Per- and Poly-fluoroalkyl Substances (PFAS) in Artificial Turf: Test Methods

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Municipalities and institutions often face questions regarding the presence of PFAS in artificial turf as they make decisions about play surfacing.

This document is designed to provide information for municipalities, schools, community members and others about key concepts and considerations for obtaining and understanding laboratory tests. It builds upon and updates an earlier fact sheet, "Per- and Polyfluoroalkyl Substances (PFAS) in Artificial Turf Carpet" (2020).[2]

PFAS Vocabulary and Definitions

PFAS are a category of organic chemicals that contain fluorine atoms bonded to carbon atoms. There are many PFAS chemicals – the US EPA Comptox database identifies nearly **15,000 PFAS chemicals.**[3–5]

Definitions. A variety of definitions of the term PFAS have been developed by state, federal and other entities. Some definitions have been updated over time to reflect a new understanding of the science of PFAS, or to reflect policy priorities. The definition published by the Organization for Economic Cooperation and Development (OECD) is useful as a current, authoritative, and practical definition:

> "PFASs are defined as fluorinated substances that contain at least one fully fluorinated methyl or methylene carbon atom (without any H/Cl/Br/I atom attached to it), i.e. with a few noted exceptions, any chemical with at least a perfluorinated methyl group (–CF3) or a perfluorinated methylene group (–CF2–) is a PFAS."[5]

In some situations, a definition is provided for "regulated PFAS." For example, one California regulation on PFAS in certain products provides a test method and a detection limit within its definition of regulated PFAS.[6] This approach allows for implementation without the need to determine chemical structure of each compound.

Nomenclature. Detailed information on PFAS nomenclature is available in the Interstate Technology and Regulatory Council (ITRC) fact sheet, "Naming Conventions and Physical and Chemical Properties of Per- and Polyfluoroalkyl Substances (PFAS)." Chemicals classified as PFAS include **polymers** and **non-polymers**.[7] Terminology that can arise in discussions of non-polymer PFAS include distinctions between "long chain" and "short chain" PFAS, and distinctions between "linear" and "branched" PFAS.[8]

Certain PFAS are referred to as "**precursors**." As described by ITRC, "Polyfluoroalkyl PFAS that degrade to create PFAAs [Perfluoroalkyl acids] are referred to as 'precursors.'" PFAAs "are some of the least complex PFAS and currently are the class of PFAS most commonly tested for in the environment."[8] Certain laboratory tests focus specifically on precursors, as described below.

Sources of PFAS in artificial turf

PFAS can be used in molding and extrusion of plastic products, including artificial turf.[9,10] One function of PFAS is to prevent the polymer from sticking to manufacturing equipment.

As explained by Dr. Heather Whitehead, "Specific uses of PFAS in the production of plastic and rubbers includes the application of polymeric fluorinated polymer processing aids as extrusion agents, non-polymeric PFAS as mold release agents for plastics and resins, and the direct production of fluoropolymer plastics and rubbers."[11,12] Fluorinated polymer processing aids (fPPAs) are polymers that are used "in the molding and extrusion of various grades of plastic." They may be "added directly to raw plastic resins," before the mixture is "heated, mixed and extruded or blown into a final plastic product."[11]

Some PFAS processing additives on the market specify artificial grass as an intended use.[10,11,13] In this case, PFAS is added to the artificial grass polymer mixture before it is passed through an extruder. An extruder is manufacturing equipment that melts and forms the polymer mixture into its desired shape.

As explained by the New Jersey Department of Environmental Protection, information is available from patent literature and other sources on the potential use of fluorinated materials as processing aids, coating treatments, binding matrices, and flame retardants in artificial turf. NJ DEP notes, "Since PFAS are included in the chemical makeup of fluoropolymers that are added as polymer processing aids to improve plastic extrusion, there is also the potential of leaving a low-level fluoropolymer residual on the product following processing."[9]

Health and Environmental Concerns

Most PFAS chemicals break down into a common set of degradation products. These degradation products are highly persistent in the environment; they do not break down under normal environmental conditions. Some can remain in the environment for hundreds of years. As a result, introducing them into the environment has long-lasting consequences. In addition, PFAS pose bioaccumulation concerns.[14–21]

The human health effects of certain PFAS have been studied in depth due to widespread contamination of drinking water in some areas of the US, and from studies of health effects in fluorocarbon workers. Other PFAS have been studied in laboratory animals. Health effects documented for some PFAS include increased risk of some cancers, including kidney, testicular, and prostate cancers; effects on the endocrine system, including liver and thyroid; metabolic effects such as increased cholesterol or risk of obesity; developmental effects or delays in children; reproductive effects such as decreased fertility and complications in pregnancy; neurotoxicity; and immunotoxicity, including reduced vaccine response.[22–24] Studies of polymeric PFAS also indicate that some can break down into smaller, potentially more reactive molecules in the environment.[7]

PFAS have been studied by many governmental and intergovernmental entities, including the Organization for Economic Cooperation and Development (OECD), the US Environmental Protection Agency (US EPA), and the European Chemicals Agency (ECHA). Researchers have emphasized the need to address PFAS as a group rather than one by one.[18,20,25]

PFAS Testing: Units of Measurement and Detection Limits

PFAS testing includes a variety of methods and approaches. Understanding the range of PFAS testing options can be complex because of the large number of individual chemicals in the class with varying carbon chain lengths and functional groups, and the evidence of adverse effects at very low concentrations. The choice of test method also must take account of the types of materials being tested. The following sections summarize some of the key terminology and considerations that are relevant when choosing testing methods and interpreting results.

Units of Measurement

Because of the hazards of PFAS at very low concentrations, the presence of PFAS in drinking water is generally measured in parts per trillion (ppt). PFAS information may also be shown in parts per billion (ppb) or parts per million (ppm), which are larger units of measurement. One ppm is a million times larger than one ppt: 1 ppm = 1,000 ppb = 1,000,000 ppt. As explained in an EPA publication, another way to understand these units is by "equating ppm to 'one drop in one million gallons,' ppb to 'one drop in one billion gallons,' [and] 'ppt to one drop in one trillion gallons.'"[26]

Analytical laboratories may use a variety of units to report concentrations of PFAS. For example, one lab may present results as nanograms per liter (ng/L), while another may present the same information in ppt. These units represent the same concentration. Below are several examples of unit conversion for water and solid materials.[26,27]

Examples of Unit Conversions

Parts per million (ppm) = microgram per gram (µg/g); milligram per kilogram (mg/Kg); milligram per liter (mg/L); nanogram per microliter (ng/µL)

Parts per billion (ppb) = microgram per kilogram (µg/Kg); nanogram per gram (ng/g); microgram per liter (µg/L)

Parts per trillion (ppt) = nanogram per kilogram (ng/Kg/); nanogram per L (ng/L)

Detection Limits

When ordering PFAS analyses or interpreting results, it is important to understand detection limits. If the detection limit is too high, useful information may be missed. When ordering a test or reading test results, check the detection limit to see if it corresponds to the information you need. For example, if you need information on substances that may be present at the ppb or ppt level, be sure that these levels are captured in the testing.

It can also be important to know that in some cases, a laboratory can determine that a chemical is present, but cannot accurately quantify the concentration that is present.

A variety of terms are used to describe detection and quantitation limits. For example, EPA Method 1633 defines a “method detection limit” and a “limit of quantitation.”[28] Commercial laboratories may distinguish between “method detection limit” and “reporting limit.” Academic laboratories may distinguish between “instrument detection limit” and “method detection limit.”[29] And the Department of Defense distinguishes among “detection limit,” “limit of detection,” and “limit of quantitation.”[30] Regardless of the vocabulary used, it is important to check definitions and to ensure that the limits of the test conducted are appropriate for the decision-making needs of those using the test results.

Results may have laboratory-added “flags” or qualifiers that provide additional information. For example, a letter may be used to indicate that the substance is *present* but cannot be *quantified* accurately. Vocabulary and acronyms used in lab reports can differ among laboratories, so it is important to read the definitions in each report.

PFAS Testing: Methods

There are multiple factors to consider when choosing appropriate PFAS testing methods and interpreting results.[31] The US EPA has developed methods for measuring PFAS for regulatory and monitoring purposes for measuring PFAS in water, soil, sediment, biosolids, and fish tissue.[32] The international standards development organizations American Society for Testing and Materials (ASTM) and International Organization for Standardization (ISO) have also developed methods for measuring PFAS.[33] However, there are currently no consistent guidelines for testing PFAS in synthetic materials, such as plastic and rubber. Some laboratories use modified versions of US EPA testing methods to measure PFAS in certain synthetic materials.

There are various approaches for targeted testing of individual PFAS compounds in samples. However, these methods only provide information on a limited number of compounds and for specific sample types. In many cases, testing is limited to a small group of non-polymeric PFAS that have been a particular focus of regulatory activity. For example, US EPA has published methods for testing between 18 and 40 types of PFAS depending on the method and sample type (see the summary of EPA methods in Table 1).[32] Lack of detection of these individual chemicals does not indicate that all PFAS are absent.

Other methods have been developed to understand the presence or concentrations of all PFAS in a sample, such as methods for measuring the presence of fluorine-containing organic (carbon-containing) compounds without identifying specific chemicals. These are discussed in greater detail below.

Sample preparation/extraction. It is helpful to review the laboratory’s approach, including choice of extraction solvent, to understand whether the resulting data will answer the questions that the organization wants to prioritize. For example, a test that estimates PFAS leaching into rainwater will not necessarily be sufficient to answer questions about PFAS presence and concentration in the material. It is important for a laboratory to use appropriate methods, including an appropriate extraction solvent, to answer the questions at hand.

When understanding how PFAS may leach from materials into rainwater, the US EPA recommends using an appropriate extraction fluid that is relevant to regional environmental conditions, such as rain acidity.[34]

Choice of laboratory. In general, organizations ordering a PFAS test should use an analytical laboratory that has experience analyzing PFAS in plastic materials. The choice of a laboratory to work with may depend on the goals of a testing effort. For example, academic laboratories can use innovative methods, while certified commercial laboratories can provide data that may be used in legal or regulatory settings.

Targeted PFAS analysis

Targeted chemical analyses are methods used to gather information about a specific, targeted list of chemicals.[32] Existing targeted analyses for PFAS only measure a small number of the nearly 15,000 PFAS that exist.

EPA initially developed standard targeted methods for measuring a small number of PFAS in drinking water and wastewater, with a primary focus on regulatory activity.[32] Some labs modified these methods to measure additional PFAS and to test other media, such as solids. In January 2024, EPA developed Method 1633, which can measure at least 40 PFAS compounds in wastewater, surface water, groundwater, soil, biosolids, sediment, landfill leachate, and tissue samples.

Table 1 presents a summary of EPA's targeted PFAS testing methods. Note that the table describes only EPA methods. Other methods also exist; for example, some laboratories may use methods from ASTM or ISO. Certain methods may be quicker and lower cost than others, but may be less rigorous and have higher detection limits.[35] Thus, it is essential to discuss the goals for the sample analysis with the laboratory in order to choose an analysis method and detection limits that will result in data usable for decision-making.

Non-Targeted PFAS Analysis

Non-targeted chemical analyses are methods used to gather information about a wide range of chemicals that may be present. Unlike targeted analyses, non-targeted analyses do not 'look for' specific chemicals, but attempt to identify all chemical signals in the data. These methods can be used to investigate the presence of PFAS that cannot be measured using other chemical-specific methods. These methods include use of high resolution mass spectrometry that can identify known and unknown analytes in a sample.[32] Once chemicals have been identified using a non-targeted analysis, additional analyses can be used to measure or estimate the quantity.

Table 1. Summary of EPA's standard targeted analytical methods for measuring PFAS.

Method	**Description**
Method 537.1 (published 2018/2020; replaced method 537 published in 2009)	• Measures 18 PFAS in drinking water
Method 533 (published 2019)	• Measures 25 PFAS in drinking water
Method 8327 (published 2019)	• Measures 24 PFAS in non-drinking water, including groundwater, surface water, and wastewater
Method 1633 (published 2024)	• Measures 40 PFAS in wastewater, surface water, groundwater, soil, biosolids, sediment, landfill leachate, and tissue. This method encompasses chemicals covered in the earlier methods.
Other Test Method-45	• Measures 50 PFAS in air emissions from stationary sources, with a focus on semi-volatile and particulate-bound PFAS
Other Test Method-50	• Measures 30 PFAS in air emissions from stationary sources, with a focus on certain volatile PFAS
Note that this table shows only *targeted* methods. Sources: US EPA. 2024. "PFAS Analytical Methods Development and Sampling Research." https://www.epa.gov/water-research/pfas-analytical-methods-development-and-sampling-research ; US EPA. 2024. "Method 1633: Analysis of Per- and Polyfluoroalkyl Substances (PFAS) in Aqueous, Solid, Biosolids, and Tissue Samples by LC-MS/MS." https://www.epa.gov/system/files/documents/2024-01/method-1633-final-for-web-posting.pdf	

Total Fluorine Analysis

Total fluorine (TF) analyses do not measure or identify individual PFAS compounds. Rather, TF is a measurement of fluorine atoms, in both organic and inorganic forms, without identifying specific compounds. This kind of test can be a useful first step to determining the likelihood of the presence of PFAS in a sample.[31] These measurements can be performed on aqueous or solid samples and are generally more affordable than other PFAS analysis methods.[36]

TF can be measured using particle-induced gamma ray emission (PIGE) spectroscopy, and other techniques such as combustion ion chromatography (CIC) and combustion with an ion-selective electrode. Total fluorine analyses may also be modified to avoid detecting fluoride, which is fluorine in an inorganic form.[a]

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[a] If this is important, the sample must either undergo extraction into a solvent or adsorption onto a medium that will not collect inorganic fluorine or be analyzed directly for inorganic fluoride before measuring total fluorine.

Organic Fluorine Analysis

PFAS are organic (carbon-containing) chemicals. Organic fluorine analyses consider the organic form of fluorine – that is, fluorine that is bonded to carbon. Fluorine can also exist in inorganic (non-carbon-bonded) forms. Inorganic forms of fluorine are not PFAS.

Organic fluorine analyses can capture a broader range of PFAS compounds than targeted analyses, because they show the presence or absence of a group of chemicals, rather than measuring individual chemicals. EPA and other researchers are investigating whether measuring organic fluorine can be used as a chemical class-based analytical method for PFAS.[37,38] To obtain information about **total organic fluorine,** it is possible to determine total fluorine and then subtract the inorganic portion. Other types of organic fluorine analyses include **extractable** and **adsorbable** organic fluorine analyses.

As described by EPA, "the most common sources of organofluorines are PFAS and non-PFAS compounds such as pesticides and pharmaceuticals."[39] Some pharmaceuticals and pesticides contain or are considered PFAS.[40,41] The vocabulary used to describe these compounds depends in part on the choice of definition of the term PFAS.

Total organic fluorine. To account for the possible presence of fluoride (an inorganic form of fluorine) in a sample, some labs can test a sample for both fluoride and total fluorine. If fluoride is not detected, it is usually reasonable to conclude that all of the fluorine in the sample is organic fluorine. If fluoride is detected, it can be quantified and subtracted from the total fluorine for an estimation of total organic fluorine.[b]

Extractable and adsorbable organic fluorine analyses. Extractable organic fluorine (EOF) tests measure only organic fluorine by removing the inorganic fraction of fluorine through extraction.[38] Following extraction, fluorine can be measured using CIC. Extractable organic fluorine analyses are limited to compounds that can be extracted using the chosen extraction method. In 2024, EPA published a method for measuring adsorbable organic fluorine (AOF, Method 1621) in aqueous matrices. This method uses granular activated carbon to adsorb fluorinated compounds, and its utility can vary depending on the chain length of the fluorinated compounds in the sample.[42]

Total Oxidizable Precursor Assay

A Total Oxidizable Precursor (TOP) Assay allows researchers to indirectly assess the presence of a wide range of PFAS, many of which are missed by targeted methods.

This method mimics environmental degradation by oxidizing a sample, allowing "precursors" to degrade into perfluoroalkyl acids (PFAAs).[9] One portion of a sample is analyzed for PFAS and a second portion is oxidized and then analyzed for PFAS. The difference between the pre-oxidation PFAS content and the post-oxidation PFAS content is an estimate of the amount of precursors in the sample.

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[b] Gillian Miller of Ecology Center has noted that this approach comes with a caveat that certain materials, particularly geological particles (rocks), are not suitable for total fluorine testing via combustion or inorganic fluoride testing via ion-selective electrode. Erroneous results may occur, for example, from fertilizer containing phosphate rock.

TOP assay enables researchers to detect the presence of precursors, even if they do not know which specific precursors are present.[43]

Interpreting Test Results

Interpreting and comparing testing results across sites and sample types can be challenging due to variations in methods used for analysis, units and reporting protocols, quality control criteria, and data review procedures across labs.[44] The level of detail needed for interpretation and assessment of data quality depend on the goals of testing. A pilot or general screening study may need less detail than that needed for enforcement actions or comparison to regulatory standards, for example.

When interpreting laboratory test results, it is important to understand which tests were conducted and what those tests can detect. For example, if an organization is interested in determining whether fluoropolymers are present in the product, an appropriate test must be selected. Typical methods for targeted PFAS or for extractable organic fluorine will not detect fluoropolymers, while total fluorine will detect them (although not identify them). Therefore, a total fluorine test is an important step to detect the presence of fluoropolymers.

It is also important to understand that the lack of detection of one or more specific PFAS does not indicate that a material is free of PFAS. For example, if a sample is tested for 40 PFAS compounds ("target" list), and none were detected, this means the sample did not contain those 40 compounds at the detection limit used for each compound. One cannot conclude that no PFAS of any kind were present. It is possible the sample contained compounds not on the target list, or contained levels of the targeted compounds below the detection limit. A total fluorine test, an organic fluorine test, or a TOP assay can be helpful in determining whether PFAS may be present in a sample.

When conducting targeted testing, it may also be useful to consider which chemicals are most likely to be present. For example, in some cases, some PFAS compounds may be more likely to be found in older products, and others may be more likely to be present in newer products, unless the new product also contains older, repurposed or recycled components.

Sometimes reports on laboratory tests may also include text about risk. Risk assessment is an approach to estimating possible health effects of exposure to one or more toxic chemicals. It is distinct from identifying or quantifying chemicals in products. Risk assessment relies on a variety of additional assumptions and calculations related to exposure and other factors. Results of a risk assessment can vary widely based on the assumptions that are used.

Table 2 briefly summarizes the approaches discussed in this document. The terminology used to describe and categorize approaches to testing PFAS can vary among sources, and there are other ways to categorize these types of tests. For example, some sources may categorize tests based on whether they are quantitative or qualitative. Regardless of the terminology used, it is essential to understand the scope and limitations of any tests that are used in decision-making.

Table 2. Summary of testing options and relevance for decision-making about artificial turf products

Type of test	**Function of test**	**Utility of test**
Targeted PFAS analysis	• Identifies and quantifies a specific list of compounds.	• Useful for discussions related to regulatory standards for environmental contamination.
Non-targeted PFAS analysis	• Attempts to identify all PFAS compounds that are present, without quantifying them.	• Useful if there is a need to identify exactly which PFAS compounds are present.
Total fluorine analysis	• Measures fluorine atoms, without identifying specific compounds.	• Useful as a first step in determining whether a product may contain PFAS. Less specific than an organic fluorine analysis, as inorganic fluorine is also captured by this approach. • Includes quantitative information.
Organic fluorine analysis	• Measures organic fluorine atoms, without identifying specific compounds.	• Useful in determining whether a product may contain PFAS. • Includes quantitative information.
Total oxidizable precursor (TOP) assay	• Provides information on the quantity of precursors that degrade into PFAAs.	• Useful in determining whether a product contains certain PFAS. • Encompasses more compounds than a targeted PFAS analysis, but fewer compounds than an organic fluorine analysis.
Note: The terminology used to describe and categorize approaches to testing PFAS can vary among sources; this table provides one approach. Regardless of the terminology used, it is essential to understand the scope and limitations of any tests that are employed.		

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The Lowell Center for Sustainable Production uses rigorous science, collaborative research, and innovative strategies for communities and workplaces to adopt safer and sustainable practices and products to protect human health and the environment. The Lowell Center is composed of faculty, staff, and graduate students at the University of Massachusetts Lowell who work with citizen groups, workers, businesses, institutions, and government agencies to build healthy work environments, thriving communities, and viable businesses that support a more sustainable world.

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