WHITE PAPER:

IWGACP SCIENTIFIC OPINIONS ON TESTING METHODS FOR ASBESTOS IN COSMETIC PRODUCTS CONTAINING TALC[a]

INTERAGENCY WORKING GROUP ON ASBESTOS IN CONSUMER PRODUCTS (IWGACP)

[a] Including talc intended for use in cosmetics

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Contents

ABBREVIATIONS

AHERA	Asbestos Hazard Emergency Response Act
AMA	AMA Analytical Services, Inc.
AR	Aspect Ratio
ASTM	ASTM International, formerly known as American Society for Testing and Materials
CFSAN	Center for Food Safety and Applied Nutrition
CPSC	Consumer Product Safety Commission
CTFA	Cosmetic, Toiletry, and Fragrance Association
EDS	Energy Dispersive Spectroscopy
EMP	Elongate Mineral Particle
EPA	U.S. Environmental Protection Agency
FDA	United States Food and Drug Administration
HLS	Heavy Liquid Separation
IARC	International Agency for Research on Cancer
IR	Infrared
ISO	International Organization for Standardization
IWGACP	Interagency Working Group on Asbestos in Consumer Products
NIH/NIEHS	National Institute of Health / National Institute of Environmental Health Sciences
NIOSH	National Institutes for Occupational Safety and Health
NIST	National Institute of Standards & Technology
NTP	U.S. National Toxicology Program
OSHA	Occupational Safety and Health Administration

PCM	Phase Contrast Microscopy
PLM	Polarized Light Microscopy
SAED	Selected Area Electron Diffraction Analysis
SEM	Scanning Electron Microscopy
SME	Subject Matter Experts
SVF	Synthetic Vitreous Fibers
TEM	Transmission Electron Microscopy
USGS	U.S. Geological Survey
USP	United States Pharmacopeia
WHO	World Health Organization
XRD	X-ray diffraction

I. EXECUTIVE SUMMARY

This white paper provides the scientific opinions of subject matter experts (SMEs) from an interagency working group related to testing cosmetic products containing talc and talc intended for use in cosmetics[1] for the presence of asbestos, as well as other potentially harmful amphibole particles that can affect cosmetic product safety. These opinions are intended to inform FDA's consideration of testing methods for talc-containing cosmetics and talc intended for use in cosmetics. These scientific opinions and related advice are those of the SMEs to FDA[2] and do not represent recommendations or policies of FDA or any other federal agency, or proposed changes to any regulations of the U.S. Government.

Talc is a hydrous magnesium silicate mineral used in a wide variety of consumer products, including cosmetics. Some talc deposits may also contain asbestos and other magnesium silicate minerals, notably members of the amphibole group. Asbestos is a term used to describe some silicate minerals that have an unusual fibrous (asbestiform) habit of crystal growth. Asbestos historical and current use in some commodities is due to its commercially useful properties that include flexibility, durability, and heat resistance. However, asbestos is a known human carcinogen,[3] and its health risks are well-documented. Asbestos exposure can cause sequelae ranging from inflammation to pleural disease, lung cancers, and malignant mesothelioma.

In 1976, the cosmetics industry voluntarily implemented a protocol to test cosmetic talc for amphibole asbestos minerals using the Cosmetic, Toiletry, and Fragrance Association (CTFA) J4-1 method in response to test results indicating the presence of asbestos. Talc suppliers to the pharmaceutical industry use a similar method to certify that talc meets the United States Pharmacopeia's (USP's) requirement for "Absence of Asbestos." To date, both methods rely on screening techniques [X-ray diffraction (XRD) or infrared (IR) spectroscopy] and require optical microscopy [i.e., polarized light microscopy (PLM)] only if the screening test is positive. These two published protocols have long-recognized shortcomings in specificity and sensitivity to detect the presence of asbestos and similar mineral particles that may pose a health concern (see Appendix F). For example, recent testing of cosmetics by a private laboratory under contract with FDA[4] using transmission electron microscopy (TEM) revealed the presence of asbestos in samples that had negative findings for the same products using PLM, highlighting the shortcomings of optical microscopy methods. Thus, the Interagency Working Group on

[1] References to testing of talc in this document are to talc intended for use in cosmetics.
[2] See Appendix A.
[3] As classified by the International Agency for Research on Cancer (IARC), U.S. Environmental Protection Agency (EPA), and the U.S. National Toxicology Program (NTP) 14th Report on Carcinogens.
[4] See AMA Analytical Services, Inc. (AMA) testing results at FDA's Investigation of Reports of Asbestos Contamination in Cosmetics 2017-2019 tab at https://www.fda.gov/cosmetics/cosmetic-ingredients/talc.

Asbestos in Consumer Products (IWGACP) advises that electron microscopy-based methods are preferred where the objective is to determine if asbestos is present.

In 2018, FDA formed an IWGACP comprised of SMEs from eight federal agencies that have expertise in asbestos-testing and/or asbestos-related issues (e.g., from a health perspective), or that regulate asbestos or consumer products[5] that contain talc as an ingredient. The IWGACP was asked to develop a consensus document that would support the development of standardized testing methods to improve the sensitivity and consistency of analyses, and inter-laboratory concurrence when reporting asbestos and other amphibole mineral particles in talc that could potentially affect consumer product safety. The IWGACP focused on issues that have persisted for decades in asbestos testing and related terminology and definitions.

Through its deliberations, the IWGACP developed the following scientific opinions and related advice to help ensure reliable detection and comprehensive reporting of asbestos and other amphibole particles when testing cosmetic products containing talc and talc intended for use in cosmetics:

1. Use both PLM and TEM methods to identify/report, at minimum, the presence of asbestos, other amphibole minerals, and talc particles exhibiting non-platy morphology.

2. Tabulate, at minimum, all amphibole and chrysotile particles having a length ≥ 0.5 micrometer (μm) (500 nanometer (nm)) and a ratio of length to width, i.e., aspect ratio (AR), $\geq 3:1$ in talc-containing cosmetic products and talc intended for use in cosmetics, and avoid categorizing such particles as non-asbestiform when there is ambiguity as to habit of growth.

3. Scanning electron microscopy (SEM) can be used as a complementary method to TEM, but has certain limitations at this time.

4. TEM results should be reported by tabulating each particle[6] to facilitate an estimate of the number of particles per unit mass of sample analyzed (i.e., particles/gram of talc, particles/gram cosmetic product), rather than as weight percent.

5. An adequate number of TEM images that show the morphology of representative particles in each category described in #1 and an adequate number of energy dispersive spectroscopy (EDS) spectra and selected area electron diffraction analysis (SAED) patterns to support mineral identification should be provided.

[5] By "consumer products,", we are referring to products used by consumers, which are regulated by a variety of federal agencies. This includes, but is not limited to, "consumer products" as defined under the Consumer Product Safety Act (15 U.S.C. 2051 et seq.).
[6] Particles of the types specified in scientific opinion 1 meeting the dimensions specified in scientific opinion 2.

6. Samples should be prepared to mitigate interference from the sample matrix using techniques similar to those used for the testing of bulk materials for asbestos.

7. Content and format of analytical reports should facilitate consistent and comprehensive reporting of particles (as described in #1 and 2), in conjunction with adequate documentation of findings.

8. Policies and procedures covering rigorous training, quality assurance, and quality control should accompany the implementation of these methods to maintain intra- and inter-laboratory consistency and to ensure laboratories are qualified and their qualifications are reviewed regularly.

II. INTRODUCTION

In the fall of 2018, FDA formed the IWGACP in response to reports of the presence of asbestos in talc-containing cosmetic products with SMEs from eight federal agencies.[7] Since 2017, there have been several recalls of cosmetic products in the U.S.[8] and globally (Canada, Netherlands, Taiwan).[9] The IWGACP was asked by FDA to develop a consensus document that would support the development of standardized testing methods[10] to improve the sensitivity and consistency of analyses, and inter-laboratory concurrence when reporting asbestos and other mineral particles of health concern in talc that could potentially affect consumer's health from cosmetic use. In February 2020, FDA held a public meeting[11] and opened a docket in order to discuss and obtain scientific information on topics related to testing methodologies, terminology, and criteria that can be applied to characterize and measure asbestos and other potentially harmful elongate mineral particles (EMPs) that may be present as contaminants in talc and cosmetic products manufactured using talc as an ingredient.[12] At that meeting, IWGACP members presented preliminary recommendations on testing methods, including criteria to be used for asbestos fiber identification and counting. The IWGACP considered the public comments in drafting this white paper, the scope of which is specific to cosmetic products containing talc as an ingredient, as well as talc intended for use in cosmetics.

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[7] FDA, National Institutes for Occupational Safety and Health (NIOSH), National Institute of Health (NIH)/ National Institute of Environmental Health Sciences (NIEHS), Occupational Safety and Health Administration (OSHA), Environmental Protection Agency (EPA), Consumer Product Safety Commission (CPSC), and U.S. Geological Survey (USGS). The participating federal agencies have expertise in asbestos-testing and/or asbestos-related issues (e.g., from a health perspective), or because they regulate some of the consumer products that contain talc as an ingredient. As a non-regulatory science agency, the USGS SME provided input on scientific aspects of asbestos minerology, geology, and mineral terminology that informed the IWGACP opinions, but did not participate in the development of policy recommendations. The National Institute of Standards & Technology (NIST) is no longer a member of the IWGACP because their SME retired in 2020. In November 2020, the OSHA representatives ceased active participation. See Appendix L for list of the members of the IWGACP. The use of the terms "IWGACP" or "we" refers to the consensus opinion of the working group scientists and do not necessarily reflect the opinions or policies of their agencies.

[8] https://www.fda.gov/cosmetics/cosmetics-recalls-alerts/fda-advises-consumers-stop-using-certain-cosmetic-products; https://www.fda.gov/news-events/press-announcements/statement-fda-commissioner-scott-gottlieb-md-and-susan-mayne-phd-director-center-food-safety-and.

[9] Canada: https://healthycanadians.gc.ca/recall-alert-rappel-avis/hc-sc/2019/69454r-eng.php; Netherlands: https://www.ilent.nl/documenten/publicaties/2018/03/28/rapportage-twee-op-asbest-geteste-producten; Taiwan: https://focustaiwan.tw/society/201907270005 (accessed on 11/13/20).

[10] A "standardized testing method" is a published sample preparation and/or analytical methods developed by experts and arrived at by consensus.

[11] https://www.fda.gov/cosmetics/cosmetics-news-events/public-meeting-testing-methods-asbestos-talc-and-cosmetic-products-containing-talc-02042020-02042020. See https://www.regulations.gov/docket/FDA-2020-N-0025.

[12] https://www.govinfo.gov/content/pkg/FR-2020-01-10/pdf/2020-00259.pdf.

III. TALC AS A RAW MATERIAL

Talc is a hydrous magnesium silicate mineral that is used in a wide variety of consumer products, including cosmetics, conventional foods, dietary supplements, drugs, paints, ceramics, paper products, and art materials. Some types of talc deposits may also contain asbestos and other magnesium silicate minerals—notably members of the amphibole group. Chrysotile (a serpentine mineral) and several types of amphibole minerals (such as tremolite, anthophyllite, and actinolite[13]) have sometimes been found in talc-containing cosmetic products. Removal of chrysotile and amphibole minerals by purification of talc ores is extremely difficult. Thus, it is necessary to judiciously select talc deposits that do not contain asbestos[14] and other amphibole mineral particles of potential health concern prior to mining talc for use in cosmetic products. In addition, appropriate testing methods are needed to monitor the mineral composition and purity of mined talc ores to ensure their suitability for use in talc-containing cosmetic products. (See ***Appendices B, C and F.***)

IV. ASBESTOS DEFINITIONS

There are many definitions of "asbestos" used in the commercial, geological, and regulatory domains (Lowers and Meeker 2002). Mineralogists define "asbestos" as those silicate minerals belonging to the serpentine and amphibole groups that have an unusual fibrous (asbestiform) crystal growth habit (as opposed to non-asbestiform, alternative habits of crystal growth). As a commercial term, "asbestos" refers to the group of six minerals, defined below, which have been mined and processed due to their commercially useful properties, including flexibility, durability, and heat resistance. U.S. asbestos regulations and the test methods required to establish regulatory compliance specify each regulated type of asbestos using mineral and commercial nomenclature. U.S. regulations specify the following six minerals, which historically have been used in commerce: chrysotile (a member of the serpentine group) and five species of the amphibole mineral group, specifically asbestiform riebeckite (also known as "crocidolite"), asbestiform grunerite-cummingtonite (also known as "amosite"), tremolite asbestos, actinolite asbestos, and anthophyllite asbestos. (See ***Appendices D and G.***)

There are various instructions for quantifying asbestos in federal regulations and published protocols concerned with asbestos testing (see ***Appendix F.5***). After some discussion, the IWGACP members concluded that instructions for recording and quantifying asbestos during testing of cosmetic grade talc are needed.

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[13] Some third-party laboratories (not under contract to FDA) have reported findings of the amphibole minerals richterite and winchite in cosmetics to FDA. These results have not been independently verified.

[14] In some talc deposits, asbestos minerals can naturally co-occur as trace constituents and/or in the rocks adjacent to the talc deposit; it is not intentionally added during processing, but is very difficult to remove. The IWGACP believes "contaminant" or "impurity" can be used to describe this presence of asbestos in a talc-containing cosmetic product or in talc intended for use in cosmetics.

The problem of inconsistent terminology has persisted since laboratories began to test for asbestos. Lowers and Meeker (2002) published a glossary bringing to light the multitude of definitions in use. Therefore, the IWGACP developed a glossary (see **Section XVI**.) of key terms that are valuable in resolving some of the issues associated with analytical characterization of "asbestos," "asbestiform fibers," and other mineral particles of concern based primarily on definitions that appeared in the NIOSH Current Intelligence Bulletin 62 (the "Roadmap," 2011), ISO 10312, Campbell et al. (USBM) 1977, and the EPA (2014) assessment for Libby amphibole asbestos.

V. HEALTH EFFECTS OF ASBESTOS AND OTHER AMPHIBOLE MINERALS

Asbestos is a known human carcinogen, and its health risks are well-documented. There is general agreement among U.S. federal agencies, most developed nations, and the World Health Organization (WHO) that there is no established threshold for adverse health effects from asbestos exposure. Following exposure by inhalation or ingestion, asbestos can cause sequelae ranging from inflammation to pleural disease, lung cancer, and mesothelioma. These effects rarely occur acutely, but more often occur many months or years following exposure. Exposure to asbestos may also lead to diseases in other parts of the body that are remote from the sites of primary exposure, including cancers of the larynx, gastrointestinal tract, and ovaries. In addition, irreversible formation of scar-like tissue in the lung has been associated with exposure to biologically persistent, elongate mineral particles that can be formed in the milling process to reduce talc particle size. (See ***Appendix E.***)

VI. METHODS FOR CERTIFYING THAT TALC DOES NOT CONTAIN ASBESTOS

Concern about the purity of talc used as a cosmetic raw material increased as a result of well-publicized reports in the 1960s and 1970s when numerous cosmetic products tested positive for asbestos.[15] However, at that time, there were no published test methods applicable to trace levels of asbestos in talc. In 1976, in consultation with its suppliers of talc, the cosmetics industry implemented a voluntary method for asbestos-testing of talc raw materials, known as the Cosmetic, Toiletry, and Fragrance Association (CTFA) J4-1 method. This method directs manufacturers to test for asbestiform amphibole minerals and has a stated nominal limit of detection of 0.5% by weight for amphiboles using a preliminary screen by XRD. (The method does not test for chrysotile.) If the XRD test is positive for the presence of amphibole(s), then PLM is used to determine if asbestiform amphibole is present. The J4-1 method, which has been supported by industry, has not been updated since 1976. Today, talc suppliers to the pharmaceutical industry use a similar two-step method to certify that talc meets the United States Pharmacopeia's (USP's) requirement for "Absence of Asbestos." The USP method allows the

[15] See Cralley et al., 1968; Rohl and Langer, 1974, 1976; Paoletti et al., 1984.

testing laboratory to use XRD or infrared (IR) spectroscopy to screen for amphibole or serpentine (a possible indication of chrysotile) minerals. Optical microscopy is used to determine if asbestiform amphibole or chrysotile is present only if the XRD or IR test is positive (See ***Appendix F***).

The CTFA J4-1 and USP methods remain the only published test methods for talc used in cosmetics and pharmaceuticals, respectively, despite long-recognized shortcomings in specificity and sensitivity compared with electron microscopy-based methods (Millette, 2015; Block et al. 2014). In 2010, FDA asked the USP to consider revising the current tests for asbestos in pharmaceutical talc to ensure adequate specificity (Woodcock, 2010), and, in 2014, the USP Talc Expert Panel provided recommendations toward requiring that optical microscopy be used even if XRD is negative (Block et al. 2014). In September 2020, USP issued a draft document for public comment describing round robin studies evaluating revised XRD and PLM methods (Rutstein et al. 2020). Currently, the published talc quality standards do not include TEM methods for asbestos testing for cosmetic or pharmaceutical talc, despite acknowledgement of its utility.[16,17]

VII. COMPARISON OF PLM AND TEM TESTING METHODS

PLM and TEM can be applied to detect asbestos in talc and talc-containing cosmetic products. PLM can detect large complex asbestos structures (*i.e.*, fibers present as bundles and clusters) and is generally less time-consuming to perform than TEM. However, PLM has limited ability to resolve structures that are <5 µm in length and/or where any dimension of the particle is below approximately 0.2 µm. TEM, on the other hand, can detect these smaller, thinner particles. Thus, due to these differences in resolution and sensitivity, TEM has a limit of detection that is several orders of magnitude lower than PLM.[18] Recent reports from testing of cosmetic products commissioned by FDA have corroborated the need to use TEM when PLM does not detect asbestos. For example, in 2019, tremolite and/or chrysotile asbestos was reported in nine cosmetic products analyzed by TEM; however, seven of the nine products were reported as "not detected" by PLM.[19] Today, most accredited laboratories with expertise in asbestos-testing routinely perform TEM when testing talc-containing cosmetic products, and do not rely solely on PLM.[20]

[16] See https://www.uspnf.com/notices/talc-nitr-20200731.
[17] See https://www.astm.org/DATABASE.CART/WORKITEMS/WK30039.htm.
[18] Based on calculated analytical estimates of asbestos detected by the two methods.
[19] See FDA Summary of Results from Testing of Official Samples of Talc-Containing Cosmetics for Asbestiform Fibers by AMA Laboratories During Fiscal Year 2019. Available at: https://www.fda.gov/media/135911/download.
[20] See public presentations from February 4, 2020 public meeting. https://www.fda.gov/cosmetics/cosmetics-news-events/public-meeting-testing-methods-asbestos-talc-and-cosmetic-products-containing-talc-02042020-02042020.

VIII. APPLICATION OF PUBLISHED ASBESTOS TEST METHODS TO TALC-CONTAINING COSMETICS

The absence of a standardized testing method for the analysis of asbestos in talc and talc-containing cosmetic products has led many analytical laboratories to combine and/or adapt published test methods developed for the analysis of asbestos in air or building materials. This could, at least in part, account for discrepancies in laboratory findings.

Microscopy analytical methods for asbestos in published standards (see ***Appendix F.5***) typically contain instructions designating how to prepare samples for analysis and how to identify and quantify asbestos. Instructions for preparing bulk and air samples and quantifying asbestos vary widely among testing methods and regulations. Methods based on optical microscopy [PLM or phase contrast microscopy (PCM)] were, in part, designed to ensure interlaboratory agreement for compliance with regulatory standards. One drawback of quantifying asbestos based on optical microscopy methods is that they typically exclude reporting of particles that are shorter than 5 μm in length and/or less than approximately 0.2 μm in width.

As a technique, optical microscopy methods, such as PLM and PCM, have limitations. They are sufficient for detecting >1% by weight asbestos as an intentionally added ingredient in "bulk materials,"[21] or to assess air quality in settings where asbestos was known to be present (e.g., mines, mills, factories, building construction, insulation, and fireproofing products used in buildings such as schools, and other settings). However, optical microscopy has much less utility when asbestos is present as a trace mineral (i.e., contaminant) such as in talc or talc-containing cosmetic products, where it may be present at several orders of magnitude less than 1% by weight. In this instance, the asbestos particles may be too small to be detected using optical microscopy as demonstrated in recent cosmetic testing conducted for FDA.[22] In light of the shortcomings of PLM, the IWGACP considers electron microscopy methods – particularly TEM – to play an indispensable role in the analysis of cosmetic products containing talc and for talc intended for use in cosmetics for asbestos and other amphibole particles (as described in #1 and 2).

[21] Bulk materials are those dry materials which are powdery, granular, or lumpy in nature. Examples include ores, refined minerals, and mill products.

[22] See FDA Summary of Results from Testing of Official Samples of Talc-Containing Cosmetics for Asbestiform Fibers by AMA During Fiscal Year 2019. https://www.fda.gov/media/135911/download and for example, AMA Analytical Services, Inc. Summary of Asbestos and Talc Analysis (PDF - 2MB) April 30, 2019.

IX. SAMPLE PREPARATION FOR COSMETICS CONTAINING TALC AND TALC INTENDED FOR USE IN COSMETICS

The optimal analytical approach should address potential interference by sample matrices and thereby maximally ensure detection whenever asbestos is present. Historically, laboratories have used techniques described in asbestos-testing standard methods (e.g., ISO, ASTM, EPA, OSHA) to remove interfering materials, the most common of which involve heating to remove moisture and organic matter (ashing) and acid digestion to solubilize carbonates. The IWGACP agrees these techniques are appropriate for testing cosmetics, based on established understanding of the thermal and chemical properties of talc, chrysotile, and the amphibole minerals. Moreover, the IWGACP cites additional sample preparation methods that can be used to separate chrysotile and amphibole minerals from talc and talc-containing sample matrices (see ***Appendix J***). Reproducible application of these sample preparation methods requires an understanding of the sources of variability followed by interlaboratory assessments to support the repeatability and reliability.

X. DIMENSIONAL CRITERIA AND TERMINOLOGY FOR TABULATING ASBESTOS AND AMPHIBOLE PARTICLES

Published methods (see ***Appendix F.5***) instruct laboratories to report and quantify asbestos using criteria for particle length and ratio of length to width, i.e., aspect ratio (AR). However, only a fraction of the total population of asbestos is reported and documented. After review of recent asbestos particle population distribution data in cosmetic products, the IWGACP concluded that reporting of asbestos particles is more comprehensive if laboratories tabulate all asbestos and amphibole particles ≥ 0.5 µm in length, with an AR of ≥ 3:1. The IWGACP initially adopted the term EMP, as defined in NIOSH Bulletin 62 (2011), to describe mineral particles exhibiting an AR of ≥ 3:1.[23] The term EMP provides an umbrella term for amphibole particles that may pose a health risk, regardless of how they formed.[24] The IWGACP notes that amphibole particle populations often exhibit variation in appearance and that laboratories may describe amphibole particles using terms such as "prismatic," "acicular," "cleavage fragment," and "asbestiform." The IWGACP believes the term "EMP" could help resolve discrepancies in the reporting of amphibole particles, and most importantly, that it would ensure more inclusive reporting by laboratories.

[23] The term "EMP" had been subjected to substantial scientific debate, peer review, and public comment prior to being adopted in NIOSH Bulletin 62 (2011). The IWGACP considers "EMP" to be a scientifically-preferred term, negating the need for the creation of a new phrase or acronym to describe mineral particles with an AR of ≥ 3:1. NIOSH defined a *countable EMP* as a particle having "(1) an aspect ratio of 3:1 or greater and (2) a length greater than 5 µm."

[24] An explanation of amphibole mineral geology (formation) and the resulting variations in particle morphology is provided in Appendix D.

However, based on public comments that use of "EMP" might be overly broad,[25] the IWGACP focuses on reporting particle dimensions (i.e., minimum length and AR) when discussing testing.[26] The IWGACP endorses the use of complementary microscopy methods (PLM, TEM) to establish a comprehensive and standardized record of asbestos and amphibole mineral particles present in cosmetic products that affect product safety and could be associated with both non-cancer and cancer diseases.

XI. DETERMINING HABIT OF GROWTH OF AMPHIBOLE MINERALS

The difficulty of identifying and quantifying amphibole asbestos particles in talc is compounded by the potential presence of amphibole particles that have the same elemental composition and crystal structure as one of the asbestos minerals but may have originated from their non-asbestiform analogues. (See ***Appendix D***.) The characteristic feature of an "asbestos structure" is the "bundle" consisting of multiple particles that may show definitive characteristics of asbestos particles such as splaying or longitudinal splitting at either end of the structure. However, asbestos structures are less readily identifiable after extensive processing that can result in attrition, such as milling of talc to produce cosmetics. In the milling process, non-asbestos amphibole particles in the ore can be reduced in size, resulting in particles that may look like asbestos.

EPA's regulations promulgated under the Asbestos Hazard Emergency Response Act (AHERA)[27] and ISO 10312:2019 standards for TEM analysis of asbestos offer some visual aids to assist the analyst for classifying various types of asbestos structures containing one or more asbestos fibers (***Appendix F***). However, as stated in the ISO TEM test method for asbestos (ISO 10312:2019), TEM methods cannot readily discriminate between individual particles of asbestos and non-asbestos analogues of the same amphibole mineral. [28] As a result, disputes have often arisen between laboratories over whether amphibole particles detected by TEM are to be regarded as "asbestos" or as products of the attrition of a non-asbestiform analog. Indicative of ambiguity as to their habit of growth, amphibole particles having an AR $\geq$ 3:1 viewed by TEM may appear to have blunt or sharp ends; such particles have been ascribed as being "asbestiform"

[25] https://www.regulations.gov/docket/FDA-2020-N-0025. Several comments submitted to the docket for the "Testing Methods for Asbestos in Talc and Cosmetic Products Containing Talc," expressed concern that the term "EMP" is too broad, expands the definition of asbestos, and may have additional unintended implications when used for testing talc-containing cosmetic products.

[26] These exclude man-made fibers (such as synthetic vitreous fibers, SVFs) that are unlikely to be present in talc-containing cosmetic products.

[27] 40 CFR Part 763.

[28] The inability to discriminate asbestiform from elongate non-asbestiform amphibole particles is stated in the Scope Section of TEM Methods in ISO standards 10312:2019 and 13794:2019. There is no indication of consensus among published standard methods or in the peer reviewed scientific literature on optimal boundaries (i.e., length, width, aspect ratio) to apply to differentiate habit of growth.

or alternatively "non-asbestiform," perhaps using mineralogical terms such as "bladed," "acicular," or the term "cleavage fragment" indicating a particle that was derived from attrition of a prismatic crystal. (See ***Appendix D.***) In contrast, for chrysotile, which crystallizes as a scrolled, hollow tube as asbestos, characterizing individual fibers as "asbestiform" by TEM is not subject to the same difficulties as encountered for amphibole mineral particles.

XII. IDENTIFICATION AND REPORTING OF ASBESTOS AND AMPHIBOLES IN TALC-CONTAINING COSMETICS AND TALC INTENDED FOR USE IN COSMETICS

Generally, asbestos-testing of talc and talc-containing cosmetic products involves multiple, complementary methods of analysis, which collectively provide information regarding the following three aspects of mineral identification:

(a) elemental composition,
(b) crystal structure, and
(c) morphology of minerals in either talc or a talc-containing cosmetic product.

XRD is useful to analyze bulk samples (e.g., talc); whereas microscopy methods listed below are useful to analyze individual mineral particles (e.g., amphibole and chrysotile). **Table 1** summarizes the attributes, measurements obtained and utility of each of the analytical methods the IWGACP considers relevant for the testing of a sample of talc or talc-containing cosmetic product. (See ***Appendix B.***)

Table 1 – Summary of Useful Analytical Techniques and Corresponding Attributes and Measurements to Analyze Talc and/or Talc-containing Cosmetics

Technique	Attribute to Report	Measurement and Utility
XRD	Mineral (group) type (e.g., amphibole, serpentine, chlorite)	Identity and estimate of amounts of mineral types in a bulk sample (e.g., talc); appears most useful as a qualitative method to determine presence/composition of minerals and reporting estimated amounts of each mineral using terms such as "trace," "minor," and "major"
PLM	Particle mineral type including any applicable inference to growth habit based on morphology (e.g., tremolite asbestos, chrysotile, asbestiform winchite-richterite)	Representative images useful to identify (with greater specificity than XRD) mineral type (based on particle optical characteristics) and morphology; may be used to quantify or estimate amount of each mineral type (see "point counting" methods); particle morphology (i.e., "bundles of sticks"[29]) may be indicative of "asbestiform" habit; regarded to have limited or no utility for detection of chrysotile in talc or talc-containing cosmetics
TEM	Particle morphology	Representative images showing morphology (in conjunction with SAED can be diagnostic for chrysotile) accompanied by tabulations showing each mineral particle's length and width (and calculated aspect ratio)[30]
TEM/EDS	Elemental composition of particles	Representative spectra and tabulations indicating which elements (e.g., Calcium (Ca), Magnesium (Mg), Silicon (Si), Iron (Fe), Oxygen (O), etc.) are present; semi-quantitative analysis of elemental composition is used in conjunction with TEM/SAED to help identify mineral type
TEM/SAED	Crystal structure of particles	Representative electron diffraction patterns showing spacing of atoms are generated; quantitation of distances between atoms and adjacent planes of atoms in crystal is used in conjunction with TEM/EDS to help identify mineral type; at least two zone axis measurements (from different angles) may be necessary to identify certain minerals
SEM	Particle morphology	Representative images and tabulations of particle length, width (aspect ratio); may provide enhanced visual detail (to supplement TEM) useful to determine if a particle is "asbestiform"
SEM/EDS	Elemental Composition of particles	Representative spectra and tabulations indicating which elements (e.g., Ca, Mg, Si, Fe, O, etc.) are present; semi-quantitative analysis of elemental composition.

XRD may be useful to characterize overall mineral composition in talc and ores that serve as a source of talc, but does not appear to be a useful method for detecting low levels of asbestos in talc and talc-containing cosmetics and does not provide individual particle analysis.

[29] See CTFA J4-1 for description of morphology of amphibole asbestos.
[30] Numerical values of particles counted and number of amphiboles and chrysotile detected should be reported.

PLM is an essential method for the detection of small mineral particles in products and can be used to discriminate minerals based on crystal structure using index of refraction liquids. PLM offers the advantage of inspecting a larger sample size than electron microscope analysis, albeit at much reduced resolution. A finding of bundles of particles by PLM indicates that, if sufficient sample is examined, individual particles will be found by TEM also; however, a negative finding by PLM cannot predict a negative finding by TEM. The IWGACP regards PLM as having substantial limitations in its ability to detect, resolve, and identify individual particles of asbestos and other amphibole minerals that are $\leq$ 5 µm in length with AR $\geq$ 3:1.

TEM should be used to analyze individual particle elemental composition with Energy Dispersive Spectroscopy (EDS) and crystal structure with Selected Area Electron Diffraction Analysis (SAED). TEM is able to resolve particles having length $\geq$ 0.5 µm and AR $\geq$ 3:1. As noted earlier, EPA's regulations promulgated under AHERA and ISO 10312:2019 standards for TEM analysis of asbestos offer some visual aids to assist the analyst in classifying the various types of asbestos structures (***Appendix F,*** **Figure F.5**).

SEM has the advantages of scanning large areas of sample at low- to high-magnification, providing surface and three-dimensional imaging. SEM can be used to obtain semi-quantitative elemental analysis of individual particles using EDS and also supports electron-microprobe analysis for elemental analysis. SEM does not currently support SAED analysis of individual particles, which is critical for crystal structure determination, although there is recent research into determination of crystal structure using electron backscatter diffraction cameras. For these reasons, the IWGACP acknowledges that SEM may be useful as an adjunct to TEM (**Figure 1**).

XIII. ISSUES RELATED TO SAMPLE QUANTITY AND ANALYTICAL SENSITIVITY

The amount of sample prepared for analytical determinations by PLM, XRD, and TEM should be appropriate for each of these respective methodologies and be representative of the talc-containing cosmetic product.

Several factors affect the limit of detection for asbestos testing, including analytical method (XRD, PLM, TEM, SEM), sample preparation (including removal of interfering materials, concentration methods like heavy liquid separation [HLS]; see ***Appendices I and J***), and the number of electron microscopy grid openings counted. Counting a larger number of grid openings results in greater test sensitivity, i.e., a lower detection limit. The limit of detection should be as low as possible to ensure that any asbestos particles present are detected.

Current testing by AMA[31] on behalf of FDA using PLM has a limit of detection based on a single structure of asbestos on the order of 0.1-0.2% by weight. From this testing, it appears that

[31] AMA Analytical Services, Inc. in Lanham, MD, see for example, limit of detection at https://www.fda.gov/media/135901/download.

PLM may only be useful for detecting structures consisting of bundles of individual particles. For TEM analysis used by AMA, the limit of detection for asbestos in talc-containing cosmetics is on the order of approximately 10,000,000 particles/gram based on a single particle having a length of 0.5 microns and a width of 0.04 microns (approximately four orders of magnitude lower than the detection limit for PLM).

The IWGACP believes that these matters warrant further discussion. Published methods to test for asbestos by TEM provide general guidelines for particle counting that seem to be based on laboratory efficiency and time management. Many laboratories, including AMA, routinely view 20 grid openings and count up to 100 mineral particles (maximum) as a stopping point for TEM analysis.

XIV. SCIENTIFIC OPINIONS ON TESTING APPROACH

To have a comprehensive assessment, the IWGACP advises that the development of a standardized approach should include both optical and electron microscopy, with the reporting of all asbestos and other amphibole mineral particles meeting dimensional criteria detected in talc and talc-containing cosmetic products. Product sampling and sample preparation should be consistent with established methods (e.g., EPA, OSHA, NIOSH, ASTM, ISO) for the reliable and reproducible detection of asbestos in products. The IWGACP considers it important that written protocols specify appropriate instruments, methods, and reporting criteria. Such an approach for inclusive reporting will enhance transparency and help to provide a cumulative record of mineral particles, thereby facilitating more well-conceived health-based decisions about cosmetic product safety. The approach ensures reporting of mineral particles that can be inhaled into the lungs and potentially be harmful from use of a cosmetic product, regardless of how they formed (i.e., in the earth or during cosmetic raw material milling). The health effects, although discussed generally to support the particle characteristics that laboratories report, were not the primary focus of this work group's activities.

In conclusion, the IWGACP provides the following scientific opinions and related advice with respect to testing talc intended for use in cosmetics and cosmetics that contain talc as an ingredient:

1) Use both PLM and TEM[32] methods to identify/report at minimum,[33] the presence of the following types of particles:
    a. amphibole minerals defined as asbestos in federal regulations[34]
    b. other amphibole minerals [35]
    c. chrysotile
    d. particles that contain talc and an amphibole[36]
    e. talc particles exhibiting non-platy morphology[37] (e.g., particles appearing as curved plates, or ribbons)

Rationale: Chrysotile, which can be identified using TEM based on its scrolled, hollow structure, should be reported separately from amphiboles. Amphibole minerals can be subcategorized based on chemistry and crystal structure as, e.g., tremolite, anthophyllite, actinolite, winchite, richterite, or "other."

Talc may exhibit a non-platy morphology (see ***Appendix C***). Certain non-platy particles of talc, having mixed compositions (see 1.d) and "fibrous" morphology have been reported in the literature. The IWGACP advises reporting talc particles exhibiting non-platy morphology,[38] which would include "fibrous talc," under categories described in 1.d and 1.e. Specifically, laboratory bench sheets should record non-platy talc particles, such as those with unusual particle shapes or compositions inconsistent with "platy talc." Additionally, the IWGACP advises using dual zone-axis SAED to avoid potential mischaracterization of non-platy talc particles as amphibole particles.

[32] PLM identifies particles based on optical properties. See, e.g., Mineral Database in Dyar and Gunter, "Mineralogy and Optical Mineralogy." PLM should follow existing guidelines, for example OSHA Method ID-191 specifies 160-400x. TEM identifies particles by comparison with chemical (EDS) and crystallographic (SAED) properties exhibited by reference materials.
[33] Laboratories may identify additional minerals, which include common accessory and serpentine minerals in talc (see Appendix C on talc geology and description of talc); the IWGACP considers it important that laboratory reports contain a description and identification of mineral particles.
[34] The five amphiboles that are defined as asbestos are: asbestiform riebeckite (crocidolite), asbestiform grunerite-cummingtonite (amosite), tremolite asbestos, actinolite asbestos, and anthophyllite asbestos. See definitions in 40 CFR § 763.83 and 763.163; 29 CFR § 1910.1001(b).
[35] Other amphibole species cited in mineralogical references, such as Deer, Howie, and Zussman https://www.minersoc.org/DHZ.html, IMA (https://www.ima-mineralogy.org/Minlist.htm), or Hawthorne and Oberti, 2007.
[36] Various terms (e.g., intergrowth, intermediate talc fiber, transitional fiber, talcbole, and biopyribole) have been used to describe particles composed of talc and amphibole, in various proportions. Such particles are not definable as a distinct mineral.
[37] This category excludes platy talc particles viewed perpendicular to their narrowest dimension.
[38] Talc morphology is described as platy or lamellar (see e.g., Fiume, et al,. 2015; and Campbell et al. 1977, Figure 21). Non-platy talc particles exclude platy talc particles viewed perpendicular to their narrowest dimension.

2) Tabulate, at minimum, all amphibole and chrysotile particles (see 1a, 1b, 1c, and 1d) having a length ≥ 0.5 µm (500 nm) and an AR ≥ 3:1 by indicating respective length, width, and mineral type[39] in talc and talc-containing cosmetic products, and avoid categorizing such particles as non-asbestiform when there is ambiguity as to habit of growth (e.g., whether the particle is asbestos or the result of attrition of a non-asbestiform amphibole).

Rationale: The AR ≥ 3:1 is consistent with the NIOSH Bulletin 62 (2011) and the current regulations[40] for counting asbestos by light microscopy by OSHA Method ID-191. Reporting of particles ≥ 0.5 µm in length is consistent with the rules for identification and counting established by the global standard for TEM sampling and analysis, ISO 10312:2019,[41] and by the 1987 Federal AHERA standards[42] for protecting children from asbestos in public and private elementary and secondary school buildings. Many studies indicate that asbestos and other mineral particles < 5 µm in length could pose a health concern (see ***Appendix E***). Reporting such particles can reduce interlaboratory variation associated with ambiguity in determining the habit of growth of amphibole minerals and reduce the need for laboratory analysts to apply subjective criteria for such characterization. This approach ensures the size range of mineral particles suspected of contributing to pleural disease and cancer are reported consistently and objectively.

The IWGACP acknowledges that differential counting for the purpose of classifying amphibole mineral particles into asbestiform and non-asbestiform types using TEM images[43] is often difficult (and is inconsistently applied). The IWGACP advises against categorizing particles using terms such as "cleavage fragment," "bladed," or "acicular" to imply these are not asbestiform when there is ambiguity as to a particle's habit of growth. In addition, the IWGACP advises careful use of the term "fiber" because it is defined as a type of asbestos structure in various asbestos testing standards and may mispresent a particle as an "asbestos fiber."

The IWGACP considered whether a criterion for particle width could be established to distinguish asbestiform and non-asbestiform amphibole mineral populations. However, the

[39] Laboratories should at least report whether each particle is chrysotile or amphibole, and subcategorize amphibole particles as tremolite, anthophyllite, actinolite, winchite and richterite, or other. Testing laboratories should identify minerals using naming conventions from authoritative references. The term amphibole may be used when an amphibole mineral particle's identity is ambiguous. This would exclude man-made fibers (such as synthetic vitreous fibers, SVFs), that are unlikely to be present in talc-containing cosmetic products.
[40] 29 CFR § 1910.1001(b).
[41] https://www.iso.org/standard/75577.html.
[42] 40 CFR Part 763.
[43] See ISO 10312:2019 Scope section.

IWGACP did not arrive at a unanimous conclusion regarding the utility of grouping of particles by width.

3) Use a combination of PLM with dispersion staining and TEM[44] with EDS and SAED to achieve the sensitivity and specificity to detect and identify mineral particles as described in # 1 and 2 above (see **Figure 1**).

Rationale: This approach will maximize the likelihood of detecting pertinent particles in different size ranges and ensuring interlaboratory agreement on identity of the mineral types when the objective is to detect the presence of asbestos and/or amphibole particles in talc or a talc-containing cosmetic product. The IWGACP advises using TEM even if the findings of PLM are negative, which is consistent with the opinion of many scientific experts (Rohl and Langer, 1974; Millette, 2015; Block et al. 2014). The IWGACP advises using TEM at nominally 20,000x magnification, with EDS and SAED analyses to reliably detect and identify chrysotile and amphibole minerals, including particles too narrow (<0.2 μm wide) to be resolved by PLM. See **Figure 1**. SEM could be useful as a complementary method but has shortcomings due to its inability to obtain diagnostic electron diffraction patterns or observe the inner hollow structure of chrysotile.

4) TEM results should be reported by tabulating each particle[45] to facilitate an estimate of the number of particles per unit mass of sample analyzed (i.e., particles/gram of talc, particles/gram cosmetic product), rather than as weight percent.[46]

5) An adequate number of TEM images that show the morphology of representative particles in each category (as described in # 1), an adequate number of EDS spectra and SAED patterns to support mineral identification, and descriptions of each particle using the terminology included, for example, EPA's regulations promulgated under AHERA and Annex C of ISO 10312:2019, should be provided (see ***Appendix F***).

[44] Unless the sample is rejected due to prior detection of asbestos with XRD or PLM; see **Figure 1**. The TEM should be capable of accelerating electrons with 100-120 kV for penetration of all possible asbestos and amphibole particles, and an EDS analysis that can detect and quantify sodium (Na). TEM must produce accelerated electrons with enough energy to penetrate the particle object and produce diffracted electrons. The accumulation of X-rays for EDS should be sufficient for elemental identification and rapid enough to avoid loss of cations (e.g., Na^{+}) and change or loss of structure.

[45] Particles of the types specified in # 1 meeting the dimensions specified in # 2.

[46] The IWGACP concludes that reporting as weight percent can be misleading, especially for TEM analysis of talc-containing cosmetics where widths of particles can vary by well over an order of magnitude. Also, weight percent does not necessarily correlate with the number of particles, because one large particle could dominate the weight percent value.

6) Samples should be prepared to mitigate interference from the sample matrix using techniques similar to those used for the testing of bulk materials for asbestos (see section XIII).

7) The content and format of analytical reports should facilitate consistent and comprehensive reporting of particles (as described in # 1 and 2), in conjunction with adequate documentation of findings[47] (see ***Appendix K***).

8) Policies and procedures covering rigorous training, quality assurance, and quality control accompany the implementation of these methods to maintain intra- and inter-laboratory consistency and to ensure laboratories are qualified and their qualifications are reviewed regularly (timeframe depends on organization) (see ***Appendix H***).

An analytical approach that integrates the methods discussed in this white paper is shown below in **Figure 1.**

[47] Considerations of content and preferred format for laboratory reports are described in Appendix K.

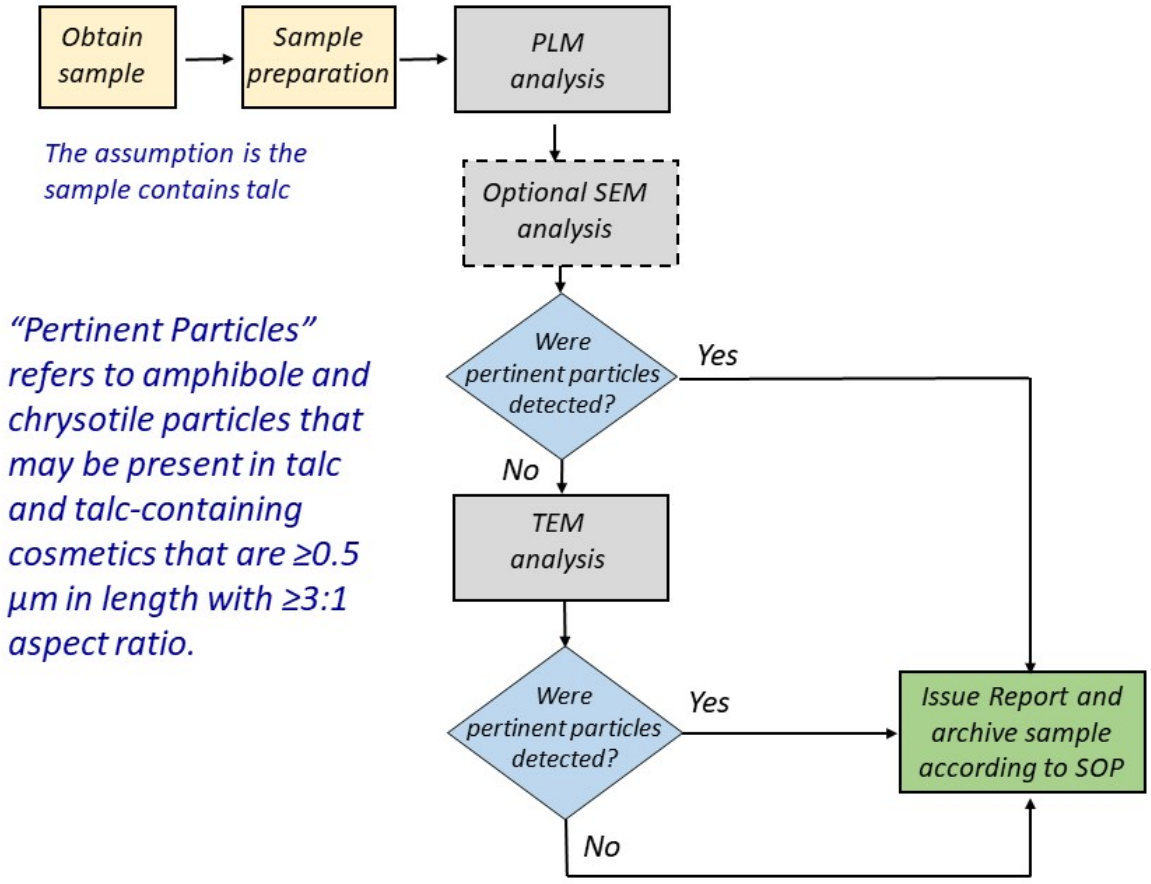

FIGURE 1. Integrated approach to analysis of talc and talc-containing cosmetics for the presence of asbestos and other mineral particles. "Pertinent particles" are defined as any amphibole or chrysotile particle with a length ≥ 0.5 µm and a minimum AR of 3:1. The **SAMPLE** would include talc or talc-containing cosmetic products. **Sample Preparation** is any preparation (e.g., mixing for homogeneity, removal of moisture, removal of organic material, concentration of mineral particles from the sample) of a representative sample. This process may be different for talc or talc-containing cosmetics. If amphiboles or chrysotile are present in the sample using **PLM**, the analyst should conclude the sample contains these particles ("Yes") and report the observation (record data). No further analysis may be required. If PLM results are negative ("No"), electron microscopy *should be* performed. The sample may be analyzed by **SEM** (optional) but *should be* analyzed by **TEM** to achieve the analysis requirements to measure and identify amphiboles and chrysotile at ≥ 0.5 µm length with AR ≥ 3:1. The analyst is expected to report the quantification and mineral identification of amphiboles, chrysotile, and other mineral particles meeting the criteria of ≥ 0.5 µm length with AR ≥ 3:1.

XV. NEXT STEPS AND FUTURE RESEARCH

The IWGACP has identified the following as areas for directing research efforts to promote reliability, sensitivity, and interlaboratory agreement of the analytical methods for asbestos and other mineral particles of potential health concern in talc-containing cosmetic products and talc intended for use in cosmetics:

1. Research and development of sampling methods specific for talc and talc-containing cosmetics that maximize sample representativeness and minimize error, false positives, and false negatives for amphibole and chrysotile particles.

2. Research and development of methods for talc and talc-containing cosmetic sample preparation, in particular, treatments (e.g., concentration methods) that improve sensitivity while leaving talc and asbestos minerals unchanged with respect to identity and dimensions.

3. Studies of protocols developed based on above numbers 1 and 2 to establish interlaboratory agreement.

4. Development and qualification of reference materials that can be used to assess laboratory and analyst proficiency, increase inter-laboratory concurrence, minimize reporting errors, and potentially provide for improved reliability of quantitative analysis. Development of appropriate talc-specific reference standards containing known concentrations of characteristic amphibole and chrysotile mineral particles found in talc (of known size distributions) would be ideal for method development and quantitation.

The IWGACP recommends that FDA participate in efforts to address the identified research needs, including collaborating with standard development organizations (e.g., USP, ASTM, ISO) when possible.

XVI. GLOSSARY OF TERMS

Actinolite: Actinolite is an amphibole silicate mineral with the chemical formula $\square Ca_2(Mg_{4.5\text{-}2.5}Fe^{2+}_{0.5\text{-}2.5})Si_8O_{22}(OH)_2$. Actinolite is an intermediate member in a solid-solution series between tremolite, $\square Ca_2(Mg_{5.0\text{-}4.5}Fe^{2+}_{0.0\text{-}0.5})Si_8O_{22}(OH)_2$, and iron-rich ferro-actinolite, $\square Ca_2(Mg_{2.5\text{-}0.0}Fe^{2+}_{2.5\text{-}5.0})Si_8O_{22}(OH)_2$. The asbestiform variety is referred to as actinolite (International Mineralogical Assoc., https://ima-mineralogy.org/Minlist.htm; some information adapted from Handbook of Mineralogy and www.mindat.org; last accessed on 26 Oct 2020; see http://www.handbookofmineralogy.org/pdfs/actinolite.pdf for more information).

($\square$ is a site vacancy in the crystal structure; International Mineralogical Association, https://ima-mineralogy.org/Minlist.htm)

Amosite: Amosite is an acronym for Asbestos Mines of South Africa, a trade name for the commercial amphibole asbestos belonging to the cummingtonite-grunerite solid solution series, commonly from South Africa.

Amphibole: A group of double-chain silicate (i.e., inosilicate) minerals having the general chemical formula $AX_2Z_5((Si,Al,Ti)_8O_{22})(OH,F,Cl,O)_2$ due to possible variations in atomic substituents at positions in the crystal. Some minerals in this group can occur in non-fibrous and fibrous varieties. (See https://www.mindat.org/min-207.html; last accessed on January 5, 2021.)

Anthophyllite: An amphibole mineral with the chemical formula $\square Mg_2Mg_5Si_8O_{22}(OH)_2$ [$\square$ is a site vacancy in the crystal structure; iron commonly substitutes for some magnesium in the mineral]. The asbestiform variety of this mineral is referred to as anthophyllite asbestos (International Mineralogical Assoc., https://ima-mineralogy.org/Minlist.htm; some information adapted from Handbook of Mineralogy and www.mindat.org; last accessed on October 26, 2020; see http://www.handbookofmineralogy.org/pdfs/anthophyllite.pdf for more information).

Asbestiform: A specific variety of a mineral or type of mineral fibrosity, associated with a unique fibrous habit of crystal growth, in which the fibers are long and thin and possess high tensile strength and flexibility. This unique habit of growth is observed in fibrous serpentine (chrysotile) and certain fibrous amphibole minerals (EPA, 2014a) (Campbell, 1997).

Asbestos (mineralogical/commercial): A group of fibrous silicate minerals that occur in an asbestiform habit of growth in which the bulk mineral readily separates into long, thin, strong fibers. These minerals are also heat resistant and chemically inert, are electrical insulators, and therefore are suitable for fabricating incombustible, nonconducting, or chemically resistant materials (EPA, 2014a).

Asbestos (regulatory): Asbestos means the asbestiform varieties of chrysotile (serpentine); crocidolite (riebeckite); amosite (cummingtonite-grunerite); anthophyllite; tremolite; and actinolite. (See 40 CFR § 763.83 and § 763.163.)

Aspect Ratio: A dimensionless value, calculated as the length of a particle divided by its diameter (or apparent width) (EPA, 2014). Also known as length:width ratio.

Chrysotile: A mineral in the serpentine mineral group that occurs in the asbestiform habit with the general formula $Mg_3Si_2O_5(OH)_4$. Chrysotile generally occurs segregated as parallel fibers in veins or veinlets forming bundles which can easily be separated into individual fibers when disturbed. Often referred to as "white asbestos," chrysotile is the lone type of asbestos in the serpentine mineral group and the most common type of commercial asbestos (EPA, 2014b).

Cosmetic (Cosmetic Products): The Federal Food, Drug and Cosmetic Act (FD&C Act), at section 201(i), defines cosmetics by their intended use, as "articles intended to be rubbed, poured, sprinkled, or sprayed on, introduced into, or otherwise applied to the human body ... for cleansing, beautifying, promoting attractiveness, or altering the appearance."

Crocidolite: The asbestiform variety of the amphibole mineral riebeckite or magnesio-riebeckite having the general formula $\square[Na_2][Z^{2+}{}_3Fe^{3+}{}_2]Si_8O_{22}(OH,F,Cl)_2$ [$\square$ is a site vacancy in the crystal structure]. Often referred to as blue asbestos (www.mindat.org).

Energy Dispersive X-ray Spectroscopy Analysis (EDS): Energy dispersive X-ray spectroscopy is a standard method for identifying and quantifying elemental compositions in a very small sample of material in TEM or SEM, respectively. In a properly equipped TEM or SEM, the atoms on the surface are excited by the electron beam, emitting specific wavelengths of X-rays that are characteristic of the atomic orbital structure of the elements. A solid-state energy dispersive detector discriminates among X-ray energies and can analyze these X-ray emissions. (See Ebnesajjad, 2014.)

Elongate Mineral Particle (EMP): Adopted as a descriptive term in NIOSH Bulletin 62 (2011). EMP is a scientifically-preferred term to describe mineral particles with an aspect ratio of $\geq$ 3:1 (NIOSH Bulletin 62 (2011)).

Grunerite: An amphibole mineral in the cummingtonite-grunerite series with the general formula $\square\{Fe^{2+}{}_2\}\{Fe^{2+}{}_5\}(Si_8O_{22})(OH)_2$ [$\square$ is a site vacancy in the crystal structure]. The asbestiform variety of this mineral is referred to as grunerite asbestos.

Habit (Crystal Habit) (mineralogical): The characteristic external shape of an individual crystal or crystal group due to crystal growth. A mineral may exhibit multiple habits due to different conditions (e.g., temperature, pressure, geological events) that were prevalent when crystal growth took place.

Mesothelioma: Mesothelioma is cancer of the mesothelium, which is the layer of cells of mesodermal origin that lines the embryonic body cavity and gives rise to the squamous cells of the peritoneum, pericardium, and pleura.

Optical microscopy: Microscopic technique that uses visible light for illumination. Includes Phase Contrast Microscopy and Polarized Light Microscopy.

Phase Contrast Microscopy (PCM): Phase contrast microscopy is an optical microscopy technique that converts phase shifts in light passing through a transparent specimen to brightness changes in the image. Phase shifts themselves are invisible but become visible when shown as brightness variations.

Polarized Light Microscopy (PLM): Polarized light microscopy is an optical microscopy technique where the illumination of the object under view involves polarized visible light. This technique can be used to identify minerals based on optical properties.

Richterite: Richterite is a sodium-calcium-magnesium-silicate amphibole mineral with the formula $[Na(CaNa)Mg_5Si_8O_{22}(OH)_2]$. If iron replaces the magnesium within the structure of the mineral, it is called ferrorichterite; if fluorine replaces the hydroxyl, it is called fluororichterite. Non-fibrous and fibrous varieties, including asbestiform, are known (International Mineralogical Assoc., https://ima-mineralogy.org/Minlist.htm; webmineral.com; see http://www.handbookofmineralogy.org/pdfs/richterite.pdf for more information).

Selected Area Electron Diffraction (SAED): A technique in TEM in which the crystal structure of a small area of a sample is examined using the beam of electrons. SAED generates a distinctive pattern related to the spatial relationship of atoms in the crystal structure of a particle and thus can be helpful in making a definitive mineral identification (ISO 10312).

Scanning Electron Microscope (SEM): The scanning electron microscope uses a focused beam of high-energy electrons to generate a variety of signals at the surface of solid specimens. The signals that derive from electron-sample interactions reveal information about the sample, including external morphology (texture), chemical composition (see EDS), crystalline structure, and orientation of materials making up the sample.

Serpentine (Serpentine Group, Serpentine Mineral): A group of hydrous magnesium-rich silicate minerals of the phyllosilicate (sheet silicates) class. The typical composition of these

minerals approximates $(Mg,Fe)_3Si_2O_5(OH)_4$. With respect to talc deposits, three noteworthy serpentine minerals are relevant: antigorite, lizardite, and chrysotile.

Talc, Mineral: Talc, in its pure mineral form, is a hydrous magnesium phyllosilicate mineral with a chemical composition of $Mg_3Si_4O_{10}(OH)_2$. (See https://geology.com; http://www.handbookofmineralogy.org/pdfs/talc.pdf.)

Transmission Electron Microscope (TEM): Transmission electron microscope generates and passes a beam of electrons through a sample to form an image.

Tremolite: A calcic amphibole mineral in the series tremolite-ferroactinolite with the formula $\square Ca_2(Mg_{5.0\text{-}4.5}Fe^{2+}_{0.0\text{-}0.5})Si_8O_{22}(OH)_2$ [$\square$ is a site vacancy in the crystal structure]. The asbestiform variety is referred to as tremolite asbestos. (See EPA, 2014, Appendix A; International Mineralogical Assoc., https://ima-mineralogy.org/Minlist.htm; see also http://www.handbookofmineralogy.org/pdfs/tremolite.pdf.)

Winchite: Winchite is a sodium-calcium amphibole with the formula $\square(NaCa)(Mg_4Al)Si_8O_{22}(OH)_2$. Non-fibrous and fibrous varieties, including asbestiform, are known. [$\square$ is a site vacancy in the crystal structure]. (International Mineralogical Assoc., https://ima-mineralogy.org/Minlist.htm; see http://www.handbookofmineralogy.org/pdfs/winchite.pdf for more information.)

X-Ray Diffraction (XRD): X-ray diffraction (XRD) analysis is a technique that provides detailed information about the crystallographic structure, chemical composition, and physical properties of materials, obtained by passing specific X-ray electromagnetic radiation through the sample (www.sciencedirect.com).

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