Fiber Taxonomy for Synthetic Vitreous Fibers

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Introduction

Taxonomy is the study of the general principles of scientific classification. Taxonomy is also the science of systematically naming, describing and classifying things. Naming conventions help to ensure that things can be properly and precisely identified. Classification schemes are used to show the differences and similarities among things, especially things that are in some way related.

For a given thing or group of things there can be multiple taxonomy approaches, each highlighting one or more characteristics. There can also be different sub-approaches for any given high-level classification approach and even combinations of high-level approaches.

There is no single correct way to classify things; the approach or combination of approaches needed will vary depending on the best way to address the question or issue at hand. Nor are classification schemes static; instead, they may change over time as, e.g., more and better data are developed that inform the classification characteristics.

Similarly, there are various ways of naming, describing and classifying the synthetic vitreous fibers ("SVF"). These man-made vitreous fibers are widely used in modern society. Some of the most common ways to classify SVFs include the following:

- Origin
- Use (application)
- Manufacturing method
- Raw materials and chemistry
- Morphology (shape)
- Hazard and hazard classification
- Numeric and letter test name and code

This review addresses the taxonomy of SVFs used for thermal and acoustical insulation. There are multiple categories discussed:

1. Fiber families
2. Applications or use
3. Manufacturing method
4. Hazard classifications
5. Biopersistence
6. Others such as numeric designation and morphology.

Commonly Referenced Fiber Families

Fibers are classified by their chemical origin, falling into two groups or families: natural fibers and manufactured fibers. Manufactured fibers are also referred to as man-made or synthetic fibers.

Origin: Synthetic vs. Natural Fibers

SVFs comprise a group of fibrous inorganic manufactured materials that contain mostly silica and alumina along with other trace oxides, and are made from rock, slag, clay, or glass. These glassy fibers differ from natural mineral fibers such as asbestos because they do not have a crystalline molecular structure and cannot split lengthwise into thinner fibers.

Use – High Level Application: Wools vs. Continuous Filaments

There are two broad categories of SVFs that are described by both their use and morphology: filaments and wools. Filaments consist of continuous glass threads, while wools are discontinuous fibers, subdivided into categories, including glass wool (also known as fiber glass), rock wool, slag wool, refractory ceramic fibers ("RCF"), and other types of newer fibers, such as alkaline earth silicate fibers.

The primary uses of filaments are to provide strength and reinforcement to other materials, especially plastic composite materials. In contrast, wools are used mostly for heat and sound insulating purposes with glass wools being some of the most widely used insulating materials in homes and buildings. But wools can also be used for non-insulation applications, such as filtration. Filaments tend filaments tend to have larger (thicker) diameters than wools.

Fiber Hazard: Presence or Absence of Potential Cancer Hazard, Hazard Classification

SVFs can also be classified by the potential hazard they present; much attention has been given over the years to whether SVFs pose any potential cancer hazard, and numerous publications are available detailing those results.

In 1987, the International Agency for Research on Cancer ("IARC") classified all SVF wools as Group 2B, possibly carcinogenic to humans. That classification was based on studies where large quantities of SVFs directly implanted into the intraperitoneal cavities of test animals (IP studies), resulted in tumor formation. The industry at the time noted that such IP studies should not be used to determine possible fiber hazard because it used a route of exposure that was not relevant to humans, where exposure of most concern is via inhalation. But since IARC determined that there were at that time no well-designed animal inhalation studies, IARC was constrained to rely on the IP studies in making its hazard classification decision.

With input from many outside experts – including members of academia and staff from regulatory agencies – sophisticated, long-term animal inhalation studies were designed and carried out by the industry in the 1990s. The results of those studies confirmed that most SVFs do not induce fibrosis and tumors in the test animals. Specifically, only the non-insulation special purpose fibers and high temperature RCFs induced fibrosis and tumors. The tests confirmed that the difference between insulation SVFs and other fibers is that the insulation SVFs are biosoluble in the lung and do not persist long enough to cause the chronic inflammation that can lead to fibrosis and tumors.

When IARC in 2001 revisited its original 1987 cancer hazard determination, it adjusted its cancer hazard classification to reflect the new science. IARC determined that insulation SVFs did not present a cancer hazard and removed those fibers from its Group 2B list of possible carcinogens and placed them in Group 3 – not classifiable as to carcinogenicity. However, IARC retained the Group 2B designation for both special purpose fibers and RCF.

By 2001, the critical role of fiber biosolubility was known and SVF manufacturers had already started reformulating both special purpose fibers and RCFs to make them more biosoluble. Since there was insufficient data to fully assess the hazards of those newly developed biosoluble fibers, IARC in 2001 did not classify them as to their cancer hazard.

In 1987, IARC put continuous filament glass fibers in the Group 3 category – not classifiable. IARC's 2001 reconsideration did not change that classification because the science around the hazards of those fibers did not change.

Special Applications: Insulation Wools vs. Special Purpose Fibers vs. RCF

SVFs are an important component in a variety of products where thermal, acoustical, or electrical resistance are required. Fibrous glass (including glass wool) accounts for about 80% of the production of SVFs in the U.S. The majority of this production is in the form of glass wool, which is used for insulation purposes, as are mineral wools, which account for about 10-15% of U.S. SVF production. RCFs and special purpose fibers account for only approximately 2% of all SVFs produced in the U.S. RCF materials are very heat resistant and find use in applications that require high temperatures. Specialty purpose glass fibers are very expensive to manufacture and, consequently, find use only in high technology applications.

Specific applications by principal fiber type are listed in the table below.[1]

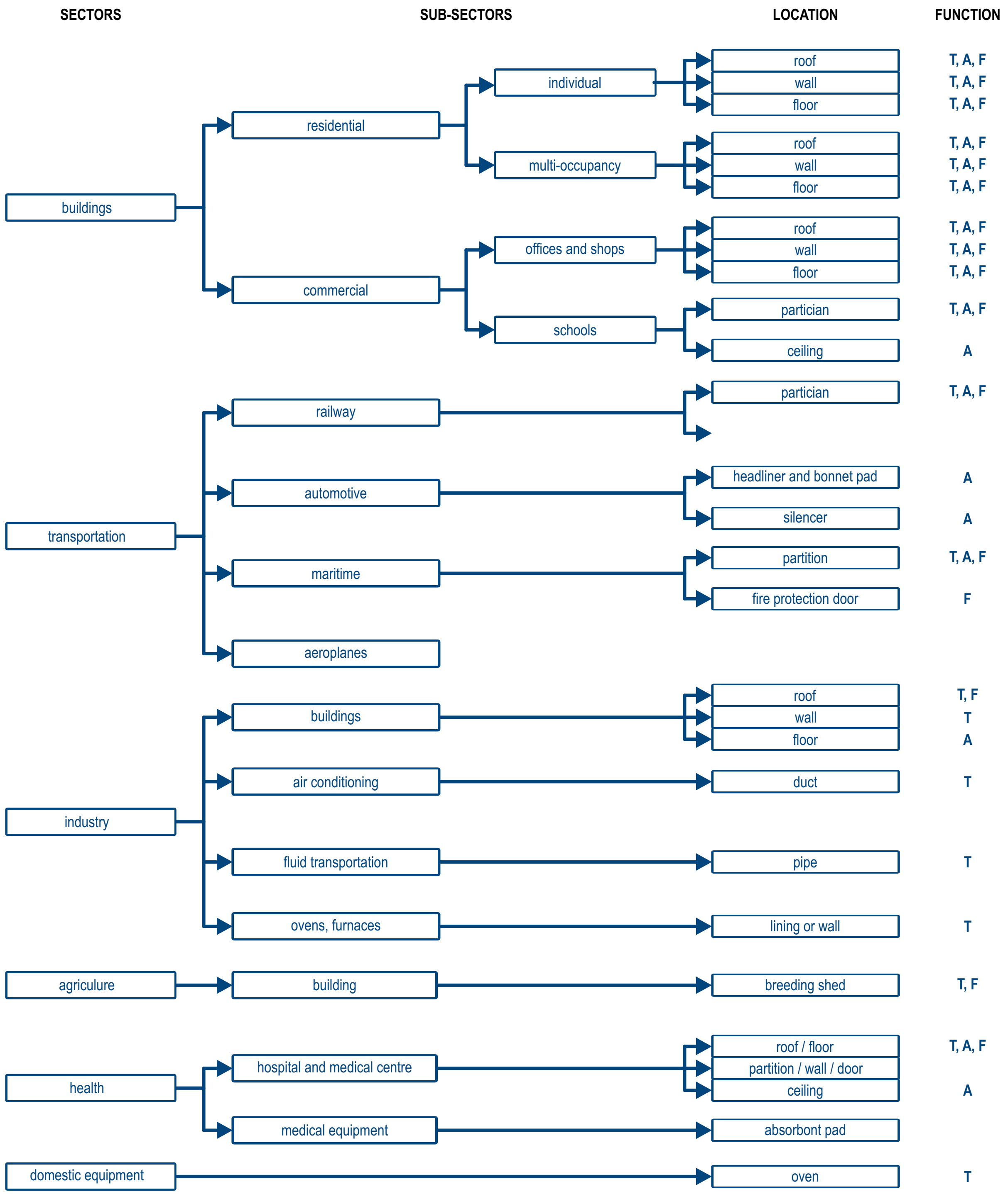
FIBER TYPES	TYPICAL USES
Continuous Filament Glass Fibers	Reinforcement in plastics and building products and in industrial fabrics
Glass Wool	Bonded batts, blankets, and boards used as thermal and acoustical insulation applications: • Construction of homes, buildings, and other structures • Appliances • Plumbing applications • Non-woven mat structures used in filtration and other end uses • Pipe and tank insulation • Panels for interior office spaces • High performance insulation in the aerospace industry Unbonded loose fill insulation for attics and walls
Mineral Wool	Bonded batts, blankets, boards, or loose wool used as thermal and acoustical insulation applications: • Construction of homes, buildings, and other structures • Appliances • Plumbing applications • Reinforcement of concrete • Agricultural growing media • Acoustical ceiling tiles • Higher temperature pipe and tank insulation Unbonded insulation
Refractory Ceramics Fibers	Blankets, boards, felts, bulk fibers, and paper and textile products: • Insulation in ships • Firewalls to contain fires • Catalytic converters in the automobile industry and in aircraft and aerospace engines • Linings for furnaces and kilns • Textile products such as yarns or fabrics find use in flame resistant clothing, curtains, and other materials
Special Purpose Glass Fibers	• Specialty filtration products • Battery separator paper • Other engineered solutions

[1] Adapted from Toxicological Profile for Synthetic Vitreous Fibers (U.S. Department of Health and Human Services, Public Health Services, Agency for Toxic Substances and Disease Registry), September 2004, p. 175. See also International Agency for Research on Cancer, *IARC Monographs on the Evaluation of Carcinogenic Risks to Humans: Man-Made Vitreous Fibres*, Vol. 81 (Lyon, France: WHO/IARC, 2002), p. 64. The Freedonia Group (2001), *World Insulation* to 2004, Cleveland, OH.

Another way of describing the uses of SVFs is by sector and subsector and by function. This figure is from IARC's 2002 Monograph and shows the ubiquitous nature of SVFs in providing both thermal and acoustical insulation properties throughout the economy.

FIGURE 1 (Chart Labeled "Figure 8" was Obtained from IARC Monograph)

Figure 8. Main uses of glass, rock (stone) and slag wools



Modified from various industry sources.
T, Thermal; A, Acoustic; F, Fire Protection

Numeric Test Designation: Names Given to Tested Fibers

As described in other literature, many individual SVFs have been tested in animal and other studies. For purposes of consistency, researchers typically referred to these fibers as man-made vitreous fibers ("MMVF") and assigned numeric designations to the fibers being tested. Those designations are ubiquitous in the scientific literature.

Below is a table showing the numeric designation of some of the fibers that have been tested, both in animals (*in vivo*) and *in vitro* (in glass), along with their IARC classification.

Table of Man-Made Vitreous Fibers ("MMVFs") Numeric Designations

MMVF Designation	Manufacturer	Trade Name	Application	IARC Classification
MMVF 10	Johns Manville	JM 901	Building insulation	Group 3
MMVF 10a	Johns Manville	JM 901a	Building insulation	Group 3
MMVF 11	CertainTeed (St. Gobain)	Insulsafe II	Building insulation	Group 3
MMVF 21	Rockwool Intnat'l.		Building insulation	Group 3
MMVF 22	USG	Slag wool	Building insulation	Group 3
MMVF 33	Johns Manville	475 glass	Air filtration	Group 2B
MMVF 34a	Rockwool Intnat'l.	HT Stonewool	Building insulation	None
MMVF 35	Johns Manville	JM 902	Aerospace insulation; filtration	None

As can be seen in this table, manufacturers may also assign their own numeric or trade name to their fibers.

Numeric and Letter Code Designations: Diameters of Special Purpose Fibers

References to various fiber "codes" are found in the scientific literature, especially the early literature. Most of these references are to special purpose fibers (475 formulation for high performance filtration application) manufactured by Johns Manville where the numeric code refers to the fiber diameter. The table below shows examples of typical codes and diameters.

Code	Glass Type	Mean Fiber Diameter (um)
90	475	.20
100	475	.32
102	475, E	.40
104	475, E	.50
106	475, E	.65
108A	475	1.0
108B	475	1.8
110	475	2.7
BX	475	2.9
112	475	4.0
CX	475	5.5

Letter Codes for Special Purpose Fibers

NRL Code	Mean Fiber Diameter (µm)
B	2.6 – 3.8
A	1.6 – 2.6
AA	0.75 – 1.6
AAA	0.5 – 0.75
AAAA	0.2 – 0.5

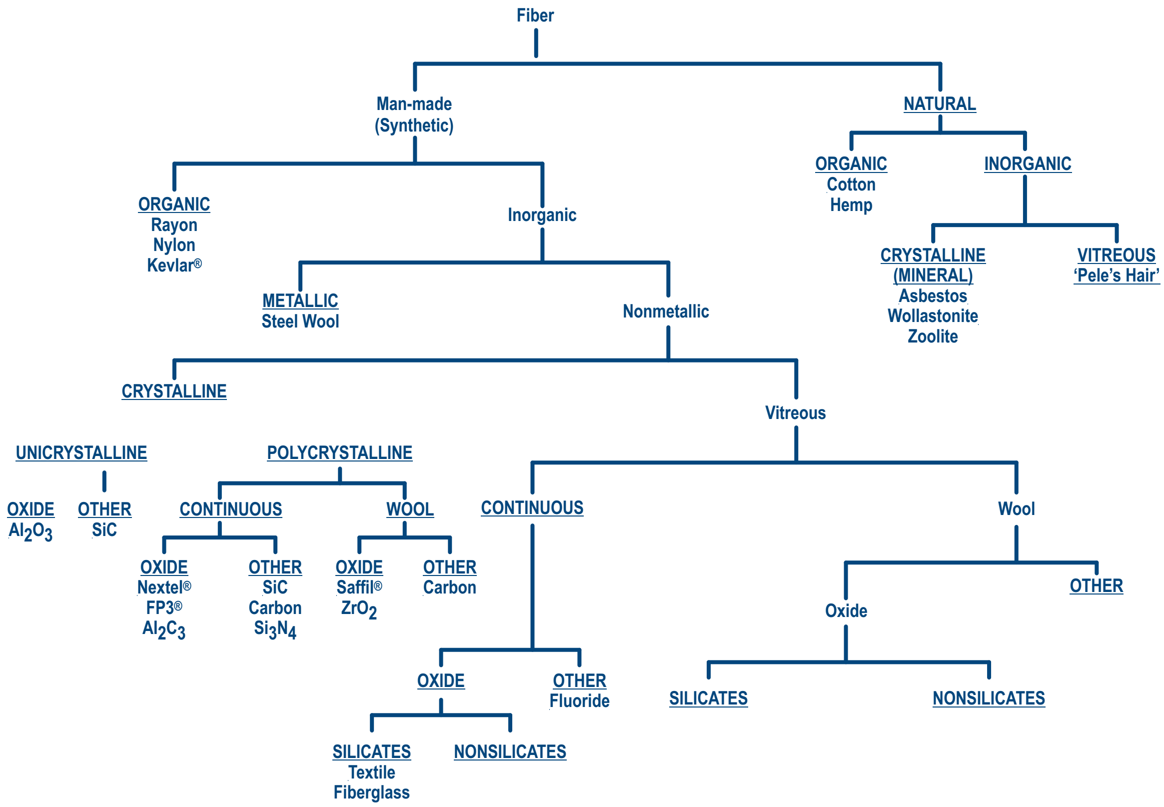
Some studies also refer to letter codes that were assigned by the Naval Research Laboratory.

EARLY FIBER CLASSIFICATION SCHEMES

In its 1990 “nomenclature document,” NAIMA (and before it TIMA) provided a taxonomy figure that classified fibers by high-level origin, chemistry and morphology.

FIGURE 2 (Chart Labeled "FIG. 1." Originated in NAIMA Nomenclature Document)

FIG. 1. Fiber taxonomy. Adapted from TIMA



This classification scheme shows the very broad nature of synthetic fibers in contrast to natural fibers. This figure is valuable because it shows how SVFs are but a small part of the “family tree” of all synthetic fibers. But this way of classifying fibers does not provide much information about the various uses of the fibers or their potential hazard.

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Results from animal studies also show that repeatedly breathing high levels of some types of SVFs may cause a slow buildup of scar-like tissue in the lungs and in the membrane surrounding the lungs. This scar-like tissue does not expand and contract like normal lung tissue, and breathing can become difficult. This condition is called pulmonary fibrosis. The types of SVF that cause this condition in animals stay in the lungs for longer periods of time than the types that do not. They are called “durable” or “biopersistent” SVFs; in the 21st century, refractory ceramic and some specialty fibers are the only fibers that fall into this category. Results from animal studies also show that repeatedly breathing high levels of durable SVFs may also cause cancer of the lung and mesothelioma. In contrast, the most common types of glass wools, stone wools, and slag wools used for insulation are far less durable than RCFs. In rat studies, they did not cause the severe lung effects caused by the more durable RCFs. Results from animal studies indicate that high-level inhalation exposure to any SVFs may cause reversible pulmonary inflammation, but only the most biopersistent of SVFs have been demonstrated to produce irreversible pleural or pulmonary fibrosis, lung cancer, or mesothelioma. In general, SVFs that cause fibrosis are more biopersistent than those that do not.

IARC has determined that RCFs are possibly carcinogenic to humans because of their high biopersistence; these are now considered to be “biopersistant” fibers. At the same time, IARC also determined that insulation glass wool, stone wool, slag wool, and continuous filament glass were not classifiable as to carcinogenicity to humans because of inadequate evidence of carcinogenicity in humans and the relatively low biopersistence of these materials. Such fibers are considered to be “non-biopersistant,” or more commonly called “biosoluble.”

FIGURE 3

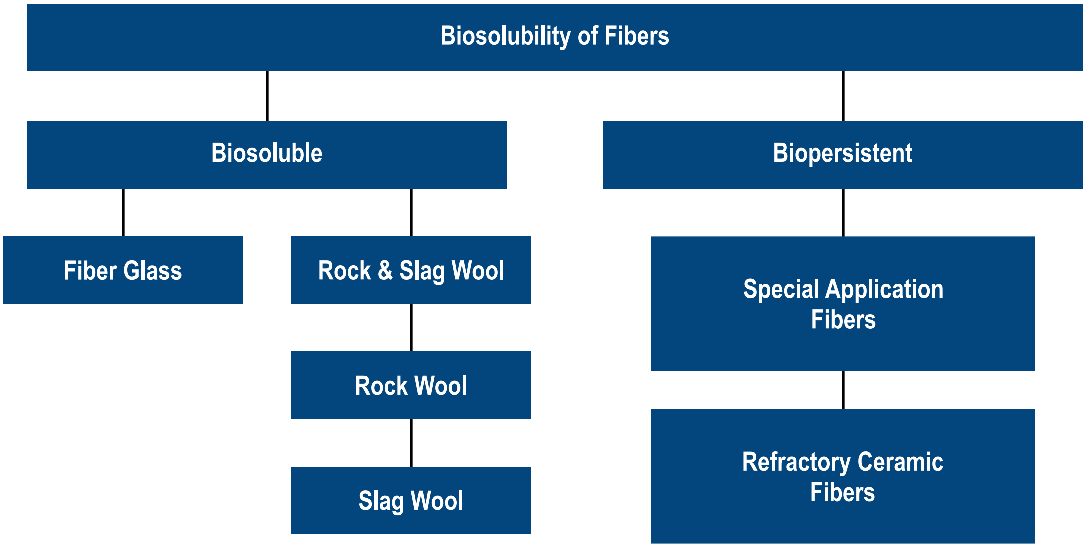
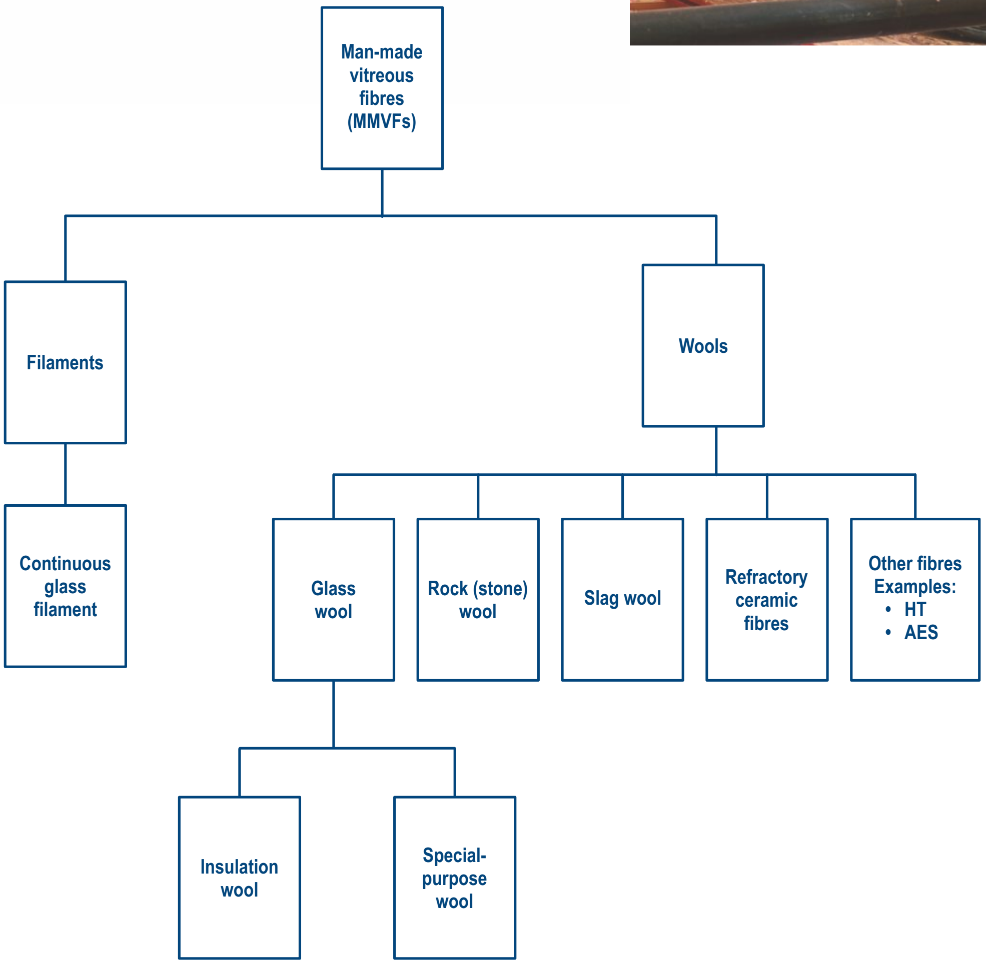


FIGURE 4:
(Chart Labeled "Figure 1" Originated in IARC Monograph)

Figure 1. Categories of MMVFs



Within each of these categories, there are commercial products representing a range of compositions and durabilities. AES, alkaline earth silicate wools; HT, high-alumina, low-silica wools

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NAIMA is the association for North American manufacturers of fiber glass, rock wool, and slag wool insulation products. Its role is to promote energy efficiency and environmental preservation through the use of fiber glass, rock wool, and slag wool insulation, and to encourage the safe production and use of these materials. Through the Insulation Institute™, we leverage the collective insulation expertise of our organization and our members to empower homeowners and professionals to make informed insulation choices. Our mission is to enable a more comfortable, energy-efficient and sustainable future through insulation — and we are constantly working with building professionals, homeowners, government agencies, and public interest, energy and environmental groups to realize that vision.

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