35	3.43			X				X		
	18	1.20	0.25	4.80			X				X		
	19	4.75	0.23	20.65	X				G		X		
	20	1.00	0.30	3.33			X				X		

[1] *Amphibole Chemistry*

G Grunerite
A Actinolite
T Tremolite
H Hornblende
O Other

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Ore Samples

Sample Information

Sample Number:	P3O-B
Lab ID Number:	05-01304-17
Sampling (field) ID (location and/or Field No.):	
Date of Collection:	8/30/2005
Media/Sample Type:	Ore/Headfeed
Volume Filtered [1]:	NA

Mineral Information

	Fiber Count	% of Total Amphibole	Conc. [1] MFL	95% Confidence Intervals [1]		Fiber Type			
				Lower Limit	Upper Limit	**Other** (AR<3:1)	**MDH** (AR >=3:1, no min. length)	**OCC** (AR >=3:1, length >5 um)	**Asbestos** (AR>=20:1, Length>10 um)
Amphibole	3	100					X		
Cummingtonite-grunerite	1	33.3					X		
Actinolite	2	66.7					X		
Tremolite									
Hornblende									
Other Amphibole/Ambiguous									
Chrysotile									
Non-Amphibole, non-chrysotile	20						X	X	
Ambiguous	1						X		
Totals	24	12.5							

[1] Water samples only

MFL Million Fibers per Liter

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Ore Samples

Fiber Information

Grid Opening	Fiber Number	Length	Width	Aspect Ratio	Mineral Type				Amph Chem [1]	Fiber Type			
					Amphibole	Chrysotile	Non-Amphibole/Non-Chrysotile	Ambiguous		**Other** (AR<3:1)	**MDH** (AR >=3:1, no min. length)	**OCC** (AR >=3:1, length >5 um)	**Asbestos** (AR>=20:1, Length>5 um)
C4	1	0.70	0.12	5.83			X				X		
	2	0.70	0.23	3.04			X				X		
	3	1.20	0.22	5.45			X				X		
	4	1.70	0.50	3.40			X				X		
	5	0.70	0.15	4.67			X				X		
	6	0.50	0.16	3.13			X				X		
	7	0.75	0.25	3.00	X				A		X		
	8	4.75	1.00	4.75			X				X		
	9	0.90	0.25	3.60			X				X		
D3	10	1.60	0.30	5.33	X				A		X		
	11	1.20	0.37	3.24			X				X		
	12	0.60	0.12	5.00			X				X		
	13	1.70	0.11	15.45			X				X		
	14	16.00	5.00	3.20			X					X	
	15	1.50	0.50	3.00			X				X		
	16	1.15	0.23	5.00			X				X		
G4	17	1.00	0.25	4.00			X				X		
	18	1.10	0.13	8.46			X				X		
	19	1.00	0.23	4.35			X				X		
	20	1.00	0.24	4.17	X				G		X		
	21	1.30	0.25	5.20			X				X		
	22	1.00	0.30	3.33			X				X		
	23	0.75	0.25	3.00				X			X		
	24	1.50	0.25	6.00			X				X		

[1] *Amphibole Chemistry*

G Grunerite
A Actinolite
T Tremolite
H Hornblende
O Other

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Ore Samples

Sample Information

Sample Number:	P3O-C
Lab ID Number:	05-01304-18
Sampling (field) ID (location and/or Field No.):	
Date of Collection:	8/30/2005
Media/Sample Type:	Ore/Headfeed
Volume Filtered [1]:	NA

Mineral Information

	Fiber Count	% of Total Amphibole	Conc. [1] MFL	95% Confidence Intervals [1] Lower Limit	Upper Limit	Fiber Type: Other (AR<3:1)	MDH (AR >=3:1, no min. length)	OCC (AR >=3:1, length >5 um)	Asbestos (AR>=20:1, Length>10 um)
Amphibole	1	100					X		
Cummingtonite-grunerite									
Actinolite	1	100					X		
Tremolite									
Hornblende									
Other Amphibole/Ambiguous									
Chrysotile									
Non-Amphibole, non-chrysotile	19					X	X		X
Ambiguous	1						X		
Totals	21	4.8							

[1] Water samples only

MFL Million Fibers per Liter

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Ore Samples

Fiber Information

Grid Opening	Fiber Number	Length	Width	Aspect Ratio	Mineral Type				Amph Chem [1]	Fiber Type			
					Amphibole	Chrysotile	Non-Amphibole/Non-Chrysotile	Ambiguous		**Other** (AR<3:1)	**MDH** (AR >=3:1, no min. length)	**OCC** (AR >=3:1, length >5 um)	**Asbestos** (AR>=20:1, Length>5 um)
E7	1	1.00	0.30	3.33			X				X		
	2	0.90	0.23	3.91			X				X		
	3	1.25	0.25	5.00	X				A		X		
	4	2.20	0.40	5.50			X				X		
	5	1.99	0.50	3.98			X				X		
	6	0.70	0.10	7.00			X				X		
	7	6.00	0.22	27.27			X						X
	8	1.20	0.20	6.00			X				X		
	9	2.50	0.65	3.85			X				X		
	10	1.50	0.23	6.52			X				X		
	11	0.60	0.22	2.73			X			X			
	12	2.20	0.50	4.40			X				X		
	13	0.70	0.22	3.18			X				X		
	14	1.50	0.30	5.00			X				X		
G5	15	2.00	0.50	4.00			X				X		
	16	0.80	0.25	3.20			X				X		
	17	0.60	0.10	6.00				X			X		
	18	3.50	1.10	3.18			X				X		
	19	0.90	0.24	3.75			X				X		
	20	2.50	0.70	3.57			X				X		
	21	0.75	0.25	3.00			X				X		

[1] *Amphibole Chemistry*

G Grunerite
A Actinolite
T Tremolite
H Hornblende
O Other

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Process Water Samples

Sample Information

Sample Number:	P1L-A
Lab ID Number:	05-01274-1
Sampling (field) ID (location and/or Field No.):	
Date of Collection:	8/30/2005
Media/Sample Type:	Water/Floatation Process water
Volume Filtered [1]:	0.1 ml

Mineral Information

	Fiber Count	% of Total Amphibole	Conc. [1] MFL	95% Confidence Intervals [1]		Fiber Type			
				Lower Limit	Upper Limit	**Other** (AR<3:1)	**MDH** (AR >=3:1, no min. length)	**OCC** (AR >=3:1, length >5 um)	**Asbestos** (AR>=20:1, Length>10 um)
Amphibole	2	100	173.77	17.38	625.56		X		
Cummingtonite-grunerite	1	50					X		
Actinolite	1	50					X		
Tremolite									
Hornblende									
Other Amphibole/Ambiguous									
Chrysotile			0	0	321.47				
Non-Amphibole, non-chrysotile	18		1563.89	929.65	2467.5		X		
Ambiguous			0	0	321.47				
Totals	20	10.0	1737.66	1059.97	2675.99				

[1] Water samples only

MFL Million Fibers per Liter

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Process Water Samples

Fiber Information

Grid Opening	Fiber Number	Length	Width	Aspect Ratio	Mineral Type: Amphibole	Mineral Type: Chrysotile	Mineral Type: Non-Amphibole/Non-Chrysotile	Mineral Type: Ambiguous	Amph Chem [1]	Fiber Type: Other (AR<3:1)	Fiber Type: MDH (AR >=3:1, no min. length)	Fiber Type: OCC (AR >=3:1, length >5 um)	Fiber Type: Asbestos (AR>=20:1, Length>10 um)
G5	1	1.10	0.15	7.33			X				X		
G4	2	0.70	0.10	7.00			X				X		
H5	3	0.90	0.15	6.00	X				G		X		
	4	0.60	0.20	3.00			X				X		
I2	5	0.50	0.11	4.55			X				X		
	6	0.90	0.22	4.09	X				A		X		
	7	0.60	0.11	5.45			X				X		
	8	0.60	0.20	3.00			X				X		
	9	1.00	0.25	4.00			X				X		
G7	10	0.65	0.15	4.33			X				X		
	11	0.70	0.22	3.18			X				X		
C4	12	0.60	0.15	4.00			X				X		
	13	0.60	0.10	6.00			X				X		
C6	14	0.60	0.20	3.00			X				X		
	15	1.40	0.12	11.67			X				X		
D5	16	0.55	0.15	3.67			X				X		
	17	0.70	0.20	3.50			X				X		
J2	18	1.00	0.18	5.56			X				X		
G7	19	0.60	0.20	3.00			X				X		
	20	0.60	0.20	3.00			X				X		

[1] *Amphibole Chemistry*

G Grunerite
A Actinolite
T Tremolite
H Hornblende
O Other

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Process Water Samples

Sample Information

Sample Number:	P1L-B
Lab ID Number:	05-01274-2
Sampling (field) ID (location and/or Field No.):	
Date of Collection:	8/30/2005
Media/Sample Type:	Water/Floatation Process water
Volume Filtered [1]:	1.0 ml

Mineral Information

	Fiber Count	% of Total Amphibole	Conc. [1] MFL	95% Confidence Intervals [1]		Fiber Type			
				Lower Limit	Upper Limit	Other (AR<3:1)	MDH (AR >=3:1, no min. length)	OCC (AR >=3:1, length >5 um)	Asbestos (AR>=20:1, Length>10 um)
Amphibole	4	100	34.75	8.69	88.62		X		
Cummingtonite-grunerite	2	50					X		
Actinolite	2	50					X		
Tremolite									
Hornblende									
Other Amphibole/Ambiguous									
Chrysotile			0.00	0.00	32.15				
Non-Amphibole, non-chrysotile	10		86.88	40.83	159.86		X		
Ambiguous	3		26.06	5.21	76.46		X		
Totals	17	23.5	147.70	86.01	236.32				

[1] Water samples only

MFL Million Fibers per Liter

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Process Water Samples

Fiber Information

Grid Opening	Fiber Number	Length	Width	Aspect Ratio	Mineral Type: Amphibole	Mineral Type: Chrysotile	Mineral Type: Non-Amphibole/Non-Chrysotile	Mineral Type: Ambiguous	Amph Chem [1]	Fiber Type: Other (AR<3:1)	Fiber Type: MDH (AR >=3:1, no min. length)	Fiber Type: OCC (AR >=3:1, length >5 um)	Fiber Type: Asbestos (AR>=20:1, Length>10 um)
G6	1	0.70	0.15	4.67				X			X		
	2	0.60	0.15	4.00			X				X		
H5	3	1.00	0.20	5.00	X				A		X		
	4	0.75	0.25	3.00				X			X		
	5	0.55	0.15	3.67			X				X		
I4	6	0.90	0.22	4.09	X				A		X		
	7	0.70	0.22	3.18	X				G		X		
D6	8	0.80	0.15	5.33			X				X		
	9	1.70	0.20	8.50				X			X		
C4	10	1.10	0.10	11.00	X				G		X		
	11	1.50	0.10	15.00			X				X		
	12	0.75	0.20	3.75			X				X		
	13	0.90	0.25	3.60			X				X		
D6	14	1.20	0.15	8.00			X				X		
C5	15	0.70	0.10	7.00			X				X		
D3	16	1.20	0.15	8.00			X				X		
F4	17	1.20	0.30	4.00			X				X		

[1] *Amphibole Chemistry*

G Grunerite
A Actinolite
T Tremolite
H Hornblende
O Other

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Process Water Samples

Sample Information

Sample Number:	P1L-C
Lab ID Number:	05-01274-3
Sampling (field) ID (location and/or Field No.):	
Date of Collection:	8/30/2005
Media/Sample Type:	Water/Floatation Process water
Volume Filtered [1]:	0.1 ml

Mineral Information

	Fiber Count	**% of Total Amphibole**	**Conc. [1]** MFL	**95% Confidence Intervals [1]**		**Fiber Type**			
				Lower Limit	Upper Limit	**Other** (AR<3:1)	**MDH** (AR >=3:1, no min. length)	**OCC** (AR >=3:1, length >5 um)	**Asbestos** (AR>=20:1, Length>10 um)
Amphibole	1	100	173.77	17.38	973.09		X		
Cummingtonite-grunerite	1	100					X		
Actinolite									
Tremolite									
Hornblende									
Other Amphibole/Ambiguous									
Chrysotile			0.00	0.00	642.93				
Non-Amphibole, non-chrysotile	18		3127.78	1859.29	4934.9		X		
Ambiguous	1		173.77	17.38	973.09		X		
Totals	20	5.0	3475.31	2119.94	5351.98				

[1] Water samples only

MFL Million Fibers per Liter

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Process Water Samples

Fiber Information

Grid Opening	Fiber Number	Length	Width	Aspect Ratio	Mineral Type				Amph Chem [1]	Fiber Type			
					Amphibole	Chrysotile	Non-Amphibole/Non-Chrysotile	Ambiguous		Other (AR<3:1)	MDH (AR >=3:1, no min. length)	OCC (AR >=3:1, length >5 um)	Asbestos (AR>=20:1, Length>10 um)
C5	1	0.90	0.10	9.00			X				X		
	2	1.20	0.22	5.45			X				X		
B5	3	0.75	0.25	3.00			X				X		
	4	0.80	0.25	3.20			X				X		
	5	0.60	0.10	6.00			X				X		
C3	6	0.50	0.10	5.00			X				X		
	7	1.00	0.25	4.00			X				X		
	8	0.70	0.20	3.50			X				X		
	9	0.80	0.22	3.64				X			X		
	10	1.00	0.25	4.00			X				X		
E2	11	0.51	0.15	3.40			X				X		
	12	0.90	0.10	9.00			X				X		
	13	1.00	0.25	4.00			X				X		
	14	0.60	0.10	6.00			X				X		
	15	1.00	0.22	4.55			X				X		
B6	16	0.80	0.22	3.64			X				X		
	17	0.60	0.20	3.00	X				G		X		
	18	1.20	0.30	4.00			X				X		
	19	0.70	0.22	3.18			X				X		
	20	0.55	0.15	3.67			X				X		

[1] *Amphibole Chemistry*
- G Grunerite
- A Actinolite
- T Tremolite
- H Hornblende
- O Other

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Process Water Samples

Sample Information

Sample Number:	P2L-A
Lab ID Number:	05-01274-4
Sampling (field) ID (location and/or Field No.):	
Date of Collection:	8/30/2005
Media/Sample Type:	Water/Floatation Process water
Volume Filtered [1]:	5.0 ml

Mineral Information

	Fiber Count	% of Total Amphibole	Conc. [1] MFL	95% Confidence Intervals [1]		Fiber Type			
				Lower Limit	Upper Limit	Other (AR<3:1)	MDH (AR >=3:1, no min. length)	OCC (AR >=3:1, length >5 um)	Asbestos (AR>=20:1, Length>10 um)
Amphibole			0.00	0.00	6.43				
Cummingtonite-grunerite									
Actinolite									
Tremolite									
Hornblende									
Other Amphibole/Ambiguous									
Chrysotile			0.00	0.00	6.43				
Non-Amphibole, non-chrysotile	3		5.21	1.04	15.29		X		
Ambiguous			0.00	0.00	6.43				
Totals	3		5.21	1.04	15.29				

[1] Water samples only

MFL Million Fibers per Liter

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Process Water Samples

Fiber Information

Grid Opening	Fiber Number	Length	Width	Aspect Ratio	Mineral Type				Amph Chem [1]	Fiber Type			
					Amphibole	Chrysotile	Non-Amphibole/Non-Chrysotile	Ambiguous		**Other** (AR<3:1)	**MDH** (AR >=3:1, no min. length)	**OCC** (AR >=3:1, length >5 um)	**Asbestos** (AR>=20:1, Length>10 um)
E4	1	0.50	0.10	5.00			X				X		
	2	0.51	0.10	5.10			X				X		
F8	3	0.70	0.22	3.18			X				X		

[1] *Amphibole Chemistry*
- G Grunerite
- A Actinolite
- T Tremolite
- H Hornblende
- O Other

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Process Water Samples

Sample Information

Sample Number:	P2L-B
Lab ID Number:	05-01274-5
Sampling (field) ID (location and/or Field No.):	
Date of Collection:	8/30/2005
Media/Sample Type:	Water/Floatation Process water
Volume Filtered [1]:	5.0 ml

Mineral Information

	Fiber Count	% of Total Amphibole	Conc. [1] MFL	95% Confidence Intervals [1]		Fiber Type			
				Lower Limit	Upper Limit	**Other** (AR<3:1)	**MDH** (AR >=3:1, no min. length)	**OCC** (AR >=3:1, length >5 um)	**Asbestos** (AR>=20:1, Length>10 um)
Amphibole			0	0	6.43				
Cummingtonite-grunerite									
Actinolite									
Tremolite									
Hornblende									
Other Amphibole/Ambiguous									
Chrysotile			0	0	6.43				
Non-Amphibole, non-chrysotile			0	0	6.43				
Ambiguous			0	0	6.43				
Totals	0		0	0	6.43				

[1] Water samples only

MFL Million Fibers per Liter

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Process Water Samples

Fiber Information

Grid Opening	Fiber Number	Length	Width	Aspect Ratio	Mineral Type				Amph Chem [1]	Fiber Type			
					Amphibole	Chrysotile	Non-Amphibole/Non-Chrysotile	Ambiguous		**Other** (AR<3:1)	**MDH** (AR >=3:1, no min. length)	**OCC** (AR >=3:1, length >5 um)	**Asbestos** (AR>=20:1, Length>10 um)

[1] *Amphibole Chemistry*

G Grunerite
A Actinolite
T Tremolite
H Hornblende
O Other

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Process Water Samples

Sample Information

Sample Number:	P2L-C
Lab ID Number:	05-01274-6
Sampling (field) ID (location and/or Field No.):	
Date of Collection:	8/30/2005
Media/Sample Type:	Water/Floatation Process water
Volume Filtered [1]:	5.0 ml

Mineral Information

	Fiber Count	% of Total Amphibole	Conc. [1] MFL	95% Confidence Intervals [1]		Fiber Type			
				Lower Limit	Upper Limit	Other (AR<3:1)	MDH (AR >=3:1, no min. length)	OCC (AR >=3:1, length >5 um)	Asbestos (AR>=20:1, Length>10 um)
Amphibole			0	0	6.43				
Cummingtonite-grunerite									
Actinolite									
Tremolite									
Hornblende									
Other Amphibole/Ambiguous									
Chrysotile			0	0	6.43				
Non-Amphibole, non-chrysotile	7		12.16	4.87	25.02		X		
Ambiguous			0	0	6.43				
Totals	7		12.16	4.87	25.02				

[1] Water samples only

MFL Million Fibers per Liter

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Process Water Samples

Fiber Information

Grid Opening	Fiber Number	Length	Width	Aspect Ratio	Mineral Type: Amphibole	Mineral Type: Chrysotile	Mineral Type: Non-Amphibole/Non-Chrysotile	Mineral Type: Ambiguous	Amph Chem [1]	Fiber Type: **Other** (AR<3:1)	Fiber Type: **MDH** (AR >=3:1, no min. length)	Fiber Type: **OCC** (AR >=3:1, length >5 um)	Fiber Type: **Asbestos** (AR>=20:1, Length>10 um)
D9	1	1.00	0.30	3.33			X				X		
	2	1.50	0.22	6.82			X				X		
B8	3	1.50	0.35	4.29			X				X		
D3	4	0.90	0.25	3.60			X				X		
	5	3.50	0.40	8.75			X				X		
G4	6	3.00	0.70	4.29			X				X		
D7	7	0.70	0.20	3.50			X				X		

[1] *Amphibole Chemistry*

- G Grunerite
- A Actinolite
- T Tremolite
- H Hornblende
- O Other

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Process Water Samples

Sample Information

Sample Number:	P3L-A
Lab ID Number:	05-01274-7
Sampling (field) ID (location and/or Field No.):	
Date of Collection:	8/30/2005
Media/Sample Type:	Water/Floatation Process water
Volume Filtered [1]:	0.1 ml

Mineral Information

	Fiber Count	% of Total Amphibole	Conc. [1] MFL	95% Confidence Intervals [1]		Fiber Type			
				Lower Limit	Upper Limit	**Other** (AR<3:1)	**MDH** (AR >=3:1, no min. length)	**OCC** (AR >=3:1, length >5 um)	**Asbestos** (AR>=20:1, Length>10 um)
Amphibole	3	100	1303.24	260.65	3822.84	X	X		
Cummingtonite-grunerite	2	66.7				X	X		
Actinolite									
Tremolite									
Hornblende	1	33.3					X		
Other Amphibole/Ambiguous									
Chrysotile			0.00	0.00	1607.33				
Non-Amphibole, non-chrysotile	14		6081.79	3344.99	#######		X		
Ambiguous	5		2172.07	695.06	5082.64		X		
Totals	22	13.6	9557.10	5994.91	#######				

[1] Water samples only

MFL Million Fibers per Liter

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Process Water Samples

Fiber Information

Grid Opening	Fiber Number	Length	Width	Aspect Ratio	Mineral Type				Amph Chem [1]	Fiber Type			
					Amphibole	Chrysotile	Non-Amphibole/ Non-Chrysotile	Ambiguous		Other (AR<3:1)	**MDH** (AR >=3:1, no min. length)	**OCC** (AR >=3:1, length >5 um)	**Asbestos** (AR>=20:1, Length>10 um)
C6	1	1.00	0.25	4.00			X				X		
	2	0.40	0.15	2.67	X				G	X			
	3	0.80	0.20	4.00			X				X		
	4	1.20	0.10	12.00				X			X		
	5	1.00	0.25	4.00			X				X		
	6	0.50	0.10	5.00				X			X		
	7	0.90	0.20	4.50			X				X		
	8	1.00	0.10	10.00			X				X		
	9	0.60	0.15	4.00	X				G		X		
	10	1.90	0.22	8.64				X			X		
	11	1.20	0.25	4.80			X				X		
	12	0.90	0.25	3.60			X				X		
E8	13	0.90	0.25	3.60			X				X		
	14	1.10	0.11	10.00			X				X		
	15	0.70	0.15	4.67			X				X		
	16	1.00	0.25	4.00			X				X		
	17	1.00	0.10	10.00			X				X		
	18	0.70	0.20	3.50				X			X		
	19	0.50	0.15	3.33				X			X		
	20	1.00	0.30	3.33	X				H		X		
	21	2.30	0.75	3.07			X				X		
	22	1.70	0.10	17.00			X				X		

[1] *Amphibole Chemistry*

- G Grunerite
- A Actinolite
- T Tremolite
- H Hornblende
- O Other

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Process Water Samples

Sample Information

Sample Number:	P3L-B
Lab ID Number:	05-01274-8
Sampling (field) ID (location and/or Field No.):	
Date of Collection:	8/30/2005
Media/Sample Type:	Water/Floatation Process water
Volume Filtered [1]:	0.1 ml

Mineral Information

	Fiber Count	% of Total Amphibole	Conc. [1] MFL	95% Confidence Intervals [1]		Fiber Type			
				Lower Limit	Upper Limit	Other (AR<3:1)	MDH (AR >=3:1, no min. length)	OCC (AR >=3:1, length >5 um)	Asbestos (AR>=20:1, Length>10 um)
Amphibole	6	100	2606.48	955.71	5690.82		X		
Cummingtonite-grunerite	4	66.7					X		
Actinolite	2	33.3					X		
Tremolite									
Hornblende									
Other Amphibole/Ambiguous									
Chrysotile			0.00	0.00	1607.33				
Non-Amphibole, non-chrysotile	15		6516.20	3649.07	#######		X		
Ambiguous	1		434.41	43.44	2432.72		X		
Totals	22	27.3	9557.10	5994.91	#######				

[1] Water samples only

MFL Million Fibers per Liter

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Process Water Samples

Fiber Information

Grid Opening	Fiber Number	Length	Width	Aspect Ratio	Mineral Type				Amph Chem [1]	Fiber Type			
					Amphibole	Chrysotile	Non-Amphibole/ Non-Chrysotile	Ambiguous		Other (AR<3:1)	MDH (AR >=3:1, no min. length)	OCC (AR >=3:1, length >5 um)	Asbestos (AR>=20:1, Length>10 um)
D6	1	0.90	0.25	3.60			X				X		
	2	0.70	0.18	3.89			X				X		
	3	0.70	0.15	4.67	X				G		X		
	4	0.60	0.10	6.00	X				G		X		
	5	0.70	0.15	4.67			X				X		
	6	0.65	0.20	3.25			X				X		
	7	0.60	0.15	4.00			X				X		
	8	1.10	0.22	5.00	X				A		X		
D4	9	1.00	0.22	4.55			X				X		
	10	0.60	0.15	4.00			X				X		
	11	0.70	0.20	3.50			X				X		
	12	0.70	0.12	5.83			X				X		
	13	0.70	0.20	3.50	X				A		X		
	14	0.70	0.10	7.00			X				X		
	15	1.70	0.25	6.80			X				X		
	16	2.20	0.50	4.40				X			X		
	17	1.50	0.25	6.00	X				G		X		
	18	1.70	0.12	14.17	X				G		X		
	19	1.60	0.15	10.67			X				X		
	20	0.50	0.12	4.17			X				X		
	21	2.50	0.20	12.50			X				X		
	22	1.10	0.10	11.00			X				X		

[1] *Amphibole Chemistry*

G Grunerite
A Actinolite
T Tremolite
H Hornblende
O Other

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Process Water Samples

Sample Information

Sample Number:	P3L-C
Lab ID Number:	05-01274-9
Sampling (field) ID (location and/or Field No.):	
Date of Collection:	8/30/2005
Media/Sample Type:	Water/Floatation Process water
Volume Filtered [1]:	0.1 ml

Mineral Information

	Fiber Count	% of Total Amphibole	Conc. [1] MFL	95% Confidence Intervals [1]		Fiber Type			
				Lower Limit	Upper Limit	Other (AR<3:1)	MDH (AR >=3:1, no min. length)	OCC (AR >=3:1, length >5 um)	Asbestos (AR>=20:1, Length>10 um)
Amphibole	3	100	434.41	86.88	1274.28		X		
Cummingtonite-grunerite	2	66.7					X		
Actinolite									
Tremolite									
Hornblende	1	33.3					X		
Other Amphibole/Ambiguous									
Chrysotile			0.00	0.00	535.78				
Non-Amphibole, non-chrysotile	17		2461.68	1433.57	3938.68		X		
Ambiguous	3		434.41	86.88	1274.28		X		
Totals	23	13.0	3330.50	2114.15	4981.28				

[1] Water samples only

MFL Million Fibers per Liter

Transmission Electron Microscopy Results Using
Minnesota Dept. of Health Counting Rules for the NorthMet Project
Flotation Pilot Study Samples - Process Water Samples

Fiber Information

Grid Opening	Fiber Number	Length	Width	Aspect Ratio	Mineral Type				Amph Chem [1]	Fiber Type			
					Amphibole	Chrysotile	Non-Amphibole/Non-Chrysotile	Ambiguous		**Other** (AR<3:1)	**MDH** (AR >=3:1, no min. length)	**OCC** (AR >=3:1, length >5 um)	**Asbestos** (AR>=20:1, Length>10 um)
F7	1	0.70	0.15	4.67			X				X		
	2	1.10	0.10	11.00			X				X		
	3	0.90	0.22	4.09			X				X		
G6	4	0.90	0.23	3.91	X				H		X		
	5	0.75	0.25	3.00			X				X		
	6	0.60	0.10	6.00			X				X		
	7	1.00	0.25	4.00			X				X		
H7	8	0.55	0.15	3.67			X				X		
	9	1.50	0.18	8.33			X				X		
	10	0.70	0.15	4.67			X				X		
H5	11	0.75	0.25	3.00				X			X		
	12	0.50	0.15	3.33				X			X		
	13	0.51	0.10	5.10			X				X		
I8	14	0.50	0.10	5.00				X			X		
	15	1.30	0.35	3.71	X				G		X		
	16	0.61	0.20	3.05	X				G		X		
	17	0.50	0.16	3.13			X				X		
	18	0.60	0.20	3.00			X				X		
	19	0.75	0.22	3.41			X				X		
D7	20	0.90	0.25	3.60			X				X		
	21	0.70	0.15	4.67			X				X		
	22	1.20	0.12	10.00			X				X		
	23	0.90	0.10	9.00			X				X		

[1] *Amphibole Chemistry*

G Grunerite
A Actinolite
T Tremolite
H Hornblende
O Other