



RECYCLED ASPHALT SHINGLES (RAS) AS A FULL DEPTH RECLAMATION (FDR) MECHANICAL STABILIZER

Eshan V. Dave (PI)

UNH, Department of Civil & Environmental Engineering

Jo E. Sias (Co-PI)

UNH, Department of Civil & Environmental Engineering

Fausto Bisanti (Graduate Research Assistant)

UNH, Department of Civil & Environmental Engineering

Gabriele Tebaldi (Senior Researcher)

UNH, Department of Civil & Environmental Engineering

May 2026

Research Project

Reporting on Project GR1850

Final Report 2026-04

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This material is based upon work supported by the Federal Highway Administration under SPR VTRC023-603. Any opinions, findings and conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the Federal Highway Administration.

Artificial Intelligence (AI) was not used in the report, for any image, or during the conduct of the research project.

Acknowledgments

The authors would like to acknowledge the support of the VTrans staff from the Research Division, Dr. Emily Parkany and Ms. Ashlie Mercado, for all their assistance during the project. Authors also acknowledge the help and support from the project champions, Dr. Ian Anderson and Ms. Callie Ewald as well as from the whole project technical advisory committee for their technical insights and feedback. Authors especially thank Mr. Aaron Schwartz for his help with the coordination of material sampling from construction sites.

Technical Report Documentation Page

1. Report No. 2026-04	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle RECYCLED ASPHALT SHINGLES (RAS) AS A FULL DEPTH RECLAMATION (FDR) MECHANICAL STABILIZER		5. Report Date May 2026	
		6. Performing Organization Code	
7. Author(s) Dave, Eshan V. 0000-0001-9788-2246 https://orcid.org/0000-0001-9788-2246 Sias, Jo E. 0000-0001-5284-0392 https://orcid.org/0000-0001-5284-0392 Bisanti, Fausto 0000-0002-7515-9206 https://orcid.org/0000-0002-7515-9206 Tebaldi, Gabriele 0000-0001-8669-6114 https://orcid.org/0000-0001-8669-6114		8. Performing Organization Report No.	
9. Performing Organization Name and Address Department of Civil and Environmental Engineering, University of New Hampshire W183 Kingsbury Hall, 33 Academic Way, Durham NH 03824		10. Work Unit No. (TRAIS)	
		11. Contract or Grant No. GR1850	
12. Sponsoring Agency Name and Address Vermont Agency of Transportation (SPR) Research Program 219 N Main St Barre VT 05641		13. Type of Report and Period Covered Final Report 2023-2026	
		14. Sponsoring Agency Code	
15. Supplementary Notes Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration. https://vtrans.vermont.gov/sites/aot/files/Research/VTrans_RAS_FDR_GR1850_Final_Report.pdf			
16. Abstract This research investigated the use of recycled asphalt shingles (RAS) as a mechanical stabilizer in full depth reclamation (FDR) pavement rehabilitation. The study aimed to determine whether processed and minimally processed RAS could serve as sustainable alternatives to conventional stabilizers while diverting roofing waste from landfills. Laboratory testing was conducted on FDR materials from two reference projects (Marshfield-Danville and Cambridge-Johnson), blended with 5% and 10% RAS. Mechanical evaluations included indirect tensile strength, triaxial resilient modulus, and triaxial shear strength, while pavement performance was predicted using MnPAVE modeling. Results showed that the incorporation of 5% RAS, particularly minimally processed, maintained acceptable mechanical properties and service life, whereas higher contents reduced strength and stiffness. Processed RAS led to higher air voids, negatively affecting mixture performance, while minimally processed RAS improved cohesion and internal friction. Economic and environmental assessments, including life-cycle cost analysis (LCCA) and life-cycle assessment (LCA), indicated that 5% RAS is feasible when transport distances are similar to conventional aggregates and service life is not compromised. Field implementation and long-term monitoring are recommended to validate laboratory findings and optimize RAS use in practice.			
17. Key Words Recycled Asphalt Shingles (RAS); Full Depth Reclamation (FDR); mechanical stabilizer; mechanical behavior; pavement performance; Life-Cycle Assessment (LCA); Life-Cycle Cost Analysis (LCCA)		18. Distribution Statement No restrictions. This document is available through the National Technical Information Service, Springfield, VA 22161.	
19. Security Classification (of this report) Unclassified	20. Security Classification (of this page) Unclassified	21. No. of Pages 180	22. Price

FINAL REPORT

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Prepared by:

Eshan V. Dave (PI)

Jo E. Sias (Co-PI)

Fausto Bisanti (Graduate Research Assistant)

Gabriele Tebaldi (Senior Researcher)

Department of Civil and Environmental Engineering
University of New Hampshire

February 2026

Final Report

2026-02



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The authors, the Vermont Agency for Transportation, and the University of New Hampshire do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to this report

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List of Abbreviations and Acronyms

AADT: Average Annual Daily Traffic

AASHTO: American Association of State Highway and Transportation Officials

AC: Asphalt content

ACM: Asbestos Containing Material

AIA: Asbestos Information Association

ASTM: ASTM International (formerly, American Society for Testing and Materials)

CKD: Cement Kiln Dust

CR: Cold Recycling

DMF: Design Mix Formula

DOT: Department of Transportation

EUAC: Equivalent Uniform Annual Cost

FDR: Full-Depth Reclamation

FHWA: Federal Highway Administration

GDOT: Georgia Department of Transportation

GHG: Greenhouses Gas

HIR: Hot In-Place Recycling

HMA: Hot-mix asphalt

ITS: Indirect Tensile Strength

JMF: Job Mix Formula

LCA: Life-Cycle Assessment

LCCA: Life-Cycle Cost Analysis

LKD: Lime Kiln Dust

MDD: Maximum Dry Density

MnDOT: Minnesota Department of Transportation

MPPC: Minimally Processed Post-Consumer

MR: Resilient Modulus

MW: Manufacturer Waste

NDOT: Nevada Department of Transportation

NESHAP: National Emissions Standards for Hazardous Air Pollutants

NH: New Hampshire

NPV: Net Present Value

OMC: Optimum Moisture Content

PAH: Polycyclic Aromatic Hydrocarbons

PC: Post-Consumer

PFAS: Per- and Polyfluoroalkyl Substances

PI: Principal Investigator

QC: Quality Control

RAP: Reclaimed Asphalt Pavement

RAS: Recycled Asphalt Shingles

RILEM: International Union of Laboratories and Experts in Construction Materials, Systems and Structures

SOA: Secondary Organic Aerosols

SP: Special Provision

SPLP: Synthetic Precipitation Leaching Procedure

TAC: Technical Advisory Committee

TCE: Trichloroethylene

TSR: Tensile Strength Ratio

TSS: Triaxial Shear Strength

UNH: University of New Hampshire

USGS: US Geological Survey

VAOT: Vermont Agency of Transportation

VTANR-DEC: Vermont Agency of Natural Resources-Department of Environmental Conservation

VTrans: Vermont Agency of Transportation

Executive Summary

This report presents the findings of Vermont Agency of Transportation (VTrans) Project GR1850, which evaluated the feasibility of using recycled asphalt shingles (RAS) as a mechanical stabilizer in full-depth reclamation (FDR) pavement rehabilitation. Motivated by Vermont's asphalt shingle recycling mandate and the need for sustainable, cost-effective rehabilitation strategies, the study examined whether processed and minimally processed post-consumer RAS could be incorporated into FDR mixtures without compromising mechanical performance, pavement service life, or environmental compliance.

Laboratory investigations were performed on FDR materials obtained from two VTrans projects—Marshfield-Danville and Cambridge-Johnson—blended with RAS at various contents. Mechanical characterization included indirect tensile strength (ITS), triaxial resilient modulus (MR), and triaxial shear strength (TSS), followed by mechanistic-empirical pavement performance predictions using MnPAVE. Results showed that increasing RAS content generally increased air voids and reduced strength and stiffness, particularly at higher dosages. However, mixtures containing 5% RAS demonstrated acceptable mechanical behavior when density was properly controlled. Importantly, minimally processed post-consumer RAS consistently outperformed processed RAS, providing improved cohesion and internal friction while maintaining stiffness and moisture resistance comparable to baseline FDR mixtures.

Environmental suitability was evaluated by testing leachate collected using the Synthetic Precipitation Leaching Procedure (SPLP) with testing following EPA SW-846 Test Method 8082A for Polychlorinated Biphenyls (PCBs) and EPA method 1633 for Per- and Polyfluoroalkyl Substances (PFAS). The results indicating no significant leaching concerns for FDR mixtures containing 5% RAS. Economic and environmental implications were assessed through life-cycle cost analysis (LCCA) and life-cycle assessment (LCA). Initial material costs were modestly reduced with RAS inclusion; however, long-term economic outcomes were governed primarily by predicted service life. When RAS incorporation did not reduce service life, life-cycle costs were comparable to or slightly better than conventional FDR. LCA results showed that greenhouse-gas impacts were largely dependent on material hauling distances; when RAS transport distances were similar to or shorter than aggregate haul distances, environmental impacts were neutral or marginally improved.

Overall, the study demonstrates that incorporating up to 5% minimally processed post-consumer RAS in FDR mixtures is a technically viable and sustainable option for pavement rehabilitation when project-specific material characteristics, compaction control, and logistics are carefully considered. Higher RAS contents are not recommended due to adverse effects on volumetrics and mechanical performance. The report concludes that field implementation and long-term monitoring are warranted to validate laboratory findings and support the development of guidance for practical adoption of RAS-stabilized FDR in Vermont and similar contexts.

CHAPTER 1: INTRODUCTION

This report presents the results of the Vermont Agency of Transportation (VTrans) Project GR1850 – Recycled Asphalt Shingles (RAS) as a Full Depth Reclamation (FDR) Mechanical Stabilizer. The main objective of the project was to evaluate the potential use of RAS as a mechanical stabilizing agent in FDR applications and to assess its feasibility from design, performance, and implementation perspectives.

Background and objectives

Asphalt shingles are the most commonly used roofing material in the United States, renowned for their durability and affordability. The United States stands as one of the largest producers and consumers of asphalt shingles globally, reflecting the nation's extensive construction industry and housing market. Asphalt shingles have long been favored for residential and commercial roofing applications due to their cost-effectiveness, versatility, and relatively easy installation process. In the United States, the annual quantity of waste asphalt shingles is estimated at about 10 million tons, with approximately 25,000 tons generated in Vermont alone (Vermont Department of Environmental Conservation). Vermont state law (10 V.S.A. § 6605m) requires that asphalt shingles be recycled, underscoring the importance of identifying sustainable and effective reuse strategies. Incorporating RAS into pavement infrastructure could represent a promising solution, offering both environmental benefits and economic advantages by diverting large volumes of waste from landfills.

This research focuses on the potential reuse of RAS in full-depth reclamation (FDR) operations, exploring whether this waste material can serve as a stabilizing agent in road base layers. The study aims to evaluate the feasibility of this approach by addressing two critical questions:

- Can RAS be utilized in its “as-is” condition from when it is generated as architectural waste, or does it require processing to resize it?
- Does RAS provide mechanical stabilization effects to FDR?

If RAS can achieve stabilizing effects comparable to those of non-recycled products, the cost-effectiveness and sustainability of FDR practices could be further enhanced while complying with recycling mandates and improving pavement performance.

Report organization

This report is organized into eight chapters:

- Chapter 1 introduces the motivation and scope of the project, providing background information on the generation and recycling requirements of RAS and outlining the research questions addressed in this study. It also includes the overall structure and content of the report.
- Chapter 2 provides a review of the current state of knowledge and practice related to RAS and FDR, with particular attention to environmental considerations, RAS processing, and non-traditional paving applications of RAS.
- Chapter 3 summarizes VTrans practices for specification of FDR materials and construction, including the evolution of special provisions and mix design requirements currently used in Vermont.
- Chapter 4 presents the materials collected for laboratory characterization. It focuses on the physical and chemical properties of these materials, offering an initial assessment of their suitability for reuse.

- Chapter 5 outlines the laboratory procedures used to mix, compact, and cure the specimens. It also describes the mechanical testing methods employed to evaluate the mechanical properties and performance.
- Chapter 6 presents the detailed laboratory characterization of the FDR baseline mixtures and mixtures incorporating 5% and 10% of processed RAS (passing the 3/8-inch sieve).
- Chapter 7 focuses on the evaluation of mixtures containing 5% minimally processed post-consumer RAS. It includes analysis of gradation, volumetric analysis, mechanical properties and performance, and compares the results to those obtained with processed RAS.
- Chapter 8 presents the economic and environmental evaluation of incorporating 5% minimally processed post-consumer RAS in FDR mixtures. The chapter includes an initial material cost comparison, a life-cycle assessment (LCA) of environmental impacts, and a life-cycle cost analysis (LCCA) based on predicted pavement service life and rehabilitation schedules.
- Chapter 9 provides a summary of the experimental findings and key conclusions regarding the feasibility and performance implications of incorporating both processed and minimally processed RAS as a mechanical stabilizer into FDR processes.
- Appendix A presents the results of the Synthetic Precipitation Leaching Procedure (SPLP) performed to evaluate the presence of potential environmental contaminants in the RAS samples.
- Appendix B presents the results of the Synthetic Precipitation Leaching Procedure (SPLP) performed to evaluate the presence of potential environmental contaminants in the field-derived recycled (FDR) material from the C-J site and on the C-J mixture containing 5% post-consumer (PC) RAS.

CHAPTER 2: LITERATURE REVIEW

A literature review was conducted by the research team as part of Task-1, concentrating on the state of the art and state of the practice with respect to use of RAS in FDR. The review focused on several key aspects, including the economic and environmental impacts associated with RAS use, the processing of RAS prior to its incorporation in pavement construction, and applications of RAS in paving beyond plant produced (hot-mixed) asphalt. In addition, the study examined full-depth reclamation (FDR) from both the material design perspective and construction processes. These topics were selected due to their direct relevance to the objectives of this research.

Use of RAS in road pavements

The utilization of recycled asphalt shingles (RAS) in road pavement has emerged as a promising approach to sustainable infrastructure development, offering environmental, economic, and engineering benefits. In the United States, where road networks are vast and constantly in need of maintenance and rehabilitation, the incorporation of RAS into asphalt mixtures has gained traction to address both the growing waste stream from roofing shingles and the demand for cost-effective and high-performance road materials. Recycled asphalt shingles contain valuable materials such as asphalt binder, aggregate, and fibers, making them suitable for reuse in pavement applications. By integrating RAS into asphalt mixes, road agencies and contractors can reduce reliance on virgin materials, conserve natural resources, and decrease the carbon footprint associated with road construction and maintenance activities.

The use of RAS in road pavement should be assessed in context of the implications to the performance characteristics of asphalt mixtures. The asphalt binder contributing to the asphalt mixtures from the recycled shingles usually have higher stiffness and viscosity, and this can improve the rutting resistance of asphalt mixtures. At the same time, due to the stiff nature, use of RAS can also potentially lower the cracking resistance of asphalt mixtures (Ding et al. 2019; Granzier-Nakajima et al. 2022).

From an economic standpoint, the use of RAS in pavement offers cost savings for road agencies and taxpayers. Recycling asphalt shingles diverts material from landfills, reducing disposal costs and potentially lowering tipping fees for waste management. Moreover, the availability of recycled shingles as a low-cost alternative to virgin materials can help mitigate the impact of fluctuating asphalt prices, providing stability to road construction budgets.

However, challenges exist in the widespread adoption of RAS in road pavement, including concerns related to material quality, processing techniques, and regulatory constraints. Efforts to address these challenges involve research and development initiatives aimed at optimizing RAS recycling processes, improving material characterization and performance testing methods, and establishing guidelines and specifications for the use of RAS in asphalt mixes.

Despite these challenges, the use of recycled asphalt shingles in road pavement represents a promising pathway towards sustainable infrastructure development, aligning with the principles of circular economy and resource efficiency. As innovations continue to drive advancements in recycling technologies and pavement engineering practices, the integration of RAS into road construction projects is expected to play an increasingly significant role in building resilient and environmentally responsible transportation networks.

Economic and environmental implications of RAS in pavement construction

Pavement construction and rehabilitation are major consumers of natural resources, making the incorporation of recycled materials into pavements a significant opportunity to conserve both materials and energy. However, the decision to recycle materials in asphalt paving mixtures is not solely driven by environmental concerns. Profitability plays a crucial role in the sustainability of recycling processes. Considering the current and predicted future price of virgin asphalt binders, the use of RAS in asphalt paving mixtures can offer economic benefits alongside lowering carbon footprint. The primary economic driver for asphalt shingle recycling is the cost savings derived by Hot Mix Asphalt (HMA) producers, as reported by Krivit (2005) and Johnson et al. (2010). Consequently, the main environmental benefits of RAS usage encompass avoiding the deposition of millions of tons of non-biodegradable material in landfills and conserving fossil fuels and aggregates. The growing industry of asphalt shingle recycling not only aims to address environmental concerns but also presents business opportunities, job creation, and revenue generation.

Various factors influence the potential cost savings associated with using RAS in pavement construction, including the type and amount of RAS used, the price of liquid asphalt, and landfill tipping fees. Estimates suggest that roof installation annually generates millions of tons of post-consumer and manufacturing waste, representing a significant resource for asphalt paving mixtures. An estimate of annual quantity of waste shingle in United States is 10 million tons and approximately 25,000 tons in Vermont (Vermont Department of Environmental Conservation, 2015). However, only a small percentage of this waste is currently recycled, posing environmental and economic challenges. As the price of crude petroleum, and thus liquid asphalt, increases, the value of RAS also rises. Therefore, finding suitable means of reusing these materials is essential for reducing their environmental liability and maximizing their economic potential. The present study on exploring use of RAS in FDR is an innovation exploration that can serve as a sustainable avenue to efficiently recycle shingles by leveraging the performance benefits of RAS to improve pavement longevity.

The adoption of standard specifications and recommended practices by organizations such as the American Association of State Highway and Transportation Officials (AASHTO) has facilitated the utilization of RAS in HMA, such as the AASHTO Provisional Standard MP 23-15 (Standard Specification for Reclaimed Asphalt Shingles for Use in Asphalt Mixtures). These guidelines enable HMA producers to design mixtures that meet the specifications of state and local transportation agencies, promoting the widespread use of RAS.

While concerns regarding potential water contamination from asphalt shingles exist, research suggests that the leaching of harmful components from RAS is generally negligible and below allowable limits for waterways (Granzier-Nakajima et al. 2022). However, it is essential to address potential concerns related to contaminants present in RAS, such as asbestos or other hazardous materials such as the Polycyclic Aromatic Hydrocarbons (PAHs) or Per- and Polyfluoroalkyl Substances (PFAS) through proper quality control and testing procedures to ensure environmental and human health protection throughout the recycling process (Townsend et al. 2007; Granzier-Nakajima et al. 2022).

The next two subsections summarize the list of the benefits and possible challenges associated with the use of recycled asphalt shingles in road pavements, as identified in literature.

Benefits

Waste Reduction:

Recycling asphalt shingles plays a crucial role in diverting millions of tons of non-biodegradable material from landfills. By recycling asphalt shingles, valuable landfill space is conserved, and the environmental burden of waste disposal is reduced (Townsend et al. 2007; Zhou et al. 2012).

Resource Conservation:

The recycling process contributes to the conservation of fossil fuels and aggregates by reducing the demand for virgin materials (Zhou et al. 2012). This practice promotes sustainability by minimizing the need for extraction and processing of finite natural resources.

Reduced Use of Virgin Binder:

Incorporating recycled asphalt shingles into pavement materials reduces the reliance on virgin aggregates and binder (U.S. EPA, 2013; Townsend et al. 2007; Zhou et al. 2012). This not only conserves resources but also lessens the environmental footprint associated with the extraction and production of virgin materials.

Energy Savings:

Recycling asphalt shingles into Hot Mix Asphalt (HMA) leads to significant energy savings compared to landfill disposal and the use of all virgin materials for HMA production. Studies have shown that the net energy requirement associated with recycling shingles is lower, contributing to overall energy conservation (Zhou et al. 2012).

Greenhouse Gas Emissions Reduction:

By utilizing RAS in asphalt production, emissions of greenhouse gases such as CO₂ equivalents are reduced (Cochran, 2007; U.S. EPA, 2013; Granzier-Nakajima et al. 2022). This reduction in emissions helps mitigate climate change impacts and promotes a more sustainable environment.

Offset of Virgin Asphalt Use:

Incorporating RAS offsets the use of virgin asphalt in HMA production, further promoting resource efficiency and sustainability in pavement construction projects (Townsend et al. 2007).

Volume Reduction of Landfill Debris:

The diversion of asphalt shingles from landfills reduces the volume of debris disposed of in these spaces. This reduction alleviates the strain on landfill capacity and extends the lifespan of landfill sites (Townsend et al. 2007).

Possible challenges

Several potential challenges must be addressed to ensure the safe and effective utilization of recycled asphalt shingles. Among these concerns, Polycyclic Aromatic Hydrocarbons (PAHs), Secondary Organic Aerosols (SOA), Per- and Polyfluoroalkyl Substances (PFAS), and asbestos are key areas of focus due to their potential health and environmental impacts.

Polycyclic Aromatic Hydrocarbons (PAHs)

PAHs are a group of semi-volatile organic compounds (SVOCs) naturally found in petroleum-based products like asphalt shingles. Some PAH compounds pose severe health risks, including cancers, kidney problems, cataracts, and jaundice (Abdel-Shafy et al. 2016). While laboratory studies indicate that PAHs do not readily leach from asphalt products (Townsend et al. 2007), emissions can occur when asphalt mixtures are heated during production, such as in the production of hot mix asphalt (HMA).

The impact of recycled asphalt shingles on PAH emissions is not well understood, although it is known that asphalt from roads and roofing produces secondary organic aerosols (SOAs), especially when exposed to heat and solar radiation. Mitigation measures, such as the addition of PAH filters at processing facilities, can reduce PAH emissions by up to 90% (Townsend et al. 2007).

Polycyclic aromatic hydrocarbons (PAH), however, are not water soluble, but they can be readily absorbed into plants and animals, and persist in the environment (Abdel-Shafy et al. 2016).

Nevertheless, available research suggests that PAH leaching from recycled asphalt shingles is generally negligible and below allowable limits for waterways (Abdel-Shafy et al. 2016; Granzier-Nakajima et al. 2022).

Secondary Organic Aerosols (SOAs)

SOAs are pollutants produced by asphalt, particularly during hot and sunny days when exposed to heat and solar radiation (Khare et al. 2020). Asphalt from roads, roofing, and other sources can contribute to SOA pollution, which has been associated with cardiorespiratory health risks, particularly in southeastern states (Pye et al. 2021).

Per- and Polyfluoroalkyl Substances (PFAS)

Per- and polyfluoroalkyl substances (PFAS) are a large class of synthetic “forever chemicals” used for their water- and oil-repellent properties. PFAS have been used in roofing materials; for example, PFAS may be applied to coat asphalt shingle granules to enhance solar reflectivity of roofs (PFAS in Building Materials - Green Science Policy Institute). A key concern with PFAS is their extreme persistence: the U.S. EPA notes that many PFAS “break down very slowly and can build up in people, animals, and the environment” (EPA, 2023). Thus any PFAS incorporated into shingle coatings or sealants will remain indefinitely and can accumulate in recycled asphalt materials.

PFAS can enter recycled asphalt shingle (RAS) waste streams in several ways. One notable pathway is contamination from aqueous film-forming foam (AFFF) used at airports and firefighting training areas. A recent review reports that “airfields and paved firefighting training surfaces are particularly affected due to extensive use of AFFF,” and that PFAS contamination in asphalt from these areas has not been widely studied (Douglas et al., 2023). PFAS residues from such sources can persist in milled pavement and contaminate recycled materials. In fact, PFAS are so tenacious that they “can accumulate in the environment and in materials” where they were used (Dashnaw, 2024). Initial laboratory studies suggest that asphalt’s bitumen binder can “encapsulate” PFAS, potentially limiting their immediate release when RAS is reused (NAPA, 2026). UF researchers report that PFAS in foam-impacted pavements were “well encapsulated when recycled” in new asphalt mixtures (NAPA, 2026). However, the long-term leaching behavior of PFAS from recycled asphalt remains uncertain, and ongoing research is examining whether PFAS might gradually migrate out of pavement over time.

Exposure to PFAS is associated with serious health and environmental risks. Peer-reviewed studies, supported by EPA, have linked PFAS exposure to reproductive and developmental problems, liver and kidney damage, immune system suppression (e.g. reduced vaccine response), endocrine disruption, elevated cholesterol, and increased risks of certain cancers (particularly kidney, testicular, and possibly prostate) (EPA, 2023). Because PFAS do not degrade and can travel through water and soil, PFAS from recycled asphalt (e.g. via stormwater runoff or landfill leachate) could pose long-term risks to human and ecological health if not controlled.

Mitigation of PFAS in RAS requires careful management. Regulatory agencies now treat many PFAS as hazardous. Some states (e.g. New York) have issued guidance requiring PFAS sampling and cleanup criteria for soils and water, even mandating EPA Method 1633 for PFAS analysis (Dashnaw, 2024). In

practice, this means that RAS containing PFAS above background levels may need to be identified and handled under PFAS regulations. Possible mitigation steps include pre-screening shingles (especially those from known AFFF-affected sites) for PFAS, isolating or avoiding use of PFAS-contaminated materials, and adding sorbents or stabilizers (such as activated carbon) to bind PFAS if recycled asphalt is used. Until more is known, recycling programs should monitor PFAS in RAS and follow emerging guidelines to ensure that PFAS in recycled shingles do not contaminate pavements, soils, or groundwater.

Asbestos

Asbestos, a naturally occurring fibrous mineral, was historically used in shingle manufacturing for reinforcement and fireproofing purposes. The principal route of exposure to asbestos is through inhalation of asbestos fiber-containing dust, making the grinding process of asphalt shingle recycling potentially hazardous. Asbestos-related diseases, including cancer, asbestosis, and mesothelioma, may take years to develop after exposure, with symptoms appearing decades later (Townsend et al. 2007). In the 1970s, asbestos faced bans in numerous applications due to the recognized health risks associated with chronic exposure, leading to cancers and respiratory diseases among affected workers. While some asphalt roofing products containing asbestos were still manufactured post-1970s, the material's usage dwindled (Zhou et al. 2012; Townsend et al. 2007). According to the US Geological Survey (USGS), although asbestos mining ceased in the US in 2002, imports persisted, with about 55% of the 3,500 tons consumed in 2007 allocated to roofing products like coatings, cements, and mastics (USGS, 2007). The Asbestos Information Association/North America (AIA/NA) confirmed the phase-out of asbestos in asphalt shingle production by the early 1980s, although data on asbestos content in roofing products, including asphalt shingles, remains scant. Johns-Manville Corporation notably produced asbestos-asphalt roofing shingles from the late 1800s to 1979, containing 35-50% asbestos (Townsend et al. 2007).

The National Emissions Standards for Hazardous Air Pollutants (NESHAP) defines asbestos containing material (ACM) as any material containing more than 1% asbestos, and shingles are considered a potential ACM.

While roofing shingles typically have a service life of 12-25 years, re-roofing practices, where new shingles are layered atop old ones, complicate post-consumer shingle waste composition. Roofing shingle waste may sometimes contain two or three layers of old shingles (RMG, 2001). Despite this, only about 1.5% of over 27,000 asphalt shingle samples analyzed in the US were deemed asbestos-containing materials (ACM), with many detections attributed to non-shingle materials like mastic (Townsend et al. 2007). While the presence of asbestos in RAS may decrease over time as older roofs are replaced, precautions must be taken to minimize exposure during recycling operations.

In conclusion, while the recycling of asphalt shingles offers significant benefits, it is essential to address potential issues related to PAHs, SOAs, and asbestos to ensure the safety of workers, nearby residents, and the environment. Proper handling and mitigation measures, along with further research into the environmental impacts of RAS, are necessary to maximize the benefits of asphalt shingle recycling in road pavement construction.

Processing and resizing of asphalt shingles for use in pavement construction

The processing of recycled asphalt shingles is a critical step in their utilization in pavement construction. Resizing asphalt shingles for road pavement involves a multi-step process starting with the collection and separation of waste shingles from both post-manufacture and post-consumer ("tear-off") sources (Hand & Aschenbrener, 2023). Annually, around 10 million tons of asphalt shingle waste are generated

in the United States, with approximately 5 to 10% of this being post-manufacture scrap (Sengoz and Topal, 2005; VANR, 1999; Zickell, 2003). Post-manufacture scrap is typically uniform and homogeneous, remaining from specific types of shingle manufacturing processes. The majority of asphalt shingle waste in the United States, however, is post-consumer (National Association of Home Builders, 1998) with approximately 7 to 9 million tons of discarded post-consumer shingles generated annually (VANR, 1999), results from building activities such as construction, demolition, and renovation. Both types of waste may contain contaminants such as wood, plastic wrap, and other materials that must be separated before processing.

Once separated, the shingles undergo size reduction through various grinding and screening methods, including the use of shredders, hammer mills, and screens (Plunkett et al. 2002; Willis, 2013). This process removes contaminants such as nails and paper and reduces the shingles to the desired particle size. Water may be added during grinding to control dust and keep the shingles cool (Plunkett et al. 2002; Willis, 2013). The resulting resized shingles, known as recycled asphalt shingles (RAS), have diverse applications in road construction, including use in hot mix asphalt (HMA), cold patching, dust control, road and driveway aggregate base, and even as a fuel supplement in cement kilns (Plunkett et al. 2002). Effective resizing techniques contribute to the sustainable management of asphalt shingle waste, reducing landfilling and promoting the reuse of valuable materials in road infrastructure projects.

The size of the recycled asphalt shingles is a crucial factor in determining their suitability for various applications. Larger particle sizes (3/4–inch plus) are typically used for aggregate supplement, while smaller grades (1/2–inch minus) are suitable for Hot Mix Asphalt (HMA) (Krivit, 2007). Finer grinding facilitates better blending of RAS with virgin binders, thus increasing the amount of usable asphalt from the shingles and enhancing economic benefits (Williams, 2019; Willis, 2013; Krivit, 2007). Shingles that are too large may not melt and mix adequately with the virgin binder, increasing the overall requirement for virgin binder and compromising pavement quality (Willis 2013). According to the American Association of State Highway and Transportation Officials (AASHTO), stringent guidelines dictate that shingles should be ground to ensure that 100 percent of the material can pass through a 1/2–inch sieve (AASHTO MP 15-09). States such as Georgia, Oregon, South Carolina, Texas, Massachusetts, and Virginia have specifications which reflect AASHTO's guidelines. Other states transportation agencies such as North Carolina, Minnesota, Vermont, Indiana, Iowa, New Jersey, Pennsylvania, and Connecticut have different specifications for shingle sizes. The requirements used by these transportation agencies in their standard specifications are given in Table 1.

Table 1: Shingle size requirements for Plant Produced Asphalt Mixtures.

State	Percentage passing 3/4"	Percentage passing 1/2"	Percentage passing 3/8"	Percentage passing #4	Percentage passing #100	Percentage passing #200
Connecticut	-	-	100%	-	-	-
Georgia	-	100%	-	-	-	-
Indiana	-	-	100%	-	-	-
Iowa	-	100%	98% min	90% min	-	-
Massachusetts	-	100%	-	-	-	-
Minnesota	-	100%	-	90% min	-	-
New Jersey	100%	-	-	-	-	-
North Carolina	-	-	100%	-	-	-
Oregon	-	100%	90% min	-	-	-
Pennsylvania	-	-	100%	-	-	-
South Carolina	-	100%	-	70 - 95%	15% max	7% max
Texas	-	100%	-	-	-	-
Vermont	-	-	100%	-	-	-
Virginia	-	99% min	-	80% min	-	-

Note: "-" = not applicable

RAS processing challenges

The type of shingles also influences the grinding process. Shingle grinders have observed that it's simpler to grind post-consumer (PC) shingles compared to manufacturer waste (MW) shingles (Plunkett et al. 2002; Willis, 2013). This is because PC shingles, having been exposed to rooftop conditions for some time, tend to become stiffer and easier to shred. As mentioned earlier, the addition of water during grinding can help mitigate the effects of high temperatures, easing the process (Townsend et al. 2007; Plunkett et al. 2002; Willis, 2013). Achieving homogeneity in the processed shingles is crucial to ensure uniformity in size and composition. Inconsistent grinding may result in larger pieces of recycled material, commonly referred to as "corn flake" shingles (Figure 1), which can compromise the quality of asphalt mixtures (Willis, 2013). Screening during processing is essential to ensure that all material meets size specifications, with any material failing to pass the criteria requiring regrinding to ensure proper size uniformity (Townsend et al. 2007; Willis, 2013).



Figure 1: Potential challenge of “corn flake” shingles. (Willis, 2013)

Asphalt shingles are durable composite materials primarily made using fiberglass backing, although historically, cellulose was more common. The composition of tear-off shingle scrap has evolved over time, with fiberglass now predominant (Krivit, 2007). The changing composition necessitates ongoing research to document the relative share of cellulose versus fiberglass shingles and understand the differences in processing and final product quality. For instance, the proportion of asphalt binder typically ranges from 15 to 25% in modern fiberglass shingles, whereas in older cellulose shingles, it tends to be higher, typically falling between 30 to 40% (Newcomb et al. 1993; Krivit, 2007).

Additionally, the age of tear-off shingles substantially impacts RAS product quality, particularly the oxidation process of the asphalt binder within shingles (Krivit, 2007; Townsend et al. 2007). Asphalt binder content can also be a cause of processing problems as it can contribute to the heat generated during grinding; this leads to a common issue of the RAS product having a strong tendency to re-agglomerate or "chunk up" after stockpiling (Willis, 2013; Krivit, 2007). A potential remedy is blending with Recycled Asphalt Pavement (RAP) or bituminous aggregate (BA) sand (Krivit, 2007; Plunkett et al. 2002).

In conclusion, effective processing and resizing of asphalt shingles are imperative to harness their potential as a sustainable resource in road pavement. By adhering to strict grinding guidelines, employing suitable equipment, and ensuring homogeneity in the processed material, the utilization of recycled asphalt shingles can contribute significantly to enhancing pavement performance and promoting environmental sustainability in road construction projects. The review conducted in this study did not find any previous documentation of using RAS within FDR and thus no information was found with respect to pre-processing of RAS to prepare them for inclusion in the FDR process.

Alternative uses of RAS besides HMA

Shingle recycling has evolved over nearly three decades, primarily finding high-value applications as a feedstock supplement in hot mix asphalt (HMA) for road and parking lot paving. Recycled asphalt shingles (RAS) bring the value of their asphalt binder content and hard mineral aggregates to HMA pavement, enhancing its performance (McGraw et al. 2007; Zhou et al. 2012; Krivit, 2005; Krivit, 2007).

State departments of transportation (DOT) have conducted independent tests to assess the impact of adding RAS on pavement performance, finding that up to 5% shingles by weight of mixture perform comparably to traditional pavement (Krivit, 2005). However, higher percentages of shingles without mix adjustments may affect HMA performance due to the stiffer asphalt binder in RAS.

Recycled asphalt shingles have potential for several applications besides the HMA, some of which offer the opportunity to consume them in large quantities. Alternative uses are in cold patch asphalt, as aggregate in rural roads and base layers, for asphalt binder extraction, for new shingle production, for energy recovery, and as structural fill. While there exists a very large body of literature on use of RAS in HMA, this study is not focused on that application. Thus, the review conducted and reported herein focusses only on non-HMA use of RAS in paving as well as other general applications.

Cold Patch Asphalt

Cold patch asphalt is commonly used for temporary repairs on roads and driveways. The use of recycled asphalt shingles as cold patch is a practice that has been employed extensively in some regions of the US (Plunkett et al. 2002; Townsend, 2007; Krivit, 2007). Cold patch generally consists of asphalt, aggregate, and a solvent. Ground asphalt shingles are typically mixed with aggregate and an emulsion to produce a patching mix. The combination of hard asphalt, uniform and angular aggregate, and the entrained cellulose or glass fibers apparently make for a quality product that may rival “high performance” cold patch (Plunkett et al. 2002; Krivit, 2007). There have not been recent references for use RAS in cold patches.

In addition, the use of cold patches containing recycled shingles provides potential economic savings due to longer life and reduced maintenance costs compared to cold patches not containing shingles, and ease of use due to lighter weight, lack of required equipment, and time flexibility (Townsend, 2007).

Aggregate in rural roads and base layers

While there's a growing trend in using processed roofing shingles as aggregate in road construction or maintenance, there's a notable lack of scientific research on its performance.

One noteworthy study conducted by the Iowa Department of Transportation in 1995 examined the use of ground shingles as a surface treatment on an unpaved road (Marks & Petermeier 1997). In this study, approximately 300 tons of tear-off shingles were ground into pieces less than 1 inch, while another 600 tons were ground into less than 2-inch pieces. These two sizes of shingles were then mixed together before application. About 500 tons of the processed shingles were spread onto freshly laid crushed limestone. The shingles were graded back and forth to achieve a uniform mixture of shingles and limestone, approximately 2.5 inches thick. After two years of observation, the study found that the use of shingles was highly effective for dust control on rural roads. Additionally, it improved lateral vehicle control, reduced the loss of granular material into ditches, and resulted in a quieter and smoother roadway.

Bituminous Roadways, a shingle processor based in Minnesota, and the Minnesota Department of Transportation collaborated on a study regarding the utilization of processed scrap shingles for dust suppression on gravel roads. Initial observations have been promising, indicating reduced dust levels, improved road conditions, and less frequent re-application compared to conventional dust suppressants. Additionally, Bituminous Roadways has investigated the potential of using processed shingles treated with an emulsifier for smaller-scale applications like driveways and parking areas (Plunkett et al. 2002).

Vermont Agency of Transportation (VTrans) and Vermont Agency of Natural Resources-Department of Environmental Conservation (VTANR-DEC) worked on a study focused on determining the possible

benefits of RAS as an aggregate additive for gravel roads. The final report describes construction methods and results related to six RAS/gravel road projects installed between 2018 and 2020 in Vermont (Anderson, 2020). The projects included between 15 and 25% RAS content. The results were promising for all projects, highlighting how RAS/gravel roads reduce dust and require less maintenance than conventional gravel roads. The report also pointed out, however, that to achieve these benefits, RAS/gravel roads must be well graded and compacted.

Meanwhile, Commercial Paving, Inc. in Scarborough, Maine, incorporates tear-off scrap roofing into various paving projects. They utilize processed shingle material as part of a blend called "R&R", which includes aggregate, crushed and screened demolition waste, virgin aggregates, and an asphaltic emulsifier. "R&R" is tailored to meet different specifications and is employed as base and subbase material in paving applications (Plunkett et al. 2002).

Warner et al. (2012) explored the potential utilization of recycled asphalt shingles in aggregate base and subbase layers for roadway construction. Their research involved blending different proportions of RAS with native soils from Wisconsin, USA, and assessing various characteristics such as California bearing ratio, Proctor, and resilient modulus. They also investigated the effects of adding fly ash and asphalt emulsion to enhance test results. The study revealed significant variations in RAS properties depending on the source, as there were no standardized methods for creating RAS in the USA at the time. Simple addition of RAS to the aggregate was found inadequate for aggregate base applications; however, a 50:50 blend of backfill material and RAS proved acceptable for backfilling purposes. Although the addition of fly ash improved the resilient modulus of the mixture, it was insufficient to meet acceptance criteria. Nonetheless, the study provided valuable insights for designing future experiments.

MacEachern (2019) conducted a study on the suitability of recycled asphalt shingles in the base layer, which serves both structural and drainage purposes. He observed that, when incorporated into natural aggregates, the presence of RAS adversely affects the permeability coefficient and this reduction is attributed to the compacted RAS's face-to-face structure, which significantly impedes water seepage through the mixes. Dynamic compaction techniques may exacerbate the issue by breaking down RAS particles into finer particles, further decreasing hydraulic conductivity by filling voids in the mixes. This underscores the complexity of assessing drainage performance in RAS-containing mixes and highlights the need for further investigation into suitable materials and compaction methods to address this issue effectively.

While less controlled research has been conducted on the use of recycled asphalt shingles in aggregate base and aggregate sub-base applications, successful utilization has been observed in unbound aggregate or gravel base for road construction. Some shingle recyclers have been blending tear-off RAS into aggregate for road construction with success (Krivit, 2007). Processed shingles can also be blended with recycled asphalt pavement and concrete, as long as the overall bitumen content remains within state-specified maximums. However, concerns have been raised regarding the high asphalt content and fiber content of RAS potentially impeding precipitation drainage within the aggregate base (Krivit, 2007).

While some states lack specifications for this application, various demonstration projects and testing are underway to address this gap. There is a need to empirically demonstrate the quality and performance of RAS-derived aggregate products. One suggested approach involves blending RAS with a maximum of 10 percent volume to limit asphalt content and potential negative impacts on the drainage characteristics of aggregate base (Krivit, 2007).

Furthermore, the use of larger-sized RAS products, such as those from screened "overs" (that is, not passing the trommel screen with 1/2-inch mesh), for aggregate base is a recognized practice within the industry (Krivit, 2007). This practice underscores the versatility and potential applications of RAS in road

construction, albeit requiring further research and validation for optimal performance and quality assurance.

Asphalt Binder extraction

Ding et al. 2019 introduced a novel method for recycling asphalt shingles into asphalt mixtures by separating the RAS binder from RAS materials through a dissolve and extraction process using a mixed solvent. The properties of the extracted RAS binder, such as modulus, can be controlled by adjusting the components of the mixed solvent. This extracted RAS binder can then be utilized as common asphalt in pavement construction, without restrictions on the amount of RAS that can be incorporated into the mix. The proposed method is inspired by the relationship between the polarity and viscosity of asphalt fractions. The use of a mixed solvent comprising heptane and Trichloroethylene (TCE) allows for the selective dissolution of RAS binder components based on their polarity, thereby enabling precise control over the properties of the extracted binder. By employing this separation process, RAS can serve not only as a partial binder replacement but also as a standalone binder or rejuvenator for recycled asphalt pavement (RAP). This approach has the potential to increase the percentage of asphalt shingles used in the mixture and enhance control over the performance of asphalt pavement, offering promising advancements in sustainable pavement construction practices.

New shingle manufacturing

The concept of shingle-to-shingle recycling, where recycled asphalt shingles (RAS) are processed into new shingles, is still in its infancy and lacks widespread commercial implementation (Townsend 2007; Krivit, 2007). Limited data is available in the public domain regarding this process. One patent application outlines a specific method for milling RAS with limestone or dolomite aggregate to create a finely refined powder suitable for use as an admixture by shingle manufacturers. This process aims to produce a homogeneous powder free of re-agglomeration, ready for incorporation into new shingles (Krivit, 2007).

One of the challenges hindering closed-loop recycling of asphalt shingles is the need to meet stringent feedstock product specifications, which can pose difficulties in maintaining consistent quality throughout the recycling process. As research and development continue, addressing these challenges will be crucial for advancing shingle-to-shingle recycling into a viable and sustainable practice within the industry.

Energy recovery

Asphalt shingles may also be recycled to recover the energy (i.e., used as a fuel supplement), for example in cement kilns. The organic portion of the shingle is used as a fuel supplement while the inorganic portion of the shingle remains in the kiln and becomes part of the kiln's clinker, which is a solid material that has sintered into nodules or lumps (Townsend 2007; Krivit, 2007).

Advantages of this method include the higher calcining and sintering temperatures in the kiln, which potentially allow for the complete conversion of asbestos into a non-asbestos mineral form (Krivit, 2007). Moreover, the material specifications for RAS in cement kilns may be less stringent compared to those for paving applications, allowing for the use of coarser particle sizes and potentially eliminating the need for grinding the roofing material before introduction and to strip it of debris other than shingles (e.g., nails, wood, felt, "felt" for ice barrier, metal flashing) (Krivit, 2007).

Structural fill

Studies on the application of recycled asphalt shingles in hot mix asphalt production indicate that using more than 5% RAS in HMA can adversely affect its creep stiffness and tensile strength, limiting its

utilization to only 10 to 20% of total asphalt shingle waste (Button et al. 1995, Plunkett et al. 2002). An alternative application with the potential to utilize a larger volume of asphalt shingle waste is structural fill, including highway embankment fills or backfill behind retaining walls.

Preliminary compression tests have revealed that pure RAS is too compressible for structural fill use (Benson et al. 2010). To address this, researchers have explored the addition of granular materials such as bottom ash and foundry slag to improve the engineering properties of RAS (Soleimanbeigi, 2012). Bottom ash, a coal combustion byproduct, and foundry slag, collected from metal casting industries, have been extensively studied and proven suitable for various engineering applications. The study evaluates relevant engineering properties of these mixtures, including compaction characteristics, hydraulic conductivity, compressibility, shear strength, and coefficient of earth pressure at rest. Results demonstrate that the addition of bottom ash and foundry slag significantly reduces the compressibility of RAS while improving drainage capacity and shear strength (Soleimanbeigi, 2012).

Overall, RAS, bottom ash and foundry slag mixtures emerge as favorable lightweight materials for use in embankment fills or backfill behind retaining walls, offering potential solutions for the effective utilization of asphalt shingle waste in construction projects (Soleimanbeigi, 2012).

Full Depth Reclamation (FDR)

Full Depth Reclamation (FDR) is a road rehabilitation technique that involves recycling and reusing the existing road materials in place to create a new, improved base layer for the roadway. Often stabilizing agents such as asphalt emulsions and Portland cements are used within the process to improve the mechanical characteristics of the FDR layer, this is primarily a design decision that is based on the quality of base, subbase and subgrade materials that are reclaimed with the exiting asphalt pavement. This process is considered an environmentally friendly and cost-effective approach to road maintenance and repair. The environmental benefits are realized due to in-place nature of this process combined with recycling of existing materials. Both minimize energy demands and greenhouses gas (GHG) emissions.

In a typical FDR project, the existing road pavement and a portion of the underlying materials are pulverized using specialized machinery, creating a mixture of aggregate and old asphalt. This mixture is then typically mixed with new aggregates or recycled materials (e.g. reclaimed asphalt pavement (RAP), add rock or crushed concrete) and stabilizing agents such as asphalt emulsion, foamed asphalt, Portland cement, lime or fly ash to improve the strength and durability of the base layer and minimize the negative effects of moisture (Wegman et al. 2017; Owino et al. 2022). The process not only revitalizes the old road materials but also helps to create a stable foundation for new pavement.

This method offers several benefits and limitations that impact its suitability for various road projects. It is a sustainable road rehabilitation method that recycles 100% of the old pavement material in place, requiring minimal new materials, hauling, and traffic control. This leads to economic and environmental benefits (Figure 2), such as conserving materials, fuel, and energy (Ghasemi et al. 2018; Morian et al. 2012).

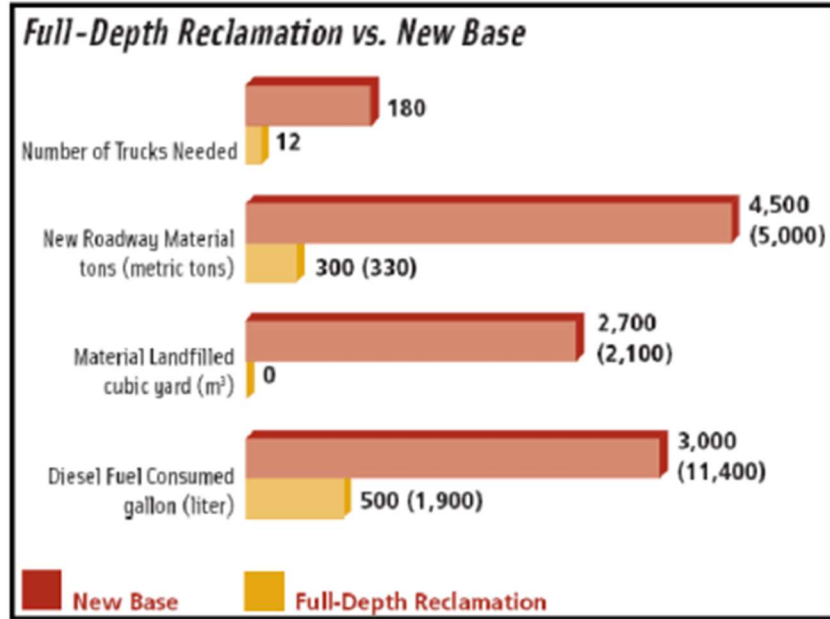


Figure 2: Economic and environmental benefits of FDR. (from Morian et al. 2012)

A life-cycle cost analysis showed that FDR costs about 16% less in maintenance over 50 years than a conventional mill and overlay method (Diefenderfer et al. 2011). In addition, the Georgia Department of Transportation (GDOT) found that the use of FDR reduced agency construction costs by 42% compared to conventional methods (Lewis et al. 2006). In addition to economic and environmental benefits, FDR improves structural capacity, restores pavement profiles, and, when chemical stabilizers are used, can reduce susceptibility to moisture. However, FDR faces limitations such as curing and subgrade support challenges during construction, and it requires specific weather conditions (Ghasemi et al. 2018). There is also a lack of a nationwide accepted design method for FDR, limiting its application in areas with less experience (Ghasemi et al. 2018). A problem was found, for example, in the implementation of FDR in the roadways of Georgia and Nevada. After 20 years of practicing FDR, NDOT found that the greatest lifetime of a pavement structure rehabilitated with FDR is 15 years; subsequently, different forms of fatigue begin to appear, especially when cement is used as a stabilizing agent (Le, 2016). Inadequate construction techniques can also lead to cracking and fatigue issues.

A major challenge for using FDR is therefore to find a single mix design proportion, which is difficult since existing base materials vary from site to site as well as often vary along the length of the project.

Stabilization methods and mix design considerations

This subsection examines the different stabilizing methods used in FDR mixtures and how the type and quantity of the additives affect the overall efficacy of FDR. In addition, the development of design methods for mixtures and their constituent materials will be addressed.

Stabilization additives

Full Depth Reclamation (FDR) is a road rehabilitation technique that involves recycling and stabilizing existing pavement materials to restore and improve roadways. This method is particularly effective for addressing pavement issues that surface treatments alone cannot resolve and can be summarized in four steps: pulverization, stabilization, shaping and compaction (Morian et al. 2012). In FDR, the existing

asphalt and base materials are pulverized to depths ranging from 6 to 9 inches, with maximum depths seldom exceeding 12 inches, depending upon the existing asphalt layer thickness (ARRA, 2001; Ghasemi et al. 2018; Le, 2016). Care must be taken to ensure the stabilized layer remains within these limits to avoid complications, especially on roads with thick asphalt layers and high traffic volumes.

The selection of stabilization method and additives is a critical aspect of the FDR process, as these agents play a significant role in the performance and durability of the rehabilitated road. Their effectiveness is influenced by various factors, including traffic levels, the condition of the pavement structure, and material properties (Ghasemi et al. 2018). These stabilizing methods are:

- Mechanical
- Chemical
- Bituminous

Figure 3 illustrates the stabilization methods and materials.

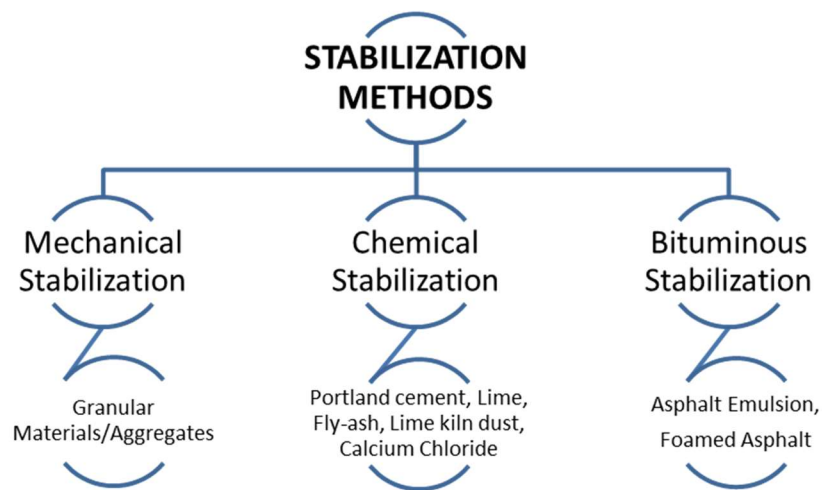


Figure 3: Stabilization methods and materials.

Mechanical stabilization

Mechanical stabilization is a technique especially used when dealing with high traffic levels (Ghasemi et al. 2018). The process consists of pulverizing, mixing, and compacting the reclaimed materials with the inclusion of granular materials such as virgin aggregates, reclaimed granular materials, or recycled asphalt pavement (RAP) if additional structural support is needed (ARRA, 2001). The addition of granular materials is determined by factors such as the gradation and physical properties of the reclaimed materials, existing roadway geometry, achievable mixing and compaction depths, and economic considerations (ARRA, 2001; Morian et al. 2012).

In cases where the reclaimed material is too coarse or fine, adjustments with finer or coarser granular materials may be necessary to achieve a uniformly graded mixture for optimal compaction and structural stability (ARRA, 2001).

Mechanical stabilization can also be used with additional bituminous or chemical stabilizing additives. The use of RAS in conjunction with FDR in the present study is expected to offer a degree of mechanical stabilizing that can enhance stiffness of the RAS stabilized FDR.

Chemical stabilization

Chemical stabilization in Full Depth Reclamation (FDR) enhances strength and stability by creating a matrix that binds aggregate particles together through chemical reactions. These reactions can occur between stabilizers and the material being stabilized, such as lime with clay, or through the formation of cementing compounds from the additives themselves, like Portland cement (Wegman et al. 2017). It is essential to use the correct amount of stabilizing agent; too little may not provide adequate binding, while too much can increase the rigidity of the base layer, potentially leading to cracking of the overlying pavement surface (Wegman et al. 2017).

Common chemical stabilizers include Portland cement, lime, class C or F fly ash, cement kiln dust (CKD), lime kiln dust (LKD), calcium chloride or magnesium chloride (Reeder, 2017). By mixing these additives with the pulverized asphalt pavement and subsurface materials, chemical stabilization can achieve a strong bond between particles within the FDR layer, resulting in improved performance and durability (King & Akakin, 2023; Reeder, 2017).

Bituminous Stabilization

Bituminous stabilization is achieved by mixing the pulverized asphalt pavement and subsurface materials with either asphalt emulsion or foamed asphalt (Reeder, 2017). This method can also be combined with other stabilizers like Portland cement for optimal FDR performance.

The use of bituminous stabilization provides several benefits, including waterproofing aggregates by coating them, achieving strength through adhesive bonding, and protecting against temperature fluctuations and varying loading rates (Wegman et al. 2017). Care must be taken to use the right amount of additive to achieve the desired waterproofing and strength without causing instability in the mixture.

Bituminous stabilization is typically conducted using either:

- **Asphalt Emulsion:** A mixture of asphalt binder, water, and an emulsifier that, when it "breaks," causes the asphalt binder to adhere to aggregate materials. This process does not require heat, so it does not contribute to aging the asphalt.
- **Foamed Asphalt:** A mixture of compressed air and a small amount of cold water injected into hot asphalt binder (140°C to 170°C). This creates a binder that adheres to fine particles, acting as a mortar to bind coarse aggregates. With foamed asphalt, around 5 to 20% of the material should pass the 200 sieve to prevent issues such as "stringers" or asphalt-rich agglomerations that can weaken the mixture (Wegman et al. 2017).

Both methods provide effective solutions for enhancing the stability and performance of FDR mixtures. In the present study, the research team anticipates a degree of bituminous stabilizing action from RAS in addition to mechanical stabilization. To aid this action, research team is considering to use recycling agents that can aid in mobilization of the asphalt binder from RAS into the FDR.

Mix design approaches

Although FDR is a versatile method, there is no nationally accepted procedure for FDR mix design, similar to other recycling methods such as Hot In-Place Recycling (HIR) and Cold Recycling (CR). Various agencies have employed different FDR mix design methods, but only a few have been documented in the literature (ARRA, 2001). Table 2 shows the results of a survey conducted by UNH among U.S. State Transportation Agencies as part of recent NCHRP Synthesis on FDR Practices (National Academies of Sciences, Engineering, and Medicine, 2025). Agencies were asked whether they use Mechanical FDR or FDR, whether they have standard specifications for FDR materials and construction, and whether they have standard specifications for FDR mix design.

Table 2: Survey conducted by UNH on FDR practices.

Agencies that reported that they do not use Mechanical FDR or FDR		AZ; DC; HI; KS; KY; NY; MD
Does your agency have a standard specification for materials and construction of FDR?		
	Responding Agencies	
Yes	AK; AL; CA; CO; CT; FL; GA; ID; IN; LA; MA; ME; MI; MS; MT; NC; ND; NE; NH; NV; OH; PA; RI; SC; SD; TN; TX; UT; VA; VT; WI; WV; WY	
No	AR; DE; OR; MO; MN; NJ; PR	
Does your agency have a standard specification for mix design of FDR?		
	Responding Agencies	
Yes	AL; AK; CA; FL; GA; IN; ME; MN; NC; ND; NM; NV; OH; PA; PR; SC; TN; TX; VA; VT; WV; WY	
No	AR; CO; CT; DE; ID; MA; MI; MO; MT; MS; NE; NH; NJ; OR; RI; SD; UT; WI	
Unsure	LA	

When utilizing FDR, the mix design process is crucial to optimize the amount of stabilizing agent and ensure the physical properties of the reclaimed mix meet the project's needs. The process begins with evaluating historical, structural capacity, and material property assessments to determine whether pulverization alone will be adequate. If additional mechanical stabilization is required, additional granular materials may be incorporated. In situations where mechanical stabilization is not possible due to cost or geometric constraints, chemical or bituminous stabilization may be necessary (ARRA, 2001). The selection of a suitable stabilizing agent depends on factors such as the thickness of the existing pavement, properties of the reclaimed material, the level of strengthening required, availability of stabilizing agents, economics, and previous experience (ARRA, 2001). It is important to select the optimal amount of stabilizing additive to ensure the rehabilitated pavement performs well over its service life. One key aspect influencing the design and additive selection is the angularity and uniformity of the aggregate base layer. These properties can impact the performance and stability of the final mixture, as they determine how well the materials will interlock and bond with one another (Wegman et al. 2017). Other factors to consider when selecting the appropriate recycling method and additive type include drainage, shoulder characteristics, and the extent of surface distress (Wegman et al. 2017). These adjustments can influence the decision on the most cost-effective recycling method and additive choice for the project. Ultimately, optimizing these parameters will lead to a more successful and durable FDR project.

Constituent materials of FDR

- **Reclaimed Asphalt Pavement (RAP)/Aggregates:** The quality and amount of RAP/granular materials used in Full Depth Reclamation (FDR) can be affected by a range of factors such as moisture content, source of aggregate, asphalt binder content and its current condition, and the gradation of the RAP. Given that the FDR process operates at relatively low temperatures, there is little to no reactivation of the asphalt binder within the RAP. As a result, the main consideration when evaluating RAP materials for FDR projects is the gradation of the RAP

(Tebaldi et al. 2014). The gradation is substantially controlled by the type of reclaiming equipment as well as its operational parameters (such as, drum rotation speeds).

- **Asphalt Stabilizers:** Asphalt binders are utilized as stabilizing agents in the two forms previously described, i.e. asphalt emulsion or foamed asphalt.
- **Active Fillers (Chemical Stabilizers):** Active fillers, which are characterized by a high void content, improve the dispersion of asphalt binder in the mixture, facilitate moisture control and favor curing when used with asphalt emulsion (SABITA, 2020). Common chemical stabilizers include Portland cement, lime, class C or F fly ash, cement kiln dust (CKD), lime kiln dust (LKD), calcium chloride or magnesium chloride (Reeder, 2017), and they can be used alone or in combination. According to research and experience, the success of a chemical stabilizer cannot be accurately predicted without conducting trial tests during mix design.
- **Water:** Moisture plays a very important role in FDR mixtures and in cold recycling in general. It is necessary to consider the overall fluid content of the mix, which includes the moisture content of the asphalt binder. The fluids in cold recycling mixtures consist of the moisture content of the aggregates before mixing, the water content in the asphalt emulsion, the amount of asphalt in the emulsion or residual asphalt in the case of stabilization with foamed asphalt, and any additional water added to the mixture, such as that needed for hydration of cement or lime.

A laboratory mix design is essential for determining the ideal quantities and physical characteristics of the reclaimed mix, regardless of the type or variety of materials involved. It is important to recognize that this process may not perfectly replicate field conditions during construction, but with the right combination of materials, a highly efficient FDR mix can be formulated, leading to a durable FDR structure.

Construction processes

This section outlines the key construction processes involved in FDR projects, including pulverization, stabilization, shaping, and compaction. The proper execution of each step is critical to the success of an FDR project. It is common practice in United States, including in Vermont, for overall FDR process to be in two passes. The pulverization is conducted in the first pass and in the second pass stabilization is accomplished.

Pulverization

The FDR process begins with pulverizing the existing asphalt pavement and a portion of the underlying base, subbase, or subgrade materials. This step is accomplished using a roadway reclaimer equipped with a cutting drum and tungsten carbide-tipped cutting tools. The cutting head typically rotates in an "up-cut" direction, opposite to the reclaimer's tire rotation, which improves pulverization and reduces the size of reclaimed materials (ARRA, 2001; Morian et al. 2012). Modern reclaimers also have the capability to add water or other fluid stabilizing agents during the reclaiming process (Reeder, 2017). The added water not only is relevant to obtaining suitable densities but also to act as a cooling medium for the cutting tools on the reclaimer. An example of the FDR construction process showing the water tanker and reclaimer used for the first reclamation pass of VTrans Marshfield-Danville project (Figure 4).



Figure 4: Reclamation pass of VTrans Marshfield-Danville project in 2024.

The choice of how much of the underlying granular base to mix with the pulverized asphalt layers is influenced by several factors (ARRA, 2001), including:

- **Thickness Comparison:** Thickness of the asphalt layers relative to the granular base, subbase, or subgrade thickness.
- **Physical Properties of Asphalt Layers:** Gradation and other physical characteristics of the pulverized asphalt layers.
- **Physical Properties of Granular Material:** Gradation and other physical characteristics of the granular base.
- **Subgrade Soil Condition:** Type and state of the subgrade soils underneath the pavement.
- **Use of Stabilizing Agents:** Whether any chemical, mechanical, or bituminous stabilizing agents will be added during the FDR process.
- **Desired Outcome:** Specific goals and final outcome desired from the FDR process.

Stabilization

After pulverization, the selected stabilizing additive is added to the pulverized surface. Stabilization can involve mechanical, chemical, bituminous, or a combination of agents to improve the mixture's strength and durability. In a second pass of the reclaimer, the additive and water are mixed into the pulverized materials (Morian et al. 2012). This stage is crucial for achieving the desired physical properties and performance of the FDR mix.

Shaping

Shaping involves grading the pulverized material to achieve the desired road profile and cross-section. This process ensures that the final product aligns with design specifications and creates a uniform surface for the subsequent compaction phase. A motor grader is typically used for this purpose (Ghasemi et al. 2018).

Compaction

The final step in the FDR construction process is compaction, which ensures maximum density and strength of the rehabilitated road. Compaction is matched to the depth of the reclamation, and various types of rollers are used, including padfoot, smooth drum vibratory, and pneumatic tire rollers (Reeder 2017; Morian et al. 2012). The initial compaction phase is followed by rough grading and intermediate shaping, leading to final compaction and fine grading to achieve the required density and smoothness (ARRA, 2001). The initial compaction using sheep-foot roller is shown in Figure 5 for the stabilized FDR construction in Minnesota.



Figure 5: Initial compaction of FDR using Sheep-foot or Pad-foot Roller.

Additional Considerations

Moisture Content: It is essential to maintain the optimal moisture content in the reclaimed mixture for efficient compaction and hydration. Water may be added to the surface during compaction to achieve more uniform curing (Wegman et al. 2017).

Additive Proportioning: Proportioning of stabilizing agents and other additives should align with the laboratory mix design to ensure the final product meets performance expectations.

Consistent Mixing: It is important to ensure homogeneity of recycled material properties, which results in homogeneous performance.

Surface Finishing: After compaction, the surface may be finished with a seal or wearing course for added protection and durability (ARRA, 2001).

CHAPTER 3: VTRANS PRACTICES FOR DESIGN AND CONSTRUCTION OF FDR

This chapter presents a summary of VTrans practices for specification of FDR materials and construction. The content of this chapter was prepared using the provisional standards and project specifications from recent FDR construction projects that were provided to the research team by the technical advisory committee (TAC) of this study. The content of this chapter is based on FDR material designs that have been used in previous five construction projects, the VTrans FDR special provision (SP) that was used until 2023 as well as a new FDR special provision that is planned to be used from 2024 onwards. This chapter is organized to first present a summary of the previous VTrans FDR special provision, which is referred to as “2023 VTrans SP” in this report, including highlights of the main changes that are used in the current special provision, which is referred to as “2024 VTrans SP” in this report. Thereafter a summary in terms of mix design differences between the five recently used FDR materials is presented.

Summary of the VTrans special provision for Full Depth Reclamation (FDR) with emulsified asphalt

Full Depth Reclamation (FDR) consists of removing a volume of material by coarse milling (when specified), and pulverizing and stabilizing the existing roadway by adding emulsified asphalt and Portland cement to the lines, gradations, and dimensions as typically specified in the contract. This work includes shaping, finishing, fine grading, and compaction of the stabilized base materials to the depth, width, grade, and desired density as specified in the project contract. The work is required to be performed in accordance with these specifications, plans, and the appropriate provisions of VTrans Section 310 of the Standard Specifications.

Material

The 2023 VTrans SP for FDR references use of Portland cement (VTrans item 701.02), emulsified asphalt (VTrans item 702.4) and water (VTrans item 745.01) as the primary material sources that can be used in construction of FDR. Emulsified asphalt for base stabilization is required to be of the type MS-2h, CMS-2h, SS-1h, or CSS-1h.

The 2024 VTrans SP also include high float emulsions allowing type HFMS-2, HFMS-2h, HFMS-2s, and CSS-1. The 2024 VTrans SP also provides gradation requirements (Table 3) of the pulverized material, which consists of the existing pavement blended with underlying subbase material and additional aggregate material.

Table 3: Gradation requirements (from 2024 VTrans FDR SP).

Sieve Designation	Percentage by Mass (Weight) Passing Square Mesh Sieves
3 inch (75.0 mm)	100
1-1/2 inch (37.5 mm)	80 - 100
No. 4 (4.75 mm)	30 - 60

Mix Design

, While the 2023 FDR SP did not include explicit pass/fail mix design criteria and relied on Marshall-stability, flow and quotient parameters (AASHTO T 245), the 2024 FDR SP introduced defined mix design requirements. The requirements are summarized in this subsection. The FDR mix design is required to meet the design criteria requirements as shown in Table 4.

Table 4: Design requirements (2024 VTrans SP).

Test Method	Criteria
Indirect tensile strength, dry subset, AASHTO T 283	40 psi min.
Ratio of residual asphalt to cement	2.5:1.0 min.

The construction contractor is required to develop an FDR mix design consisting of blended aggregate, RAP, emulsified asphalt, and Portland cement. To obtain material to develop the mix design, the contractor is required to sample existing pavement to represent the reclaimed aggregates that would be expected to result from the first pass of the reclamation process. A minimum of four samples representative of the quarter points of the entire length of the project should be taken. The sampling process may occur either before or after milling, however, if it occurs before milling, any alternate means of removing the excess pavement to conduct the simulation shall be approved by the VTrans personnel. The construction contractor is required to develop and submit a material sampling plan for review and approval by the agency a minimum of 5 working days prior to obtaining mix design samples. At a minimum, the sampling plan shall include the number of samples, location of samples, and the method of sampling and backfilling. Additional FDR and subbase blends may be required in design analysis as directed by the VTrans engineer.

The AASHTO R 109 (Standard Practice for Emulsified Asphalt Content of Full-Depth Reclamation Mixture Design) is the method that is required to be used to develop a mix design in accordance with AASHTO M 347 (Standard Specification for Materials for Full-Depth Reclamation Mixtures with Emulsified Asphalt), except only meeting specified design requirements in Table 4. The resultant job mix formula (JMF) contains the final blend of FDR material with cumulative percent passing on each of the specified sieve, emulsified asphalt type and content as a percent of total weight of FDR material, Portland cement content as a percent of total weight of FDR material, maximum density, and recommended water content range as a percentage of the dry weight of FDR material.

A minimum of 10 working days are required for agency to evaluate the submitted mix design. A copy of all test data used in developing the mix design, including graphs, is required with the submittal of the mix design to the agency.

The engineer in charge may approve changes in the design's job-mix formula or discontinue use of the design if placement, finishing, or compaction characteristics are determined to be unsatisfactory.

Equipment

Any additional equipment used by the contractor beyond those specified below are required to be approved by the engineer based on its suitability to produce the specification requirements.

Compaction

According to the 2023 VTrans SP, the contractor is required to utilize a vibratory pad-foot roller having a dynamic force of 25 tons for the breakdown compaction and this is followed by intermediate rolling using a single or tandem steel drum static roller of 12 to 14 tons. A pneumatic tire roller may be used to achieve design requirements associated with in-place density. After compaction, the roadway surface is required to be rolled with pneumatic-tired rollers to create a close-knit texture.

Reclamation

The construction contractor is required to utilize a self-propelled, traveling rotary reclaimer or equivalent machine capable of cutting through existing roadway material to depths of up to 16 inches with one pass. The equipment shall be capable of pulverizing the existing pavement, base, and subgrade “in-place”, and mixing any added materials to the specified depth. The cutting drum should have the ability to operate at various speeds (rpm), independent of the machine’s forward speed, to control oversized material and gradation.

The contractor should provide and utilize equipment that will produce the completed FDR emulsion base. In addition, the equipment used should be capable of automatically metering the emulsion with a variation of less than +/- 2% by weight of the emulsion. Calibration records are required to be provided to the project engineer before use of any equipment as requested.

VTrans requires “up-cutting”, that is the reclaimer’s drum should rotate in the opposite direction of the reclaimer’s tires or as per the manufacturer’s recommendation. Additional passes may be conducted as necessary to pulverize the material to meet the gradation in agreement with the design mix formula (DMF).

Weather limitations

VTrans only allows to perform stabilization from May 15th to September 1st, inclusive, unless requested in writing and subsequently approved by the project engineer. Emulsified asphalt stabilization is not allowed to be performed when soil temperatures are expected to be less than 40°F within the 72 hours of stabilization and/or freezing temperatures are expected within seven calendar days of curing operations. Stabilization is also not allowed when rainfall is expected within 24 hours of the emulsion application. Rainfall prior to appreciable curing of FDR can cause objectionable runoff, over-saturate the pulverized or mixed materials leading to unstable conditions that will compromise the safety of the roadway for public use, or compromise the stability of the treated material. The construction contractor is required to monitor the weather and sequence operations accordingly and provide necessary repairs to work that has been damaged by inclement weather. The quality control program is required to adequately address these factors.

Quality Control

The contractor is required to sample, test, and evaluate the FDR with Emulsified Asphalt process in accordance with the procedures and minimum frequencies specified as shown the in Table 5 for 2023 and 2024 VTrans SP.

Table 5: Minimum quality control frequencies for 2023 and 2024 VTrans SP.

Test or Action	Frequency	2023 VTrans SP	2024 VTrans SP
Density	1 per 1,000 ft/lane	AASHTO T 310 or ASTM D 7830	ASSHTO T 310 or ASTM D 7830
Stability, Flow, Quotient	1 per day	ASTM D 1632	-
Moisture Content	3 per day	AASHTO T 217, AASHTO T 255, ASSHTO T 310, or ASTM D 7830	AASHTO T 217, AASHTO T 255, ASSHTO T 310, or ASTM D 7830
Gradation and AC Content of Final Product	1 per day	AASHTO T 30*, AASHTO T 164, or AASTHO T 308	AASHTO T 30 (dry), AASHTO T 164, or AASTHO T 308
Yield for Cement and Emulsion	2 per day at even intervals	-	Tank check

* Except procedures 7.1.1 - 7.4

- Not provided

Minimum process control parameters

The QC requirements for FDR construction for VTrans provide the minimum process control parameters.

A list of required process control parameters is shown below:

- (1) Initial FDR, Emulsified Asphalt simulation process (also commonly referred to as the “test strip”).
- (2) Make and type of reclaimer. [2024 VTrans SP]
- (3) Make and type of rollers and their respective location. [2024 VTrans SP]
- (4) Gradation and asphalt content results.
- (5) Moisture content behind the reclaimer.
- (6) Emulsion application rate.
- (7) Water addition rate and distribution.
- (8) Mixing-via drum speed, reclaimer ground speed, depth.
- (9) Accurate moisture density curves and targets.
- (10) Specifics of the testing methods used for density and moisture content. [2024 VTrans SP]
- (11) Stability, flow, and quotient values.
- (12) Final density after compaction (both passes).
- (13) Curing plan.

Construction requirements

Geometry and limits of Pulverization, Reclamation and Grading

The stabilized material is required to extend to the depth and width of the roadway (as specified in construction plans) and shall not be more than 2 inches narrower than the proposed edge of stabilized material nor more than 6 inches wider than the planned edge of stabilized material. The design depth and line of stabilized material is required to be fully homogenous of emulsion stabilizer, shaped, graded and compacted to within 1 inch of the design depth.

Stabilization

Emulsified asphalt is required to be the stabilizing agent and its type and dosage is required to be in accordance with the project design mix formula (DMF). The emulsion is required to be delivered to the reclaimer and distributed by the reclaimer in such a way as to ensure a uniform distribution across the roadway. At no time shall the reclaimer forward speed progress at a rate is allowed to be greater than 30 feet per minute to ensure that sufficient and uniform mixing of emulsion is occurring within the FDR layer.

Longitudinal joints between successive reclamation passes are required to overlap a minimum of 6 inches to prevent cold joints with potential for failure at the seams. The contractor is required to sequence the operations in order to complete all pulverization and mixing activities across the full width of the roadway within 36 hours (within the same work shift for the 2024 VTrans SP).

Compaction

For production field operations, the moisture content is required to be within 2% of the optimum moisture content. Monitoring of the processed FDR as well as final graded material is required in accordance with the accepted QC plan, this is to ensure that the material is uniformly compacted. The 2023 VTrans SP requires a 92% to 96% of the theoretical maximum density from the Proctor testing. The 2024 VTrans SP has adopted use of theoretical maximum density obtained from the field control section, 95% to 105% of this maximum density require for the whole project.

The 2023 VTrans SP also states that prior to field density testing and whenever a gradation sample is taken, the contractor shall determine the asphalt content of the reclaimed material in accordance with AASHTO T 308.

Curing and treatment of stabilized base

After the recycled material has been compacted, traffic, including the construction equipment, shall not be permitted on the pulverized pavement for a minimum of two hours. Prior to placement of any bituminous overlay, the pulverized pavement is required to cure until the free moisture is reduced to 2% free moisture or less, by the total weight of mix in accordance with the AASHTO T 217. However, the pulverized pavement is required to be covered by bituminous pavement within 14 calendar days after it has been mixed and compacted.

The 2024 VTrans SP states that dust control treatment should be applied on the FDR sections to reduce the production of nuisance dust and reduce the hazard to the traffic. When a dust control agent is not specified in the construction plans, water or calcium chloride can be used.

Control section

The 2024 VTrans SP includes the construction of a control section (“test strip”) to establish the theoretical maximum density and to verify moisture content at the beginning of the FDR, and through the project as needed.

The construction of a control section assures that the equipment and procedures are suitable for the work specified and establish the target maximum density and moisture content. The theoretical maximum density is defined to be the density readings when dry density has stabilized and there is less than 1 pcf increase for the final four roller passes of each roller.

The control section is required to be full lane width and a minimum of 500 feet long. No further reclamation is allowed to be performed until all aspects of the control section and the theoretical maximum density are approved. Thereafter the same equipment as used for building the accepted test sections is to be used for performing the FDR work on the project.

The control section is also used to verify the optimum moisture content, four quarter point samples are taken from the initial test section and combined to produce a representative sample and tested for optimum moisture content in accordance with AASHTO T 180, Method D (modified Proctor test with 6 inch mold), using a minimum of 4 moisture contents.

The initial control section is also used to determine if supplemental aggregate are needed to comply with the gradation requirements. Four quarter point samples are taken from the initial test section and combined to produce a representative sample and tested for gradation using AASHTO T 30.

Summary of FDR material composition used in recent VTrans projects

It is important to note that the emulsion content in projects developed under the 2023 VTrans SP was typically based on Marshall stability, flow, and quotient values obtained using AASHTO T 245, whereas the 2024 VTrans SP requires the use of AASHTO R 109 in conjunction with AASHTO M 347 and specified design criteria. Therefore, this distinction should be considered when comparing mix designs from previous projects to those developed under the current specifications.

A summary in terms of differences in the mix designs of the FDR materials that have been used in the five recent VTrans FDR construction projects is presented in this section. The mix design reports for all of these projects are provided in the appendix to this report. Table 6 shows the materials used with their respective percentages and including chemical and bituminous stabilizers. In addition, peak dry density and optimum moisture content are shown. Observing the different projects, it can be noted that four of them include the addition of between 12 and 35% of crushed gravel. Instead, in all of them an emulsified asphalt of grade CSS-1H as bituminous stabilizer in contents ranging from 2.6 to 4% by weights of the reclaimed materials, in addition to a Portland cement content of between 0.5 and 1%. It is evident that the optimum moisture content decreases with the addition of crushed gravel.

Table 6: Different VTrans mix designs.

PROJECT	MATERIAL	DESIGN BLEND [% by wt.]	PEAK DRY DENSITY [pcf]	OPTIMUM MOISTURE [%]
Marshfield-Danville NH PS19(1) [2023]	First Pass FDR (20% Hot mix asphalt and 80% subbase)	69% of RAP and aggregates	135.9	6.30%
	Second Pass FDR (Added fine-graded crushed gravel)	31% of RAP and aggregate		
	Portland cement	0.5% of reclaimed material		
	Emulsified Asphalt	4% of reclaimed material		
Brattleboro-Newfane STP 2940(1) [2023]	First Pass FDR (25% Hot mix asphalt and 75% subbase)	88% of RAP and aggregates	138	6.50%
	Second Pass FDR (Added fine-graded crushed gravel)	12% of RAP and aggregate		
	Portland cement	0.5% of reclaimed material		
	Emulsified Asphalt	3% of reclaimed material		
Wilmington-Brattleboro NH 2971(1) [2022]	FDR Material	75% of RAP and aggregates	143.7	6.24%
	Crushed Gravel	25% of RAP and aggregates		
	Portland cement	1% of reclaimed material		
	Emulsified Asphalt	2.7% of reclaimed material		
Johnson-Morristown STP 2919(1) & Morristown STP 2020(1) & Johnson STP 030- 2(35) [2021]	FDR Material	100% of RAP and aggregate	138.1	7.20%
	Portland cement	1% of reclaimed material		
	Emulsified Asphalt	3.3% of reclaimed material		
Stowe-Morristown STP PS19(3) [2020]	FDR Material	64% of aggregate, RAP and cement (dry components)	141.8	6.00%
	Crushed Gravel	35% of aggregate, RAP and cement (dry components)		
	Portland cement	1% of aggregate, RAP and cement (dry components)		
	Emulsified Asphalt	4% of reclaimed material		

The Marshall stability, flow, and quotient (stability/flow) values for the five VTrans projects are shown in Table 7. It can be noted from this data that between the five FDR projects there is fairly wide range of stability, flow and quotient values, each one showing between 60 and 70% variations with respect to average of the five projects. This indicates that mechanical properties of FDR are expected to have a reasonably broad range depending on the project. Thus for the proposed study, it would be preferable

to gather samples from more than one construction project to ensure that a range of materials were considered.

Table 7: Stability, Flow and Quotient values for the five different VTrans projects.

PROJECT	STABILITY [lbs]	FLOW [0.01 inch units]	QUOTIENT [lbs./inch]
Marshfield-Danville NH PS19(1) [2023]	4235.1	21.0	201.94
Brattleboro-Newfane STP 2940(1) [2023]	3266.9	22.3	146.5
Wilmington-Brattleboro NH 2971(1) [2022]	4490.9	16.3	275.5
Johnson-Morristown STP 2919(1) & Morristown STP 2020(1) & Johnson STP 030-2(35) [2021]	4400	31.5	139.68
Stowe-Morristown STP PS19(3) [2020]	2626.6	12.0	218.9

CHAPTER 4: EXPERIMENTAL PLAN

This chapter presents the materials collected for the laboratory characterization. It focuses on the physical and chemical properties of these materials, offering an initial assessment of their suitability for reuse, and outlines the experimental plan adopted for their testing.

Selection of projects for sampling

Based on the literature review and observations from the review of the five previous VTrans FDR projects, the research team determined that it was important to consider more than one source of FDR material for laboratory evaluation. Two 2024 VTrans projects were selected for sampling FDR materials for this project:

- Marshfield-Danville NH PS19(1)
- Cambridge-Johnson STP 2925(1)

Material sampling and initial characterization

RAS

Two different types of RAS were sampled, a manufacture waste (MW) from Indiana, and a post-consumer (PC) waste from Vermont. MW were collected in a processed condition, passing the 3/8-inch sieve, while PC were collected passing the 3/8-inch sieve and in their unprocessed (“as is”) condition (Figure 6).



Figure 6: Processed (left) and unprocessed (right) RAS.

Laboratory characterization to assess the physical properties and the possible presence of environmental contaminants was conducted to evaluate RAS potential as stabilizing agents in FDR processes. The results are summarized in the subsections below. The two sources of RAS collected, along with relevant information such as their assigned labels, source locations, and approximate collection dates, are summarized in Table 8.

Table 8: Details of the two RAS sources (assigned labels, locations, and collection dates). MW = Manufacture-waste; PC = Post-consumer.

Label	Source location	Approx. date of collection
MW	Indiana	July 2024
PC	Vermont	September 2024

Environmental contaminant testing

The presence of potential environmental contaminants in the RAS was evaluated by obtaining leachate using the Synthetic Precipitation Leaching Procedure (SPLP) procedure (SW-846 Method 1312) and testing it for semi volatile Organic Compounds (SVOCs) using SW-846 Method 8270E, Polychlorinated Biphenyls (PCBs) using SW-846 Method 8082A and Per- and Polyfluoroalkyl Substances (PFAS) using EPA Method 1633. This analysis aimed to ensure that the use of RAS in road construction would not pose risks to soil or groundwater quality. The testing was conducted by Eurofins Environment Testing New England (North Kingstown, Rhode Island) and the full report is attached as Appendix A. A TAC member for the research project confirmed that the use of asbestos in roofing shingles has been restricted for more than 40 years, thus, no testing for asbestos was included in this study.

The results show that no significant concentrations of semi volatile Organic Compounds (SVOCs) or Polychlorinated Biphenyls (PCBs) were detected in either of the RAS materials. These test results alleviate the concerns for presence of PAHs in RAS that was initially identified in literature review. However, as shown in Table 9 and Table 10, the analysis did identify the presence of Per- and Polyfluoroalkyl Substances (PFAS) in both RAS sources. There is no national threshold value for PFAS concentration in solid waste by EPA, however, there is 4 PPT (approx. 4 ng/L) concentration limit for drinking water, thus, leachate extracted from solid waste should be below this limit. The values presented in Table 9 and Table 10 for both MW and PC shingles exceed this limit.

Table 9: Per- and Polyfluoroalkyl Substances (PFAS) detected in MW.

<i>Sample: MW</i>		
Analyte	Result	Unit
<i>Perfluoropentanoic acid (PFPeA)</i>	2.18	ng/L
<i>Perfluorooctanoic acid (PFOA)</i>	9.39	ng/L
<i>Perfluorooctanesulfonic acid (PFOS)</i>	40.6	ng/L
<i>Perfluorooctanesulfonamide (PFOSA)</i>	4.85	ng/L
<i>N-ethylperfluorooctanesulfonamidoacetic acid (NEtFOSAA)</i>	7.47	ng/L

Table 10: Per- and Polyfluoroalkyl Substances (PFAS) detected in PC.

<i>Sample: PC</i>		
Analyte	Result	Unit
<i>Perfluorohexanoic acid (PFHxA)</i>	1.97	ng/L
<i>Perfluoroheptanoic acid (PFHpA)</i>	3.57	ng/L
<i>Perfluorooctanoic acid (PFOA)</i>	41.5	ng/L
<i>Perfluorononanoic acid (PFNA)</i>	8.54	ng/L
<i>Perfluorodecanoic acid (PFDA)</i>	5.26	ng/L
<i>Perfluorooctanesulfonic acid (PFOS)</i>	226	ng/L
<i>Perfluorooctanesulfonamide (PFOSA)</i>	8.44	ng/L
<i>N-ethylperfluorooctanesulfonamidoacetic acid (NEtFOSAA)</i>	32.7	ng/L

For completeness, Table 11 presents the PFAS Soil-to-Groundwater Screening Values (Table 755.02A), which are currently adopted in Vermont when evaluating materials such as manufactured topsoil for potential environmental impacts. These screening values represent threshold concentrations in the solid material intended to ensure protection of groundwater quality.

It is important to note that these limits are based on direct testing of the solid material, whereas the present study evaluated PFAS concentrations through leachate generated using the Synthetic Precipitation Leaching Procedure (SPLP). Therefore, the results obtained in this study are not directly comparable to the soil-to-groundwater screening values. However, the inclusion of these criteria provides useful context for interpreting PFAS concentrations in RAS materials, as highlighted by the TAC feedback. A direct comparison would require PFAS testing on the solid RAS material rather than leachate extraction.

Table 11: PFAS Soil-to-Groundwater Screening Values (Table 755.02A)

PFAS Analyte	Chemical Abstract Service (CAS) Number	Soil to Groundwater Screening Value (µg/kg)
Perfluoroheptanoic acid (PFHpA)	375-85-9	0.84
Perfluorohexane sulfonic acid (PFHxS)	355-46-4	0.38
Perfluorononanoic acid (PFNA)	375-95-1	0.44
Perfluorooctane sulfonic acid (PFOS)	1763-23-1	3.40
Perfluorooctanoic acid (PFOA)	335-67-1	1.60

Physical properties

The particle size distribution of the processed RAS was obtained by sieve analysis (ASTM C136) and is shown in Figure 7. The MW asphalt shingles contained a notably higher fraction of fine particles than the PC asphalt shingles, a distinction that may influence both the mixing process and the performance of the stabilized material in FDR applications.

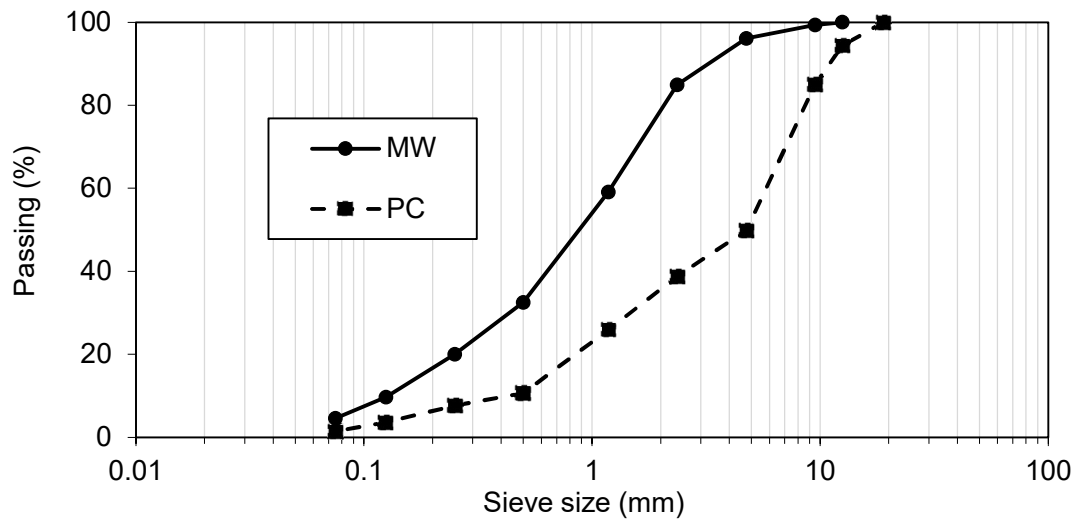


Figure 7: Particle size distribution of manufacture waste (MW) asphalt shingles and post-consumer (PC) asphalt shingles.

A cohesion test was conducted on the processed RAS samples to evaluate the potential activity of the asphalt binder within the shingles and its ability to contribute to bonding action in the mixture. The test consists of an Indirect Tensile Strength (ITS) test (ASTM D6931) conducted on 100% RAS specimens and allows to evaluate the material strength in terms of ITS, which is a function of the maximum applied load and specimen geometry. Through the cohesion test, the material can be classified as "active" or "inactive," depending on the ability of the residual binder to bond the particles together after compaction. Figure 8 shows the results of the ITS test performed on specimens compacted by a gyratory compactor at two different temperatures (158 and 284°F). The results revealed that MW exhibited a higher binder activity potential. This is consistent with the fact that MW shingles have never been exposed to service conditions and retain a more active, unaged binder compared to the hardened, aged binder found in PC shingles.

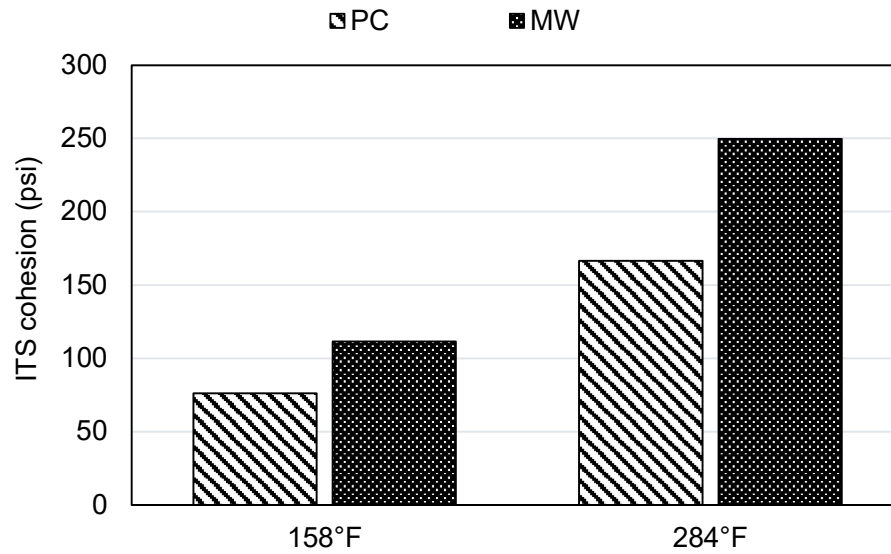


Figure 8: Cohesion test results of manufacture waste (MW) asphalt shingles and post-consumer (PC) asphalt shingles.

FDR materials

FDR materials from the Marshfield-Danville (M-D) (Figure 9) and Cambridge-Johnson (C-J) (Figure 10) projects were sampled during construction. Approximately 1,600 pounds of first-pass FDR material and 750 pounds of crushed gravel were collected along with samples of asphalt emulsion and cement from both projects.



Figure 9: Marshfield-Danville materials sampling.

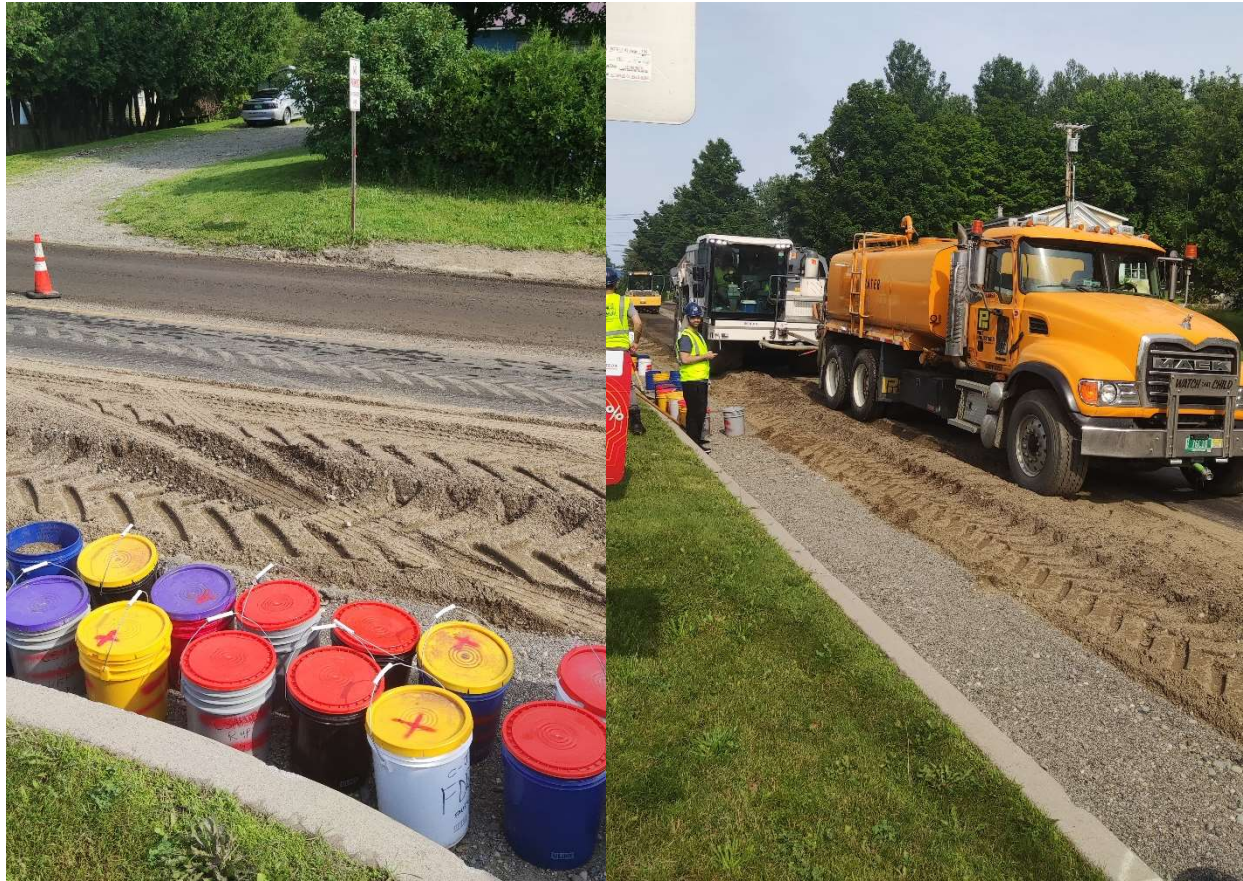


Figure 10: Cambridge-Johnson materials sampling.

Physical properties

The particle size distribution of both sources of FDR material was obtained by a classical sieving process (ASTM C136) and it is shown in Figure 11. Both materials can be classified as well-graded, as they exhibit a continuous distribution of particle sizes across a broad range. However, differences in the shape and position of the gradation curves are evident.

The M-D FDR curve is generally shifted upward in the finer particle size range, indicating a higher percentage of fines and a finer overall gradation. In contrast, the C-J FDR presents a slightly coarser distribution, with lower percentages passing in the fine range and a more balanced distribution across intermediate and coarse particle sizes. These differences in gradation are important in the context of RAS incorporation, this is discussed more in detail later in this report.

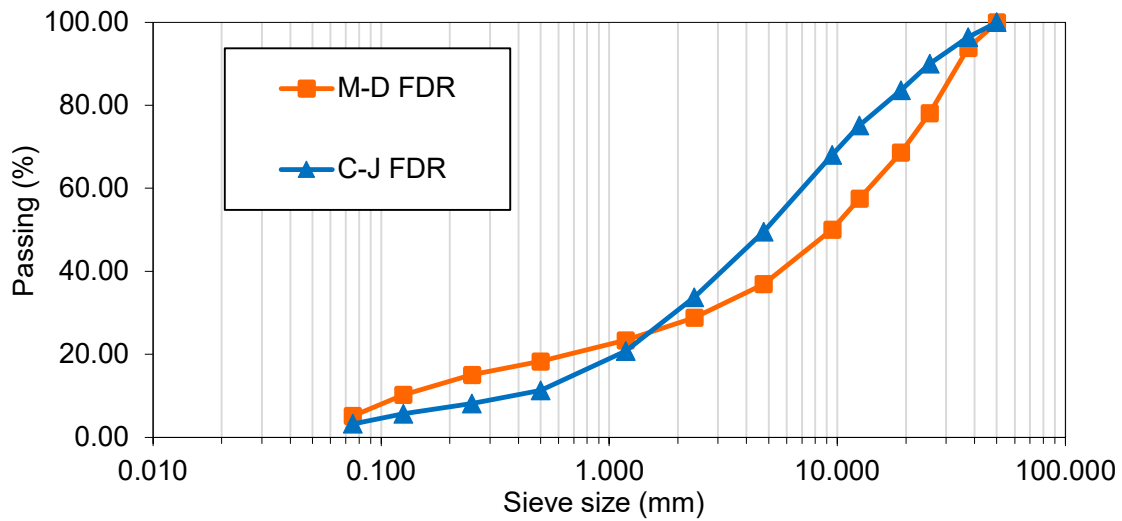


Figure 11: Particle size distribution of Marshfield-Danville FDR (M-D FDR) and Cambridge-Johnson FDR (C-J FDR)

Maximum dry density and optimum moisture content (OMC) were determined by modified Proctor compaction tests (ASTM D1557). The tests were performed on specimens obtained from the combination of FDR material and crushed gravel, following the mix design of the two VTrans projects. Figure 12 and Figure 13 show the moisture-density curves of M-D FDR material and C-J FDR material. OMC and maximum dry density (γ_d) of the two sources of FDR material are shown in Table 12.

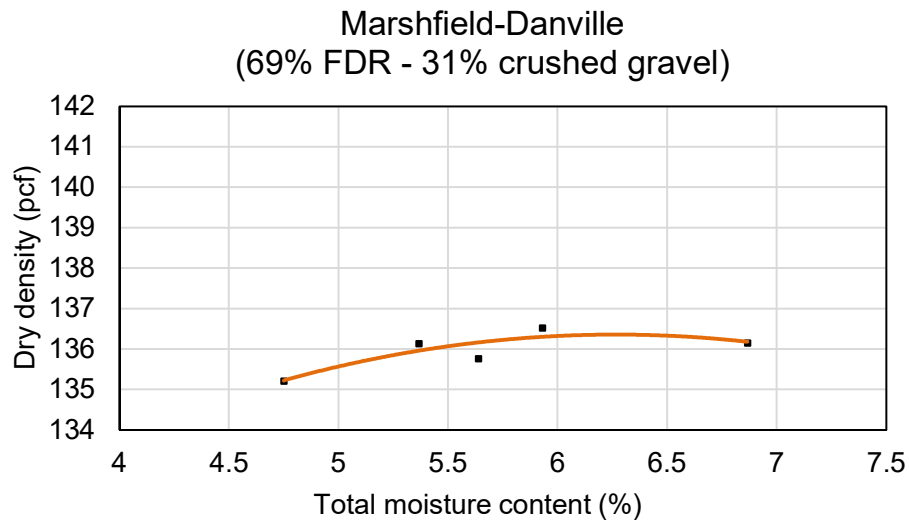


Figure 12: M-D moisture-density curve.

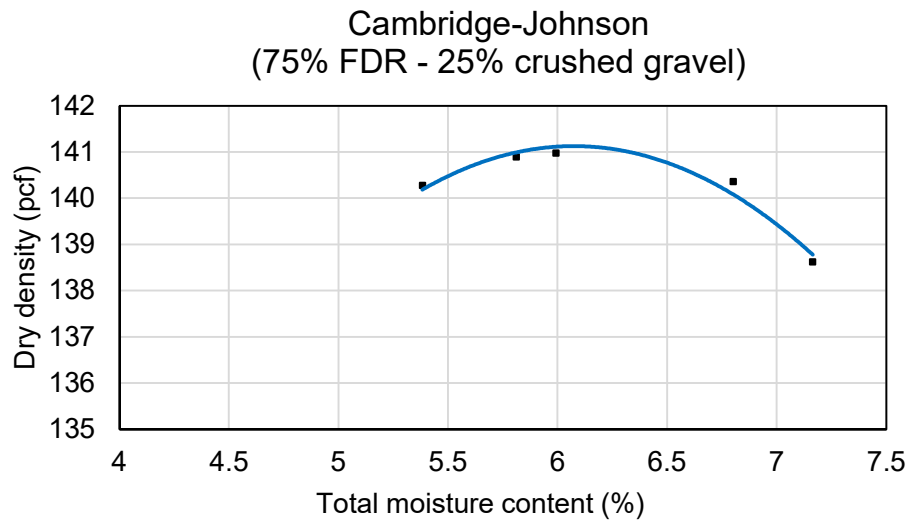


Figure 13: C-J moisture-density curve.

Table 12: Modified Proctor test results on Marshfield-Danville (M-D) and Cambridge-Johnson (C-J) samples (OMC: Optimum moisture content; γ_d : Maximum dry density).

	M-D	C-J
OMC [%]	6.25	6.07
γ_d [pcf]	136.3	141.1

FDR + RAS

A gradation analysis of the FDR materials was performed by adding the two sources of processed RAS (3/8 inch minus) in three different percentages (5, 10 and 15%). Figure 14 and Figure 15 show the particle size distribution of the FDR baselines and the combinations FDR baseline + 5/15% of both types of RAS. As it can be seen from the gradation analysis, the addition of PC shingles results in minimal change to the overall particle size distribution for the FDR from both M-D and C-J projects. However, the addition of MW, especially in high percentage (15%), causes a substantial change in the particle size distribution.

These results highlight the influence of the initial gradation of the FDR materials on their ability to accommodate RAS. The C-J FDR gradation appears to be better optimized to incorporate RAS without significantly altering the overall particle size distribution. Conversely, the higher fines content of the M-D FDR makes its gradation more sensitive to the addition of RAS, leading to a more pronounced shift toward finer particles and a less desirable overall grading.

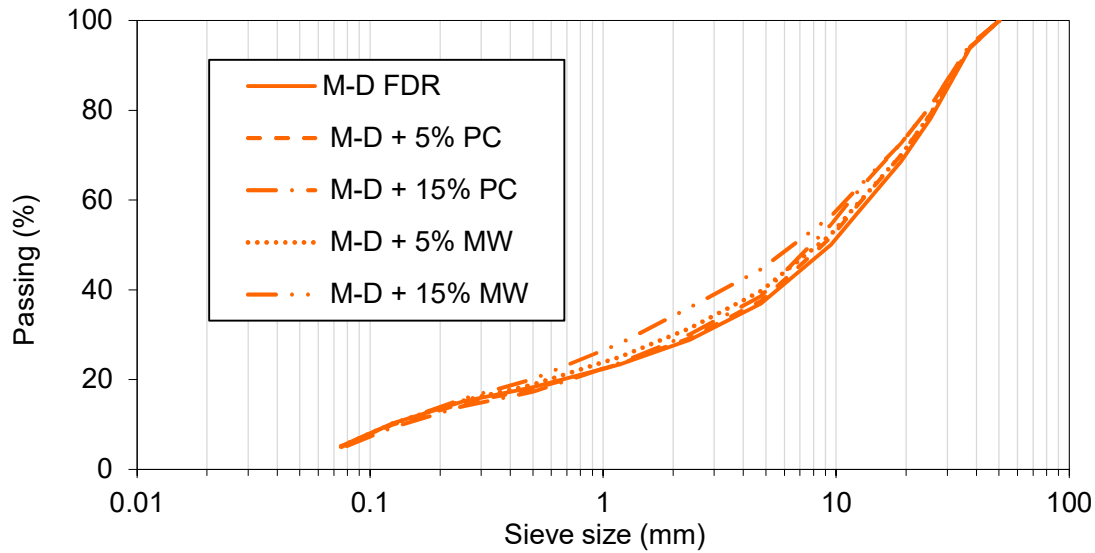


Figure 14: Gradation of M-D baseline and M-D + 5/15% of both types of processed RAS.

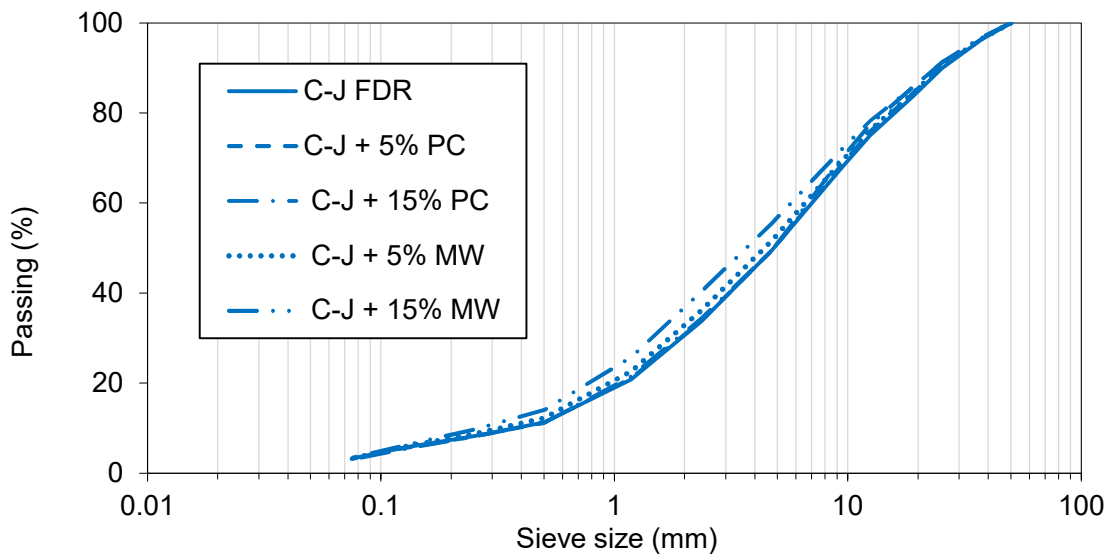


Figure 15: Gradation of C-J baseline and C-J + 5/15% of both types of processed RAS.

A volumetric evaluation was conducted on component materials (RAP, crushed gravel, RAS) as well as trial FDR specimens, following the mix design of the two VTrans projects, adding the three percentages of processed RAS (5, 10 and 15%). A correction factor was applied to the air void content obtained from VTrans for both FDR baselines. This same correction factor was also used for the mixtures containing FDR and RAS, with the final air void content to be determined following specimen compaction and curing. The application of this factor was necessary to ensure that the density values of the laboratory-fabricated mixtures were directly comparable to those calculated in the field, thereby providing consistency between laboratory and in-situ conditions. The results of the volumetric evaluations are presented in Table 13 and Table 14 where the air void contents represent the final air void contents that were obtained after multiple iterations (including corrections between theoretical estimated air-void and actual air-void content on cured specimen bulk specific gravity testing). PC5: 5% Post-consumer

RAS; PC10: 10% Post-consumer RAS; PC15: 15% Post-consumer RAS; MW5: 5% Manufacture-waste RAS; MW10: 10% Manufacture-waste RAS; MW15: 15% Manufacture-waste RAS

Table 13: M-D FDR + processed RAS volumetric parameters.

ID	M-D	PC5	PC10	PC15	MW5	MW10	MW15
Max. Theoretical Specific Gravity (G_{mm})	2.360	2.296	2.236	2.345	2.337	2.315	2.292
Bulk Specific Gravity (G_{mb})	2.104	1.982	1.919	1.958	2.055	2.0313	1.946
Air void content (%)	10.85	13.69	14.15	16.51	12.08	13.02	15.12

Table 14: C-J FDR + processed RAS volumetric parameters.

ID	C-J	PC5	PC10	PC15	MW5	MW10	MW15
Max. Theoretical Specific Gravity (G_{mm})	2.572	2.485	2.405	2.410	2.533	2.496	2.504
Bulk Specific Gravity (G_{mb})	2.264	2.068	1.992	2.018	2.111	2.065	2.119
Air void content (%)	11.96	16.80	17.15	16.25	16.68	17.25	15.4

The volumetric testing and analysis helped in developing mix designs with different RAS amounts. Specifically, the total weight of each specimen was determined while maintaining the target percentages of each component, in order to achieve the density and air void values established through the volumetric evaluation. This ensured that the designed mixtures reflected the expected gradation and compaction characteristics. Table 15 shows the mix design of all mixtures analyzed where RAS replaces FDR and gravel by weight. The contents of cement, water, and emulsion were kept consistent with those of the original project mix designs. The proportions of FDR material and gravel were then adjusted accordingly based on the amount of RAS replacing these components by weight.

Table 15: Mix designs (by total weight).

Project	ID	FDR	RAS	Gravel	Other
M-D	M-D	63.5%	0%	28.5%	Cement: 0.46% Water: 3.8% Emulsion: 3.7%
	M-D PC5 / M-D MW5	60.3%	4.6%	27.1%	
	M-D PC10 / M-D MW10	57.2%	9.2%	25.7%	
	M-D PC15 / M-D MW15	54.0%	13.8%	24.3%	
C-J	C-J	69.1%	0%	23%	Cement: 0.46% Water: 4.2% Emulsion: 3.2%
	C-J PC5 / C-J MW5	65.6%	4.6%	21.9%	
	C-J PC10 / C-J MW10	62.2%	9.2%	20.7%	
	C-J PC15 / C-J MW15	58.7%	13.81%	19.6%	

CHAPTER 5: LABORATORY CHARACTERIZATION METHODS AND ANALYSIS

This chapter outlines the laboratory procedures used to mix, compact, and cure the specimens. It also describes the mechanical testing methods employed to evaluate the mechanical properties and performance.

Mixing, compaction and curing

All mixing was carried out with a Wirtgen pugmill WLM 30 mixer (Figure 16). This device provides a similar type of mechanical input as a reclaimer. According to information provided by the equipment manufacturer the resizing experienced through the Wirtgen mixer should be comparable to what occurs in the field.



Figure 16: Wirtgen pugmill WLM 30 mixer.

Specimens for ITS and triaxial testing were compacted using a Wirtgen WLW 1 vibratory hammer (Figure 17), an apparatus capable of producing cylindrical specimens and maintaining specific moisture characteristics and internal distribution of aggregate grains.

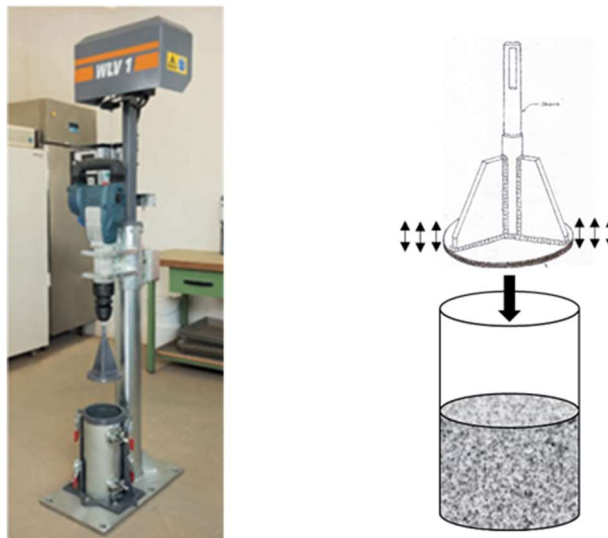


Figure 17: Wirtgen WLW 1 vibratory hammer (left) and schematic of the compaction method (right).

After compaction, all specimens were free surface cured in a ventilated oven at $140 \pm 2^\circ\text{F}$ ($60 \pm 1^\circ\text{C}$) without any lateral confinement, following the procedure described in AASHTO R109. Curing continued until a constant mass was achieved, which is defined as a change in mass of 0.05% or less between two consecutive measurements.

For each mix design presented in Table 14, six specimens for indirect tensile strength (ITS) testing and six specimens for triaxial configuration testing were prepared using processed MW and PC RAS. ITS specimens required approximately 4 days, while triaxial specimens required about 8 days to cure.

Mechanical characterization

Mechanical characterization of FDR mixtures was carried out by performing the following tests:

- Indirect tensile strength (ITS) with and without conditioning (dry and wet) (ASTM D6931)
 - 95 mm height and 150 mm diameter specimen
- Triaxial resilient modulus test at three confinement levels (0, 2.9 and 5.8 psi) (ASTM D7369)
 - 300 mm height and 150 mm diameter specimen
- Triaxial shear strength test at three confinement levels (0, 7.25 and 14.5 psi)
 - 300 mm height and 150 mm diameter specimen

All mechanical tests were performed at 25°C / 77°F after curing.

Indirect tensile strength (ITS) test

The ITS test provides an indirect measure of tensile strength and deformability by measuring the resistance to failure of a specimen under a constant displacement (50.8 mm/min) (Figure 18b). A set of 6 specimens of 95 mm in height and 150 mm in diameter (Figure 18a) is compacted with a vibratory hammer, then free surface cured until the weight is constant. After the curing period, 3 specimens are tested dry. The other 3 are conditioned in a water bath at room temperature for 24 hours, then the surface dried and tested. This allowed evaluation of the indirect tensile strength ratio (TSR), which is an index of moisture susceptibility. All tests are performed at 25°C / 77°F .

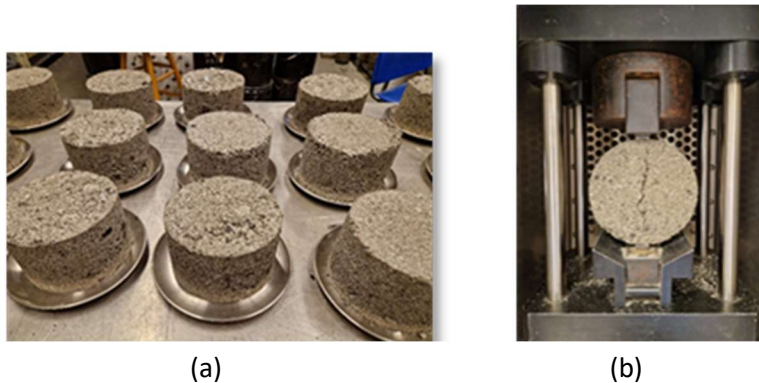


Figure 18: Typical ITS specimens (a) and testing setup (b).

Indirect tensile strength (ITS) values are determined using Equation 1.

$$ITS = \frac{2 \times P}{\pi \times h \times d} \times 10^3 \quad [psi]$$

where P is the maximum applied load [kN, lbf]; h is the average specimen height [m, in]; d is the specimen diameter [m, in].

Equation 1: Indirect Tensile Strength (ITS)

The indirect tensile strength ratio (TSR) is calculated using Equation 2.

$$TSR = \frac{ITS_{wet}}{ITS_{dry}}$$

Equation 2: Tensile Strength Ratio (TSR)

Triaxial resilient modulus (MR) test

The triaxial resilient modulus (MR) test is used to analyze the response of pavement to repeated traffic loads by measuring the resilient modulus according to ASTM D7369. The test is performed on specimens loaded with an impulsive diametral force. The specimens used in this type of characterization have dimensions of 300 mm in height and 150 mm in diameter and they are usually compacted with a vibratory hammer into five equal layers. The resilient modulus test setup includes two extensometers (adjustments implemented by the UNH research team) placed on the triaxial cell to accurately measure specimen strain (Figure 19) with axial stresses carefully decided upon to generate strain levels within the linear elastic range. The test protocol generally involves the application of 105 load cycles at a frequency of 2 Hz, with each cycle consisting of 0.1 seconds of load application followed by 0.9 seconds of rest. The initial 100 cycles serve as the conditioning period, while analytical data are derived from the last 5 cycles only. Tests are conducted based on the average summer season temperature in all projects, and specimens are tested at different confining pressures. Equation 3 presents the expression used to calculate the resilient modulus (MR).

$$M_R = \frac{S_{cyclic}}{\epsilon_{recoverable}}$$

where S_{cyclic} is the applied axial stress [MPa, psi]; $\epsilon_{recoverable}$ is the recoverable axial strain [mm/mm, in/in].

Equation 3: Resilient Modulus (MR)



Figure 19: Triaxial resilient modulus testing setup.

Triaxial shear strength (TSS) test

The triaxial shear strength (TSS) test enables the shear properties (cohesion and internal friction angle) of cold recycled materials to be obtained according to Mohr-Coulomb theory (Figure 20) and their behavior under confining conditions to be assessed.

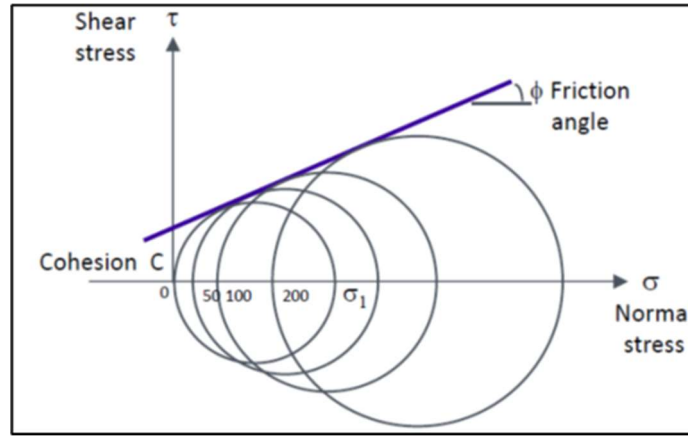


Figure 20: Cohesion (C) and internal friction angle (φ) according to Mohr-Coulomb theory.

The specimens used in this type of characterization have dimensions of 300 mm in height and 150 mm in diameter and they are usually compacted with a vibratory hammer into five equal layers. The test procedure consists of inserting the specimen into the triaxial cell, applying the desired confining pressure, and starting the test by applying a monotonic displacement in the vertical direction (3 mm/min) until material shear failure (Figure 21).

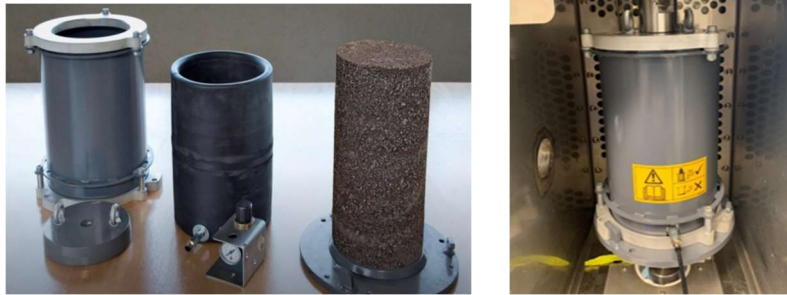


Figure 21: Triaxial mold, specimen and testing setup.

For each test specimen the applied failure load ($P_{a,f}$) is recorded in order to calculate the applied failure stress ($\sigma_{a,f}$) using Equation 4.

$$\sigma_{a,f} = \frac{P_{a,f}}{A} \times 10^{-3}$$

where A is the area of the cylindrical specimen at the beginning of the test.

Equation 4: Applied failure stress

In the second step, the major principal stress at failure ($\sigma_{1,f}$) is calculated following Equation 5.

$$\sigma_{1,f} = \sigma_{a,f} + \sigma_{dw}$$

where σ_{dw} is the pressure resulting from dead weight of top disk and loading ram.

Equation 5: Major principal stress at failure

The relationship between the major principal stress at failure and the confining stress (σ_3) is described in Equation 6.

$$\sigma_{1,f} = A \cdot \sigma_3 + B$$

where $A = \frac{1+\sin\phi}{1-\sin\phi}$ and $B = \frac{2 \cdot C \cdot \cos\phi}{1-\sin\phi}$

Equation 6: Relationship between the major principal stress at failure ($\sigma_{1,f}$) and the confining stress (σ_3)

Values A and B can be determined by performing a linear regression analysis on the combinations of major principal stress at failure and confining stress. Values of internal friction angle (ϕ) and cohesion (C) for the material can be accordingly calculated.

Pavement performance prediction

The resilient modulus results were used as input to predict pavement performance. For this purpose, MnPAVE, a mechanistic-empirical pavement design software developed by the Minnesota Department of Transportation (MnDOT), was employed. The pavement cross-sections of M-D (Figure 22) and C-J (Figure 23) projects were considered, with information about the different layers, including resilient modulus (MR) and Poisson's ratio (ν). The measured MR values were used for the FDR layer. The software was used to estimate the allowed number of load repetitions to prevent phenomena such as fatigue and rutting failure.

HMA PG70-28 (MR = 613.5 ksi, $\nu = 0.26$)	4.25"
Plant Mixed Recycled (MR = 109 ksi, $\nu = 0.35$)	3"
FDR Stabilized ($\nu = 0.4$)	6"
Subbase (MR = 12 ksi, $\nu = 0.45$)	5"
Undisturbed Soil (MR = 7 ksi, $\nu = 0.45$)	

Figure 22: M-D pavement cross-section model.

HMA PG70-28 (MR = 613.5 ksi, $\nu = 0.26$)	4.25"
Plant Mixed Recycled (MR = 109 ksi, $\nu = 0.35$)	2.5"
FDR Stabilized ($\nu = 0.4$)	6"
Subbase (MR = 12 ksi, $\nu = 0.45$)	10"
Undisturbed Soil (MR = 7 ksi, $\nu = 0.45$)	

Figure 23: C-J pavement cross-section model.

CHAPTER 6: FDR TREATED WITH PROCESSED RAS

This chapter presents the detailed laboratory characterization of the FDR baseline mixtures and mixtures incorporating processed RAS.

Mechanical characterization

The following sections present the mechanical test results of the FDR baseline mixtures, the FDR + 5% processed RAS, and the FDR + 10% processed RAS blends. The results are influenced by the different density levels and air void contents observed with the addition of RAS (see Table 12 and Table 13), which lead to variations in the mechanical properties when compared to the FDR baselines. In the subsequent study presented later in this chapter, corrections were applied to achieve density and air void contents comparable to the baseline mixtures, thereby reducing the differences in mechanical properties between the baseline mixtures and those incorporating RAS. This outcome highlights how volumetric properties directly affect the mechanical behavior of the mixtures

Indirect tensile strength (ITS)

The indirect tensile strength (ITS) test was conducted on all FDR + RAS combinations in dry and wet conditions. Figure 24 shows the ITS and TSR of the mixtures fabricated with the Marshfield-Danville baseline, respectively. Error bars represent one standard deviation.

The results indicate that the inclusion of RAS leads to a reduction in ITS, with lower values observed as the RAS content increases, regardless of the type used. A drop of up to 40% in ITS is noted including PC RAS and approximately 15% for MW RAS. The reduction in ITS appears to be directly associated with the increase in air void content resulting from the addition of RAS, the air void increase ranged between 1.2% and 3.3%. Additionally, the results show that the M-D baseline mixture fails to meet the minimum ITS requirement of 40 psi established by the new VAOT specifications. It is important to mention that this project was constructed under the prior VAOT requirements. On the other hand, the moisture resistance of the mixtures improved with the addition of RAS, with TSR values consistently exceeding 79%. It should also be noted that no specific threshold for TSR is currently established in the VAOT specifications for these types of cold recycled materials.

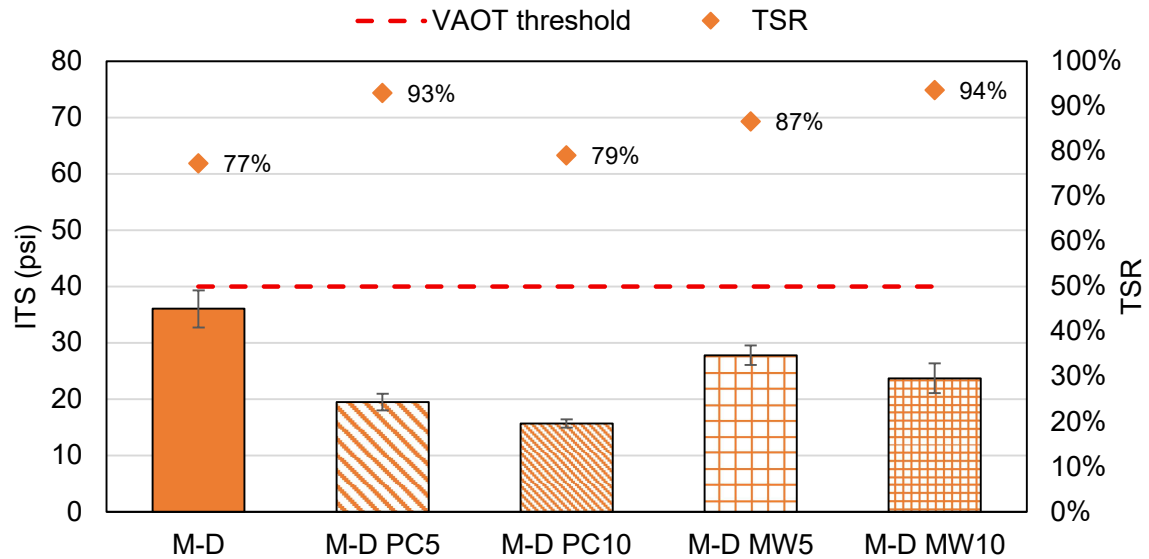


Figure 24: Indirect tensile strength (ITS) test results of M-D + processed RAS.

Figure 25 shows the ITS and TSR of the mixtures fabricated with the C-J baseline, respectively. Error bars represent one standard deviation. The ITS results confirm that the incorporation of RAS results in a reduction in indirect tensile strength, with lower ITS values observed as the RAS content increases, regardless of the type used. A drop of up to 35% in ITS is noted including both PC RAS and MW RAS. This is in accordance with the increase in air void content adding RAS, the increase in case of C-J materials ranged between 4% and 5.3%. However, unlike mixtures produced with the M-D baseline material, those prepared using the C-J baseline meet the new VAOT specifications for ITS at RAS contents up to 5%. The TSR remains consistently above 82% across all mixtures, with a notable improvement observed when MW RAS is utilized, indicating enhanced durability under moisture-induced damage conditions.

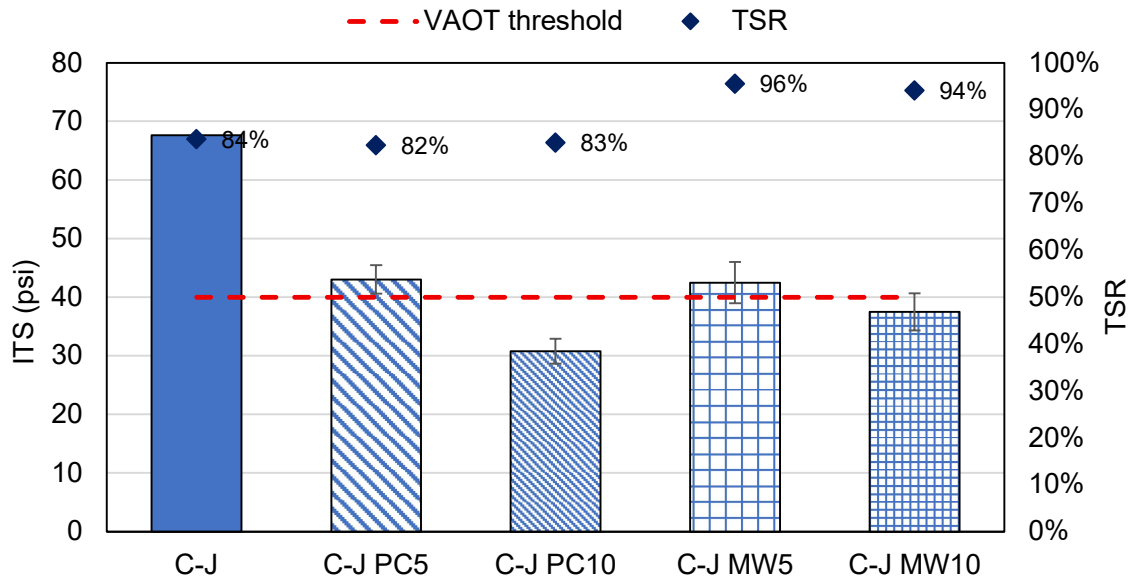


Figure 25: Indirect tensile strength (ITS) test results of C-J + processed RAS.

Triaxial resilient modulus (MR)

The resilient modulus (MR) test was conducted on the specimens in triaxial configuration. Figure 26 shows the results of the triaxial resilient modulus test performed on the specimens fabricated with the FDR baseline M-D + the two types of RAS at three confining pressures (0, 2.9 and 5.8 psi). Error bars represent one standard deviation. The test results indicate a reduction in stiffness with the incorporation of RAS, with a drop ranging between 15% and 40%. This reduction in resilient modulus is consistent with the findings of the volumetric analysis, which revealed an increase in air void content ranging between 1.2% and 3.3% in the RAS-containing mixtures. The elevated void content likely contributes to the observed decrease in stiffness.

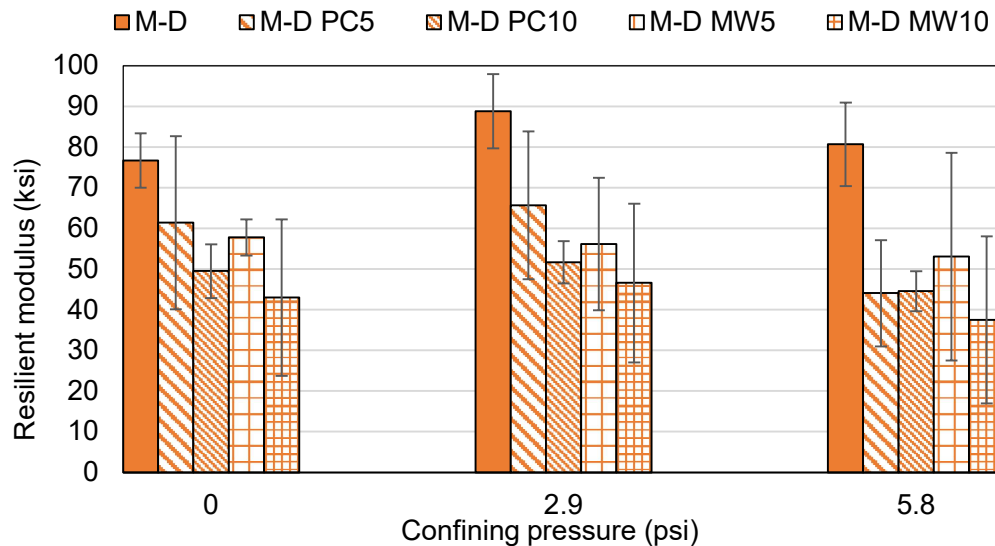


Figure 26: Resilient modulus of M-D + processed RAS.

Figure 27 shows the results of the triaxial resilient modulus test performed on the specimens fabricated with the FDR baseline C-J + the two investigated types of RAS at three confining pressures (0, 2.9 and 5.8 psi). Error bars represent one standard deviation. The test results indicate that mixtures prepared with the C-J FDR baseline consistently exhibit lower resilient modulus values, primarily due to their higher air void content. While the incorporation of RAS results in an increase in voids ranging from 4% to 5.3%, the corresponding reduction in stiffness is less pronounced than that observed in Figure 26. This is likely due to the less substantial change in gradation when RAS is added to the C-J baseline mixture, compared to the more pronounced change observed when RAS is added to the M-D baseline mixture.

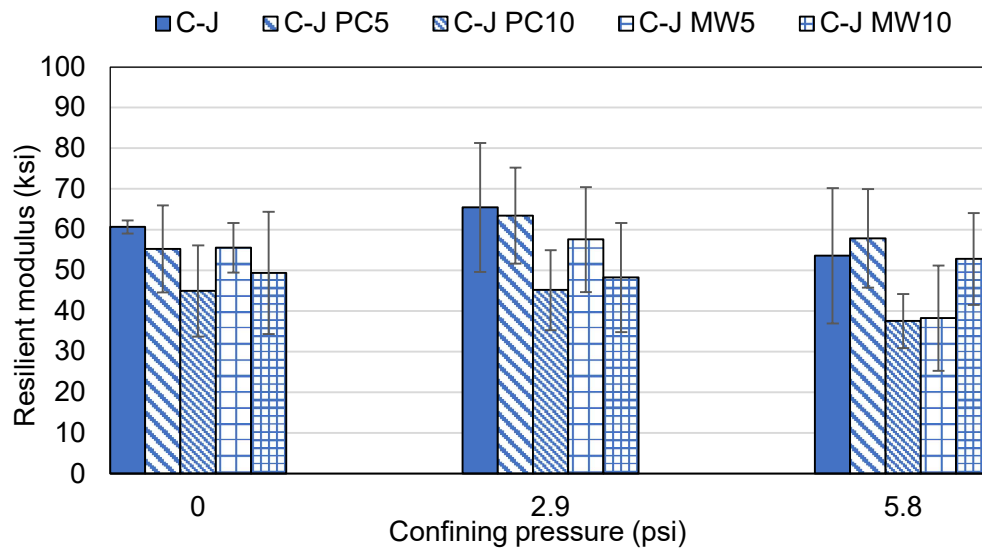


Figure 27: Resilient modulus of C-J + processed RAS.

Triaxial shear strength (TSS)

The monotonic triaxial shear strength test was conducted on the specimens to measure the shear properties. Figure 28 and Figure 29 show the results of the test performed on the specimens fabricated with the FDR baseline M-D and with the two types of RAS in terms of cohesion and internal friction angle, respectively. The results confirm the trend previously observed for the ITS tests, showing that the inclusion of RAS negatively impacts the mechanical properties of the mixtures. In particular, higher RAS content is associated with reduced shear strength, once again likely due to an increase in void content of 1.2% and 3.3%.

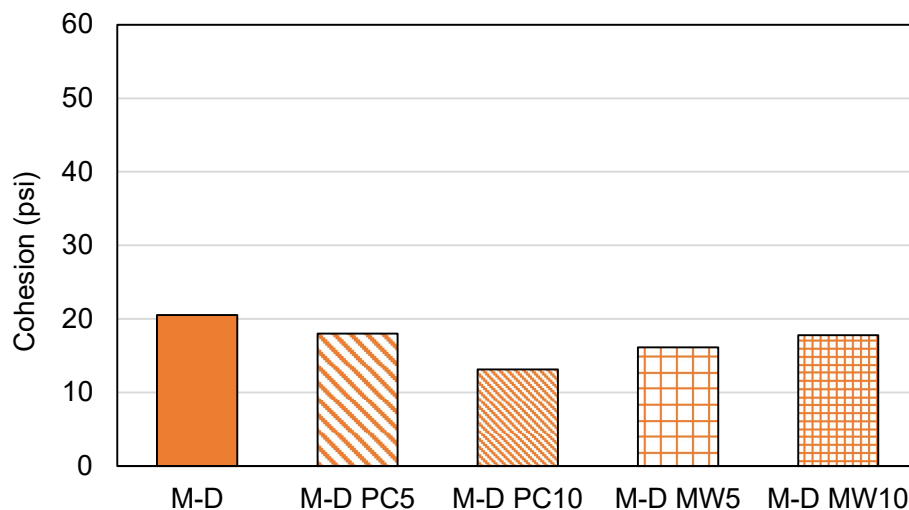


Figure 28: Cohesion of M-D + processed RAS.

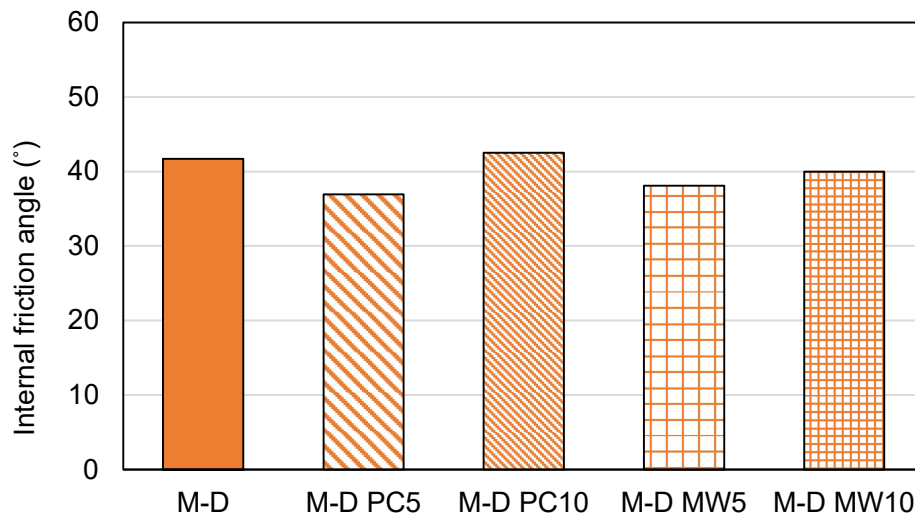


Figure 29: Internal friction angle of M-D + processed RAS

Figure 30 and Figure 31 show the results of the monotonic triaxial test performed on the specimens fabricated with the FDR baseline C-J + the two investigated types of RAS in terms of cohesion and internal friction angle, respectively. Similar to the ITS results, the shear strength parameters (cohesion and internal friction angle) are consistently higher when the C-J baseline is used compared to the M-D baseline, regardless of RAS type or content. As the amount of RAS in the mixture increases, shear strength tends to decrease, which aligns with the observed increase in void content in the range of 4% and 5.3%.

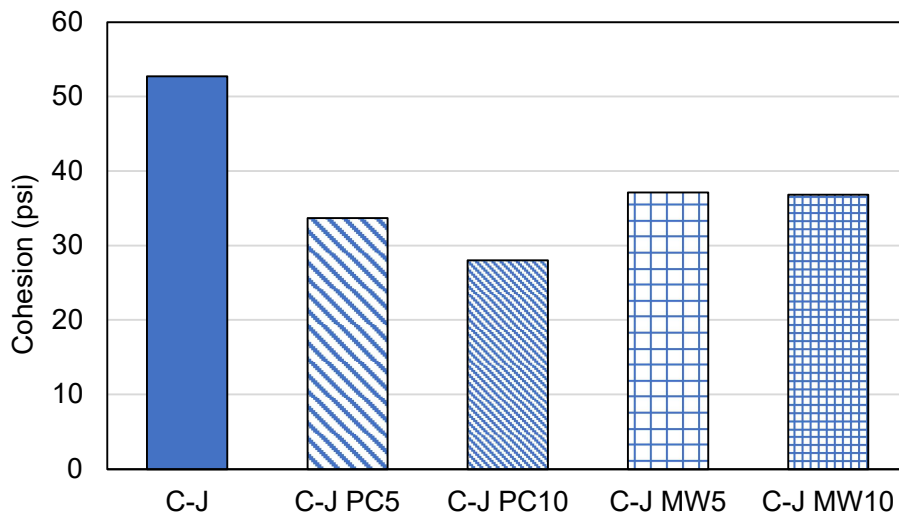


Figure 30: Cohesion of C-J + processed RAS.

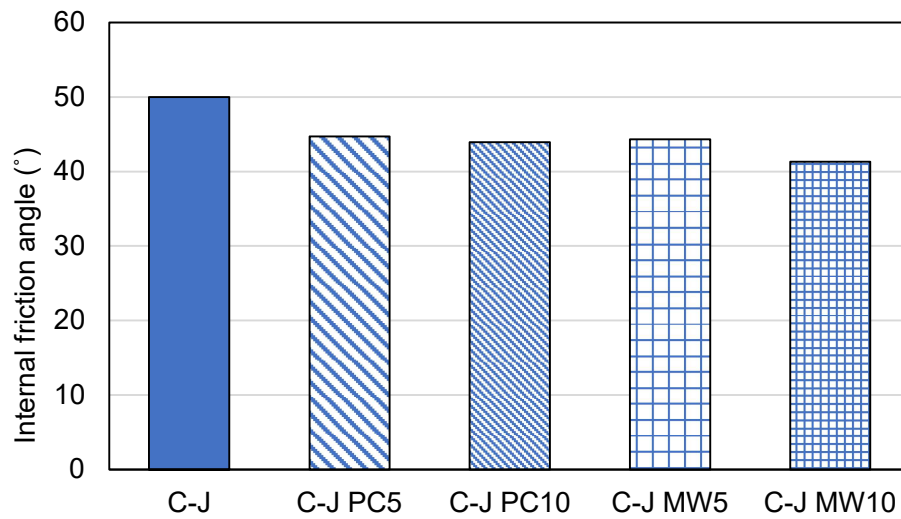


Figure 31: Internal friction angle of C-J + processed RAS.

Pavement life analysis for FDR with 5 and 10% RAS

Based on the results of the pavement performance prediction, rutting emerged as the predominant distress mechanism.

Figure 32 shows the number of ESALs beyond which the threshold of 12.5 mm (0.5 inches) of rutting, commonly used as the failure limit by MnDOT, is exceeded. The plot shows that the incorporation of RAS negatively impacts pavement performance in terms of rutting resistance. A progressive decrease in the number of allowed load repetitions is observed as RAS content increases, regardless of the type of asphalt shingles. This trend is more pronounced for the M-D baseline, where the addition of RAS leads to a noticeable reduction in pavement service life ranging between 20.6% and 36%. Regarding C-J, mixtures containing 5% RAS exhibit rutting resistance comparable to that of the baseline (pavement service life reduction between 1.96% and 19.7%), suggesting that 5% RAS is low enough to not substantially impact predicted performance.

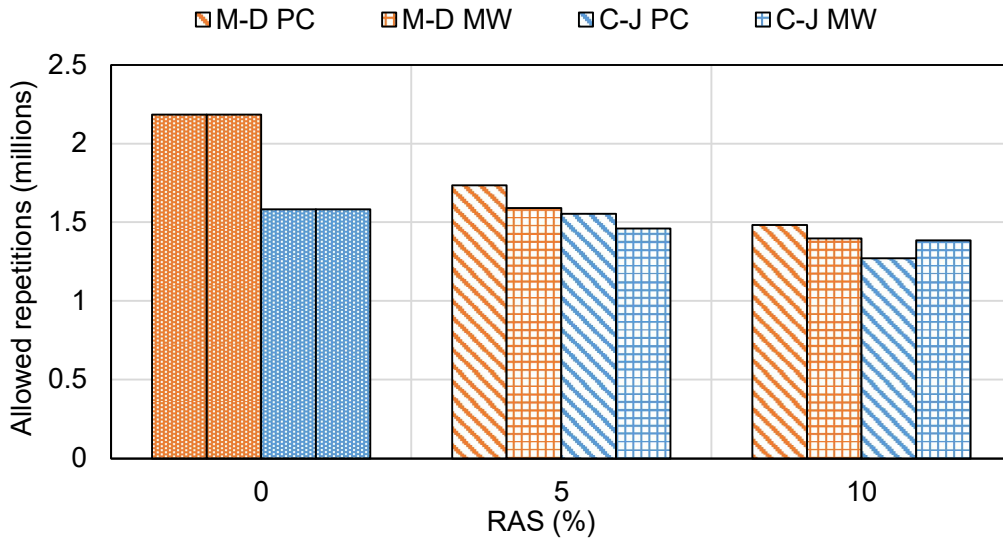


Figure 32: Allowed load repetitions to rutting failure.

Laboratory characterization of FDR with 5% RAS at increased density

According to the results, a RAS content of 5% was identified as the “optimal” dosage, as it produced mechanical properties comparable to those of the FDR baselines and, in the case of mixtures prepared with the C-J baseline, ITS values that satisfied the new VAOT specifications. Based on the feedback received during the TAC meeting, further investigations were conducted on mixtures containing 5% processed post-consumer RAS. The objective was to achieve bulk densities and, consequently, air void contents comparable to those of the corresponding FDR baselines. This step was important because the air void tables (Table 13 and Table 14) clearly showed that the incorporation of RAS led to higher air void contents compared to the baselines. Since the results demonstrated that volumetric properties have a direct influence on mechanical behavior, aligning the densities and air void levels allowed for a more consistent comparison between the baseline mixtures and those containing RAS. These increased density trials are referred to as “corrected” in this report.

For the C-J project, the adjustment was done by applying the same compaction energy used for the baseline mixtures to those containing 5% RAS. In the case of the M-D project, the adjustment was done by determining the appropriate ITS specimen height to reach a target bulk density similar to that of the baseline mixture. Table 16 compares the air void content of the baseline FDR mixtures (baseline), with the original mixtures containing 5% post-consumer RAS (Original PC5) and the mixtures adjusted to achieve comparable density with the same RAS content (Corrected PC5). The results show that the applied adjustments led to a reduction in air void content, bringing it to a level comparable to that of the FDR baseline mixtures.

Table 16: Comparison of air void content between baseline FDR mixtures (Baseline), original mixtures with 5% post-consumer RAS (Original PC5) and corrected mixtures with 5% post-consumer RAS (Corrected PC5).

	Air Voids			Correction Type
	Baseline	Original PC5	Corrected PC5	
C-J	11.96	16.8	13.31	Increased compaction time
M-D	10.85	13.69	11.15	Reduced final specimen height

Figure 33 presents the ITS results for specimens containing 5% PC RAS with applied corrections (PC5 Corr). Error bars represent one standard deviation. For comparison, the figure also includes the ITS values of the baseline mixtures (Baseline) and those of the original 5% RAS specimens (PC5) previously analyzed. For both FDR baselines, the application of the corrections resulted in higher ITS values. The effect was particularly pronounced for the C-J baseline, where ITS increased by approximately 46.7% compared to the original mixture with the same 5% PC RAS content. For the M-D baseline, the increase in ITS was more moderate, at about 23.4%.

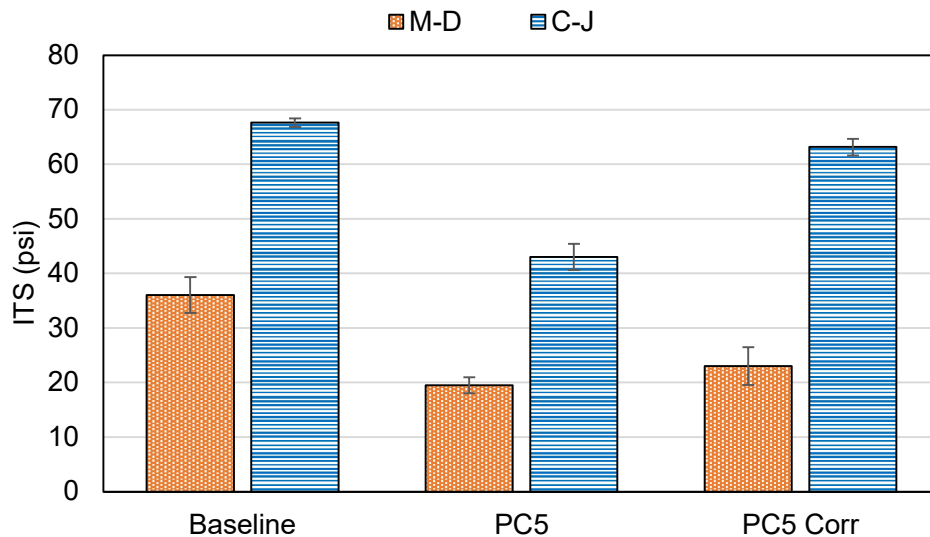


Figure 33: Indirect tensile strength (ITS) of baseline mixtures (Baseline), original 5% post-consumer RAS mixtures (PC5), and corrected 5% post-consumer RAS mixtures (PC5 Corr).

Environmental contaminant testing on C-J FDR and C-J + 5% PC RAS

To provide consistency with the initial characterization of the RAS materials described earlier in this report, the Synthetic Precipitation Leaching Procedure (SPLP) (SW-846 Method 1312) was also used on the field-derived recycled (FDR) material from the C-J site and on the C-J FDR mixture containing 5% minimally processed post-consumer (PC) RAS. The testing was conducted by the same laboratory,

Eurofins Environment Testing New England (North Kingstown, Rhode Island) and the full report is attached as Appendix B.

The contaminant testing on SPLP for PCBs and PFAS indicate that no environmental contaminants were detected in the FDR material (Table 17). In contrast, the C-J mixture containing 5% PC RAS showed the presence of Per- and Polyfluoroalkyl Substances (PFAS), specifically PFOS (Table 18). However, the measured concentrations were minimal and substantially lower than those observed in the PC RAS material during the initial RAS characterization. Overall, the results suggest that the incorporation of 5% PC RAS in the FDR mixture does not significantly increase the leaching potential of environmental contaminants.

Table 17: Per- and Polyfluoroalkyl Substances (PFAS) detected in C-J FDR.

<i>Sample: C-J FDR</i>		
Analyte	Result	Unit
<i>No Detections.</i>		

Table 18: Per- and Polyfluoroalkyl Substances (PFAS) detected in C-J + 5% PC RAS

<i>Sample: C-J + 5% PC RAS</i>		
Analyte	Result	Unit
<i>Perfluorooctanesulfonic acid (PFOS)</i>	<i>5.17</i>	<i>ng/L</i>

CHAPTER 7: FDR TREATED WITH MINIMALLY PROCESSED RAS

This chapter presents the laboratory characterization of mixtures composed of FDR material from the two selected projects and 5% minimally processed post-consumer RAS (MPPC5) provided by VTrans. For the purposes of this study, “minimally processed” RAS denotes material that was cleaned to remove foreign waste (such as nails and wood) but retained its original size, as generated at end of service life.

Gradation analysis

An initial assessment was conducted to evaluate how the incorporation of minimally processed PC RAS would affect the gradation of the mixtures. This procedure was carried out because the mixing process was expected to alter the gradation of the RAS itself, due to particle breakdown or disaggregation during blending. To this end, all dry components from both projects were combined using the same percentages defined in the previous mix design analysis, with the addition of 5% minimally processed RAS (Figure 34).



Figure 34: FDR + minimally processed RAS before mixing (left) and after mixing (right).

After mixing, the gradation curves of the resulting blends containing 5% minimally processed RAS were determined and compared to those of the two baseline mixtures. When minimally processed RAS was mixed with the FDR material from the M-D project (Figure 35), little change in gradation was observed. This outcome can be attributed to the fact that the M-D FDR material already contained a higher proportion of fine particles compared to the C-J FDR material, which minimized the impact of the additional fines introduced by the RAS. In contrast, the inclusion of minimally processed RAS slightly altered the gradation of the blends produced with the C-J FDR material (Figure 36), primarily by increasing the proportion of particles in the mid-size fraction of the aggregate distribution curve. This

change may be attributed to the detachment of fine particles from the surface of the shingles during the mixing process.

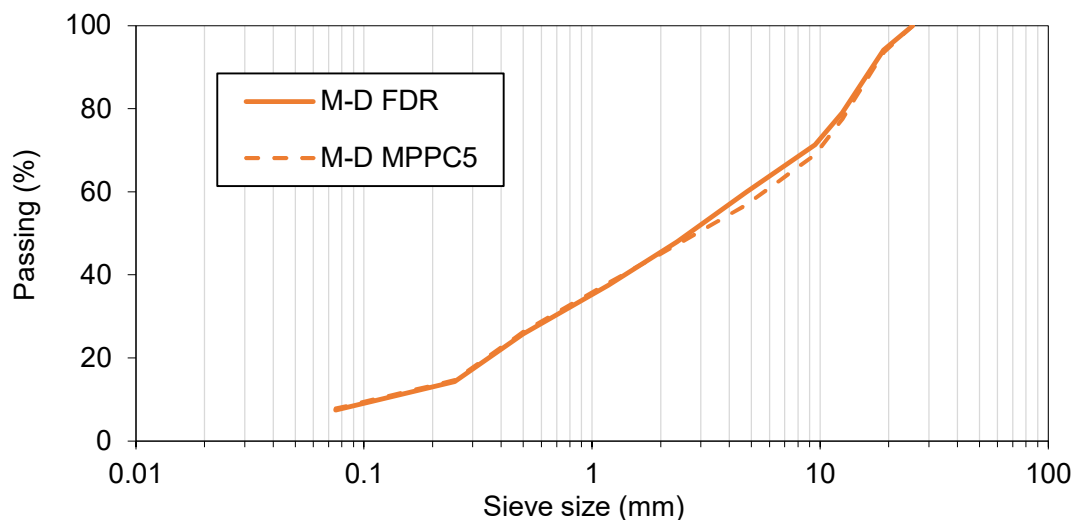


Figure 35: Particle size distribution of M-D FDR baseline and M-D + 5% minimally processed PC RAS.

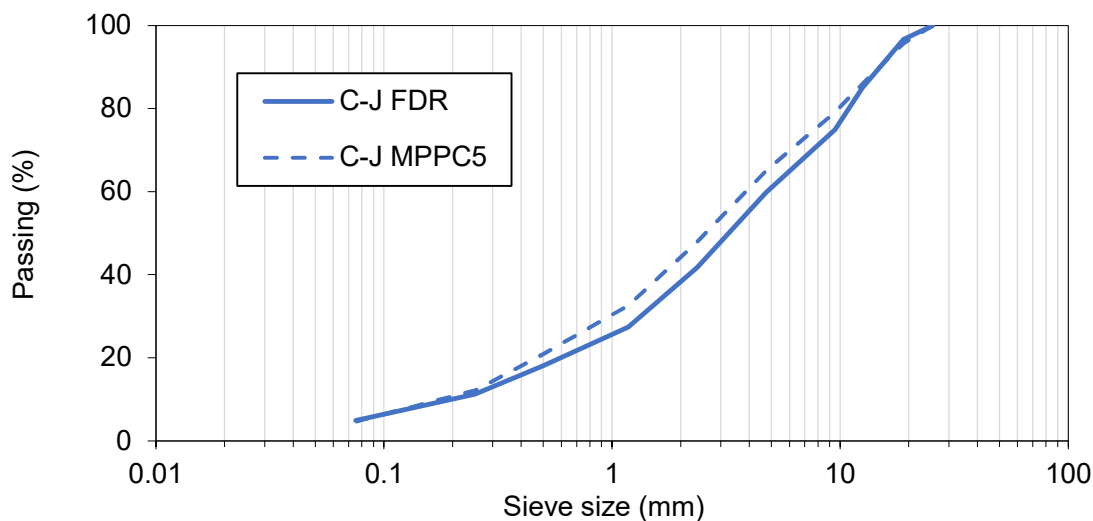


Figure 36: Particle size distribution of C-J FDR baseline and C-J + 5% minimally processed PC RAS.

Volumetric analysis

The same correction procedure employed with the 5% processed post-consumer RAS (reduced final specimen height for M-D and increased compaction time for C-J) was applied to the evaluation of mixtures incorporating 5% minimally processed post-consumer RAS. ITS specimens were prepared using this RAS source, following the same mix design used in the previous analysis and incorporating both corrections. Table 19 compares the air voids content of the baseline FDR mixtures (Baseline) with that of mixtures containing 5% minimally processed post-consumer RAS (MPPC5). The air void content of the resulting mixtures remained comparable to that of the FDR baseline mixtures.

Table 19: Comparison of air void content between baseline FDR mixtures (Baseline) and corrected mixtures with 5% minimally processed post-consumer RAS (MPPC5).

	Air Voids		Correction Type
	Baseline	MPPC5	
C-J	11.96	12.65	Increased compaction time
M-D	10.85	10.55	Reduced final specimen height

Indirect tensile strength (ITS)

The evaluation included ITS testing under dry and wet conditions. Figure 37 presents a comparison of ITS and TSR results for the M-D baseline mixture, the corrected 5% processed post-consumer RAS mixture (M-D PC5 Corr), and the mixture with 5% minimally processed post-consumer RAS (M-D MPPC5). Error bars represent one standard deviation. The results indicate that incorporating minimally processed RAS enhances the mechanical properties of the mixture, as reflected by ITS values comparable to those of the baseline. Similar to processed RAS, the use of minimally processed RAS also improves the moisture resistance of the mixtures, as reflected by the relative TSR values shown in the plot, which are always above 95%.

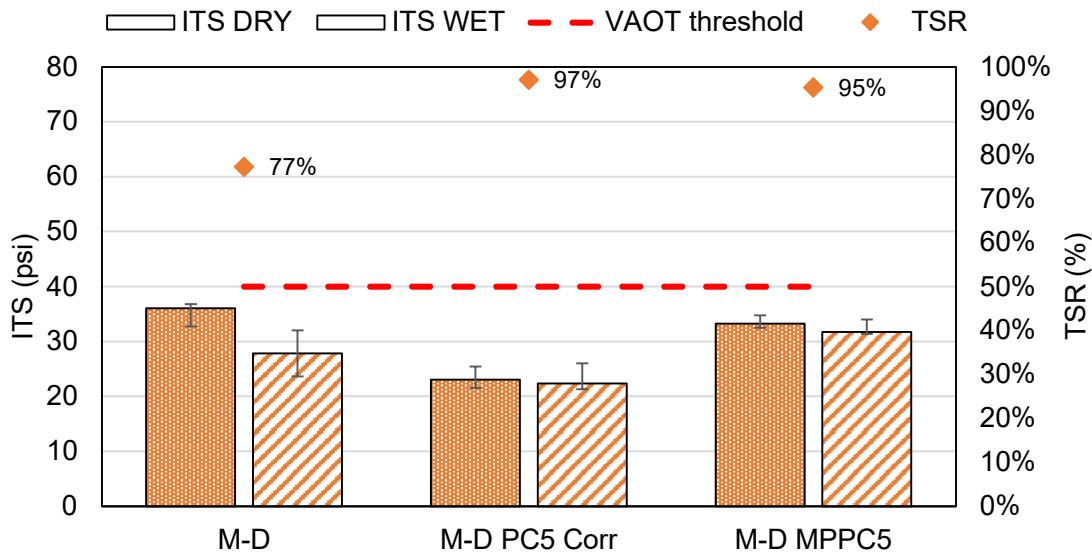


Figure 37: Indirect tensile strength (ITS) test results of M-D baseline mixture (M-D), corrected 5% processed post-consumer RAS mixture (M-D PC5 Corr), and 5% minimally processed post-consumer RAS mixture (M-D MPPC5).

Figure 38 presents a comparison of ITS and TSR results for the C-J baseline mixture, the corrected 5% processed post-consumer RAS mixture (C-J PC5 Corr), and the mixture with 5% minimally processed post-consumer RAS (C-J MPPC5). Error bars represent one standard deviation. In this case, the results show that using either RAS source—processed or minimally processed—yields ITS values that are

comparable to those of the baseline mixture. However, the addition of RAS enhances moisture resistance with TSR values always above 93%.

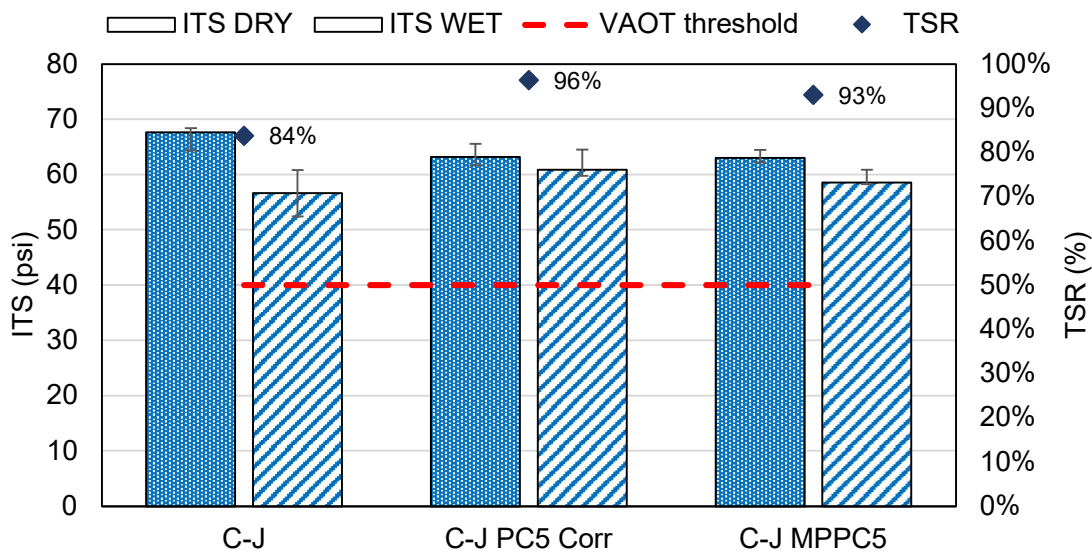


Figure 38: Indirect tensile strength (ITS) test results of C-J baseline mixture (C-J), corrected 5% processed post-consumer RAS mixture (C-J PC5 Corr), and 5% minimally processed post-consumer RAS mixture (C-J MPPC5).

Triaxial resilient modulus (MR)

Specimens with 5% minimally processed RAS were fabricated also in triaxial configuration applying the same corrections previously shown and the triaxial resilient modulus test was performed. Figure 39 presents a comparison of MR results for the M-D baseline mixture (Baseline), the original 5% processed post-consumer RAS mixture (PC5), and the mixture with 5% minimally processed post-consumer RAS (MPPC5). Error bars represent one standard deviation. The results show that the MR of the mixtures containing 5% minimally processed RAS is comparable to that of the original PC5 mixtures under low confining pressures (0 and 2.9 psi). A notable increase in stiffness is observed at a confining pressure of 5.8 psi, where the MR value becomes comparable to that of the baseline mixture. This increase suggests that the inclusion of minimally processed RAS contributes to an improvement in elastic stiffness under higher confining stress conditions, likely attributed to the reduced air void content.

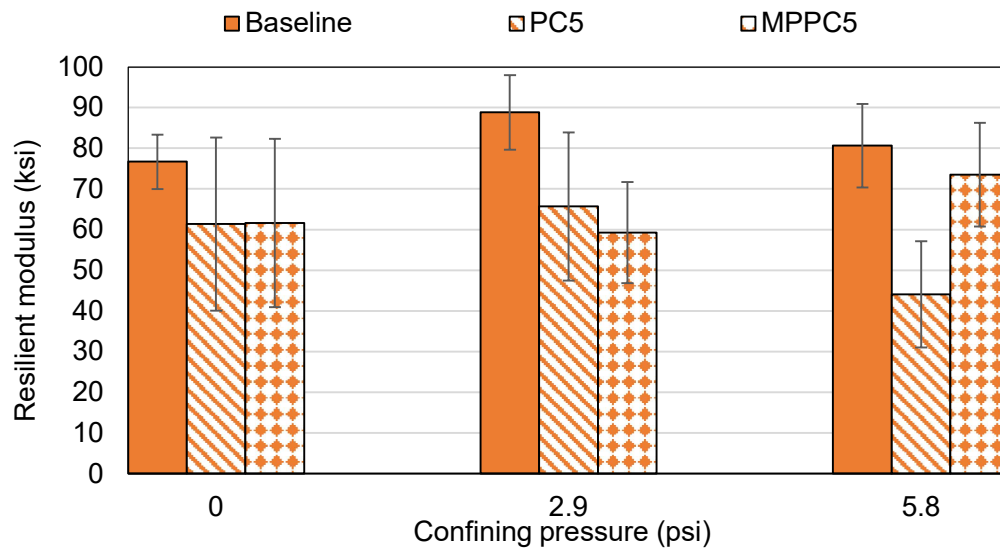


Figure 39: Resilient modulus (MR) of M-D baseline mixture (Baseline), original 5% processed post-consumer RAS mixture (PC5), and 5% minimally processed post-consumer RAS mixture (MPPC5).

Figure 40 shows the results of the triaxial resilient modulus test performed on specimens fabricated with the C-J FDR baseline (Baseline), those incorporating 5% processed post-consumer RAS (PC5) and 5% minimally processed post-consumer RAS (MPPC5), tested under three confining pressures (0, 2.9 and 5.8 psi). Error bars represent one standard deviation. The test results indicate that mixtures prepared with the C-J FDR baseline consistently exhibit lower resilient modulus values than those observed for the M-D baseline, primarily due to their higher air void content. However, the incorporation of 5% minimally processed RAS does not lead to noticeable changes in the elastic stiffness of the mixtures containing the FDR material from the Cambridge-Johnson project.

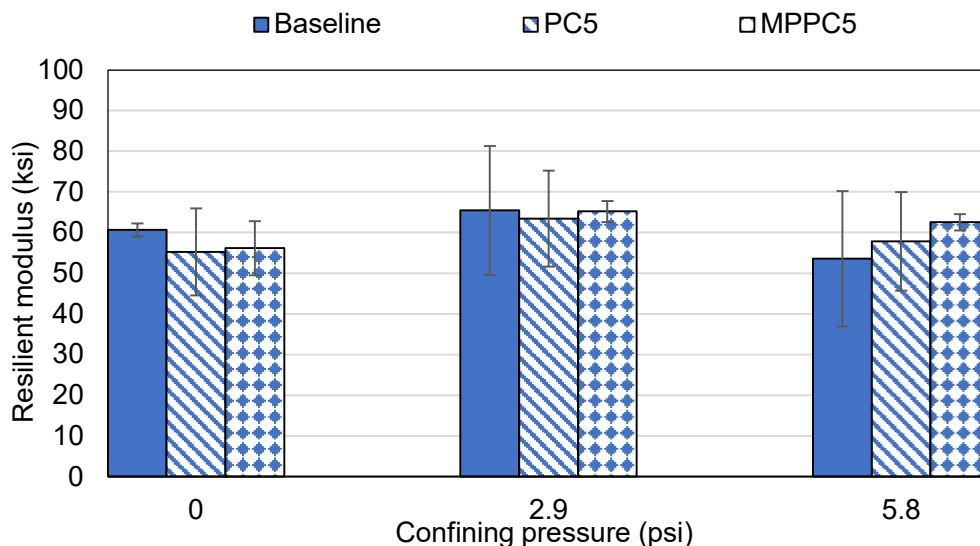


Figure 40: Resilient modulus (MR) of C-J baseline mixture (Baseline), original 5% processed post-consumer RAS mixture (PC5), and 5% minimally processed post-consumer RAS mixture (MPPC5).

Triaxial shear strength (TSS)

The monotonic triaxial shear strength test was conducted on the specimens with 5% minimally processed RAS to measure the shear properties. Figure 41 and Figure 42 show cohesion and internal friction angle of the FDR baselines (Baseline), the mixtures with 5% processed post-consumer RAS (PC5), and those with 5% minimally processed post-consumer RAS (MPPC5). The results indicate that incorporating 5% minimally processed RAS leads to an increase in cohesion compared to mixtures containing 5% processed RAS (7.6% increase for C-J and 6% for M-D), although cohesion remains lower than that of the baseline mixtures. However, a key finding is the increase in the internal friction angle (21% increase for C-J and 30% for M-D), demonstrating that the use of minimally processed RAS enhances the shear strength of the mixtures.

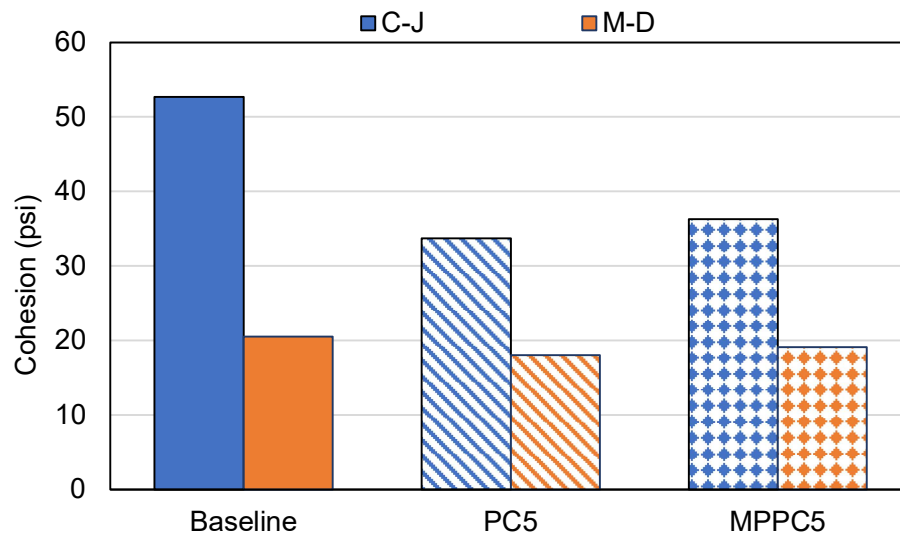


Figure 41: Cohesion of FDR baseline mixtures (Baseline), original 5% processed post-consumer RAS mixtures (PC5), and 5% minimally processed post-consumer RAS mixtures (MPPC5).

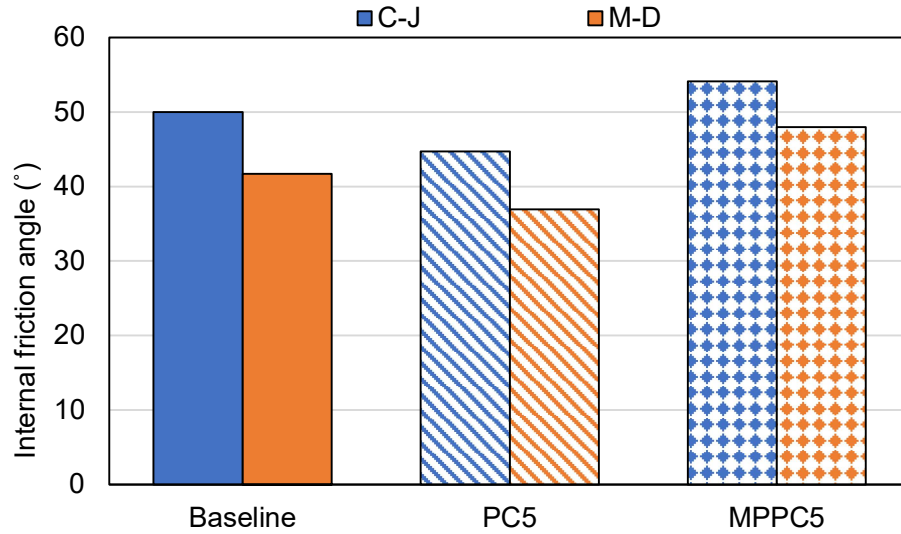


Figure 42: Internal friction angle of FDR baseline mixtures (Baseline), 5% processed post-consumer RAS mixtures (PC5), and 5% minimally processed post-consumer RAS mixtures (MPPC5).

Pavement performance prediction

The resilient modulus results were used as input to predict pavement performance and MnPAVE was employed for the analysis. The same pavement cross-sections of M-D and C-J projects shown in chapter 5 were considered. The software was used to estimate the allowed number of load repetitions to prevent phenomena such as fatigue and rutting failure. Based on the results, rutting emerged as the predominant distress mechanism.

Figure 43 shows the number of ESALs beyond which the threshold of 12.5 mm (0.5 inches) of rutting, commonly used as the failure limit by MnDOT, is exceeded. The results show that for the M-D baseline, the incorporation of 5% minimally processed RAS improves rutting resistance compared to the use of 5% processed RAS, although performance remains lower than that of the baseline mixture. Regarding C-J, no noticeable differences are observed in the number of allowed load repetitions with the inclusion of minimally processed RAS, confirming that a 5% RAS content, regardless of the type, is low enough to not substantially impact predicted pavement performance.

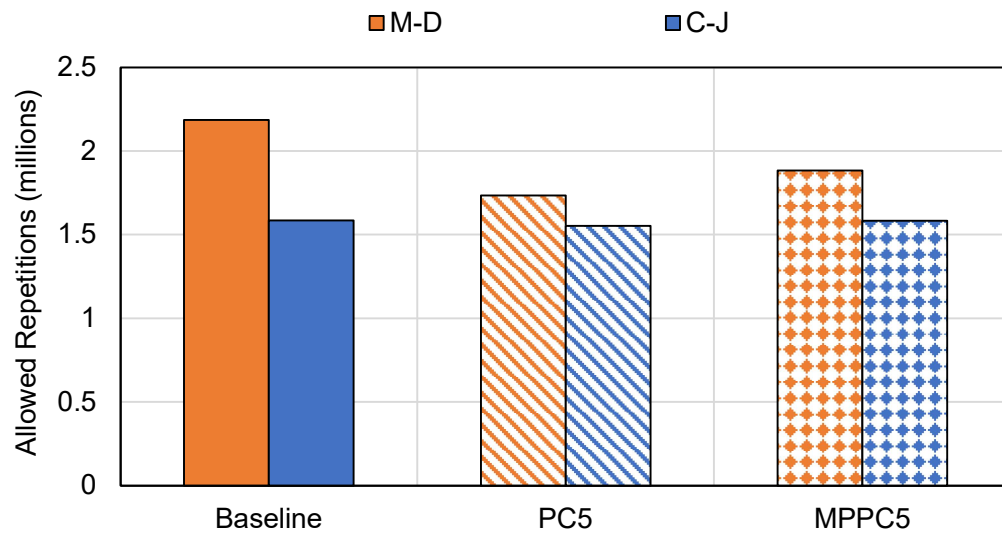


Figure 43: Allowed load repetitions to rutting failure.

CHAPTER 8: LCA AND LCCA ANALYSES

Following the laboratory testing program, performance analysis, and service life prediction presented in the previous chapters, an economic and environmental evaluation was conducted to assess the practical feasibility of incorporating RAS in full-depth reclamation processes.

This chapter presents the results of the life-cycle assessment (LCA) and life-cycle cost analysis (LCCA) performed as part of Task 3 of the project. The analysis begins with a comparison of the initial costs between the FDR materials of the two projects analyzed (M-D and C-J) and the mixtures incorporating 5% post-consumer (PC) RAS, considering material costs only.

An environmental impact assessment was then carried out using FHWA's LCA Pave tool to quantify the effects associated with the inclusion of 5% RAS. Finally, a life-cycle cost analysis was performed using FHWA's RealCost 2.1, incorporating the service lives estimated from the performance analysis presented earlier and including scheduled rehabilitation activities over a 60-year analysis period.

Together, these analyses provide a comprehensive evaluation of the economic and environmental implications of using RAS in FDR applications, complementing the structural and performance findings discussed in the preceding chapters.

Initial cost analysis

The initial material cost analysis considered data from the two projects included in the Contract Plans, including total project length, lane and shoulder widths, FDR layer thickness, stabilized FDR density, and unit prices for all materials obtained from the total bids of the projects. For the analysis, the cost of RAS was assumed to be zero.

The results indicated that incorporating 5% post-consumer (PC) RAS leads to a reduction in initial material costs for both projects. For the Marshfield-Danville project, the inclusion of 5% PC RAS resulted in a 1.8% decrease. However, since the initial material cost accounts for only approximately 4% of the total project construction cost, this reduction has a relatively small effect on the overall project cost.

A similar trend was observed for the Cambridge-Johnson project, where the inclusion of 5% PC RAS led to a 1.6% decrease in initial material costs. In this case, the initial material cost represents only about 3% of the total project construction cost, again indicating a modest impact on the overall budget.

These findings suggest that, while the use of 5% PC RAS can slightly reduce initial material costs, the effect on the total project expenditure is limited, emphasizing the importance of considering full life-cycle costs and environmental impacts in project evaluations.

Life-cycle assessment (LCA)

The life-cycle assessment (LCA) focused on evaluating the potential impact on global warming, expressed in kilograms of CO₂ equivalent (kg CO₂ eq), resulting from the use of 100% FDR mixtures versus mixtures incorporating 5% minimally processed post-consumer (MPPC) RAS for both the Marshfield-Danville and Cambridge-Johnson projects.

For this analysis, all activities common to both alternatives (production of FDR, addition of water, cement, and emulsion), were considered constant, as they contribute equally to the environmental impact in both cases. The primary difference between the alternatives is related to material transportation, specifically the reduction in gravel required and the introduction of RAS hauled to the construction site.

To account for potential variations in hauling logistics, four scenarios were evaluated by varying the transport distances for gravel and RAS delivery. For the M-D project (Table 20), the inclusion of 5% MPPC RAS resulted in variations in global warming potential ranging from a 2.76% increase (Gravel 2 miles - RAS 60 miles) to a 0.60% decrease (Gravel 25 miles - RAS 2 miles), indicating a strong dependency on transportation distances. A similar trend was observed for the C-J project (Table 21), where the change in global warming potential ranged from a 2.97% increase to a 0.57% decrease depending on the hauling scenario. When equal transport distances were assumed for both gravel and RAS, the environmental impact of the mixtures incorporating 5% MPPC RAS was nearly identical to that of the 100% FDR mixtures, indicating a negligible change in greenhouse gas emissions.

These results suggest that the environmental performance of the RAS mixtures is governed primarily by hauling logistics rather than by the material substitution itself. When the RAS source is located closer to the project site than the gravel source, incorporating 5% MPPC RAS can provide a modest environmental benefit, whereas long transport distances for RAS may slightly increase the overall environmental impact.

It should be noted that this analysis does not include the transportation and disposal of RAS to a landfill when not reused; accounting for these avoided impacts could further improve the relative environmental performance of mixtures incorporating RAS.

Table 20: Global Warming (kg CO₂ eq.) potential for M-D project.

Transport Distance	100% FDR (kg CO₂ eq.)	95% FDR + 5% MPPC (kg CO₂ eq.)
Gravel (2 miles) – RAS (60 miles)	2,036,974	2,093,266
Same distance for gravel and RAS	2,089,858	2,090,207
Gravel (25 miles) – RAS (60 miles)	2,189,016	2,200,498
Gravel (25 miles) – RAS (2 miles)	2,189,016	2,175,959

Table 21: Global Warming (kg CO₂ eq.) potential for C-J project.

Transport Distance	100% FDR (kg CO₂ eq)	95% FDR + 5% MPPC (kg CO₂ eq)
Gravel (2 miles) – RAS (60 miles)	955,618	984,032
Same distance for gravel and RAS	984,859	985,548
Gravel (25 miles) – RAS (60 miles)	1,026,934	1,053,667
Gravel (25 miles) - RAS (2 miles)	1,026,934	1,021,124

To facilitate interpretation, the percentage differences in global warming potential (GWP) between the two alternatives across the different hauling scenarios are presented graphically in Figure 44. The maximum observed variation was approximately +3%, which is well within the ±10% range typically

considered negligible in LCA studies, confirming that the environmental impacts of the two alternatives are comparable.

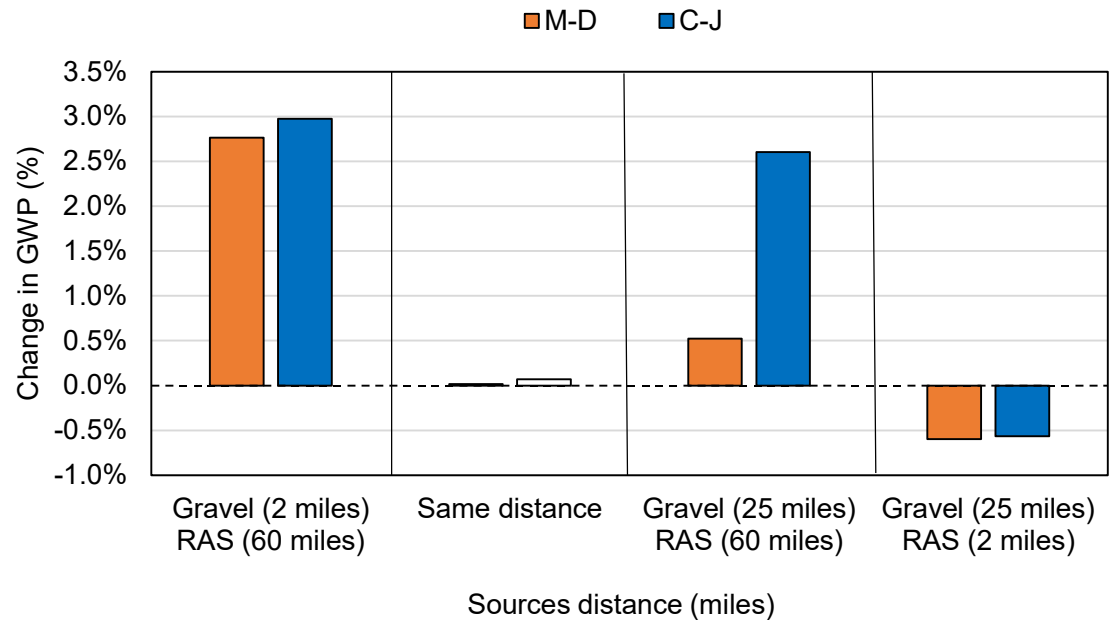


Figure 44: Change in Global Warming Potential (%)

Life-cycle cost analysis (LCCA)

A life-cycle cost analysis (LCCA) was performed using the FHWA RealCost software to evaluate the long-term economic implications of incorporating 5% post-consumer (PC) RAS in FDR mixtures for both projects. An analysis period of 60 years was adopted with an annual discount rate of 4%.

Project-specific traffic data were obtained from the VTrans Traffic Data Management System and included the Average Annual Daily Traffic (AADT), the percentage of single-unit trucks, and the percentage of combination trucks. The posted speed limit for each project was also considered. An annual traffic growth rate of 1% was assumed, consistent with the value used in the MnPAVE service life analysis.

The service lives estimated using MnPAVE for each pavement alternative were used to define the timing of rehabilitation activities throughout the 60-year analysis period. Based on these service life predictions, rehabilitation schedules were developed for each alternative and incorporated into the RealCost analysis.

Agency costs were considered in the analysis for both alternatives, namely the 100% FDR mixtures and the mixtures incorporating 5% PC RAS. The LCCA therefore evaluates the long-term economic performance of the alternatives while accounting for differences in pavement performance and the timing of future rehabilitation activities.

LCCA results

The results of the RealCost analysis for the Marshfield-Danville (M-D) and Cambridge-Johnson (C-J) projects are summarized in Table 21 and Table 22. The comparison was performed between the 100%

FDR alternative and the mixture incorporating 5% minimally processed post-consumer (MPPC) RAS, considering agency costs only.

For the M-D project (Table 22), the analysis indicated higher life-cycle costs for the alternative incorporating 5% MPPC RAS. The net present value (NPV) increased from \$62.26 million for the 100% FDR alternative to \$69.86 million for the 95% FDR + 5% MPPC RAS alternative. Similarly, the equivalent uniform annual cost (EUAC) increased from \$2.75 million per year to \$3.09 million per year.

This difference is primarily explained by the service life predicted using MnPAVE and shown in Chapter 7. The service life of the 100% FDR alternative was estimated at approximately 14 years, whereas the inclusion of 5% MPPC RAS reduced the predicted service life to approximately 12 years. The shorter service life results in more frequent rehabilitation activities over the 60-year analysis period, which offsets the small reduction in initial material costs and ultimately increases the total life-cycle cost.

Table 22: Net Present Value (NPV) and Equivalent Uniform Annual Cost (EUAC) for the M-D project considering 100% FDR and 95% FDR + 5% MPPC alternatives.

Description	100% FDR	95% FDR + 5% MPPC
NPV	\$62,258,195	\$69,858,664
EUAC	\$2,751,927	\$3,087,882

For the C-J project (Table 23), the results were markedly different. The NPV slightly decreased from \$50.32 million for the 100% FDR alternative to \$50.30 million for the 95% FDR + 5% MPPC RAS alternative, and the EUAC decreased from \$2.224 million per year to \$2.223 million per year. In this case, the predicted service life was approximately the same for both alternatives (about 10 years), resulting in nearly identical rehabilitation schedules throughout the analysis period.

Because the performance of the two alternatives was similar for the C-J project, the life-cycle costs were also essentially equivalent. This indicates that when the inclusion of 5% MPPC RAS does not negatively affect pavement service life, the economic impact over the long term is neutral or slightly favorable.

Table 23: Net Present Value (NPV) and Equivalent Uniform Annual Cost (EUAC) for the C-J project considering 100% FDR and 95% FDR + 5% MPPC alternatives.

Description	100% FDR	95% FDR + 5% MPPC
NPV	\$50,322,617	\$50,296,133
EUAC	\$2,224,352	\$2,223,182

Overall, the LCCA results demonstrate that the economic feasibility of incorporating 5% MPPC RAS in FDR mixtures is strongly governed by pavement performance. Small differences in service life have a greater influence on long-term cost than the modest changes in initial material cost observed in the initial cost analysis.

CHAPTER 9: SUMMARY AND CONCLUSIONS

This chapter provides the project summary and key conclusions regarding the feasibility and performance implications of incorporating both processed and minimally processed RAS as a mechanical stabilizer into FDR processes.

Summary

This report presents the findings of the Vermont Agency of Transportation (VTrans) Project GR1850, which examined the feasibility of using recycled asphalt shingles (RAS) as a mechanical stabilizer in full depth reclamation (FDR) operations. Motivated by both environmental considerations and Vermont's recycling requirements for asphalt shingles, the study investigated whether processed and minimally processed RAS could serve as viable alternatives to conventional stabilizers while enabling diversion of roofing waste from landfills.

Task 1 (Chapters 1-3) established the background and motivation for this study through a literature and practice review covering RAS recycling, environmental considerations, FDR construction, and VTrans specifications and mix design approaches. This task defined the research questions and provided the technical basis for the laboratory evaluations in Task 2.

Task 2 (Chapters 4-7) involved the collection of materials and the laboratory characterization of mixtures containing FDR materials collected from the Marshfield-Danville (M-D) and Cambridge-Johnson (C-J) projects, combined with both processed and minimally processed RAS.

The initial phase of the experimental plan focused on characterizing the FDR baseline mixtures and those containing 5% and 10% processed RAS passing the 3/8-inch sieve. RAS was collected from two different sources and in two forms: manufacturer waste (MW) and post-consumer (PC). As a first step, the individual components were characterized separately. Samples from both RAS sources were tested for potential environmental contaminants. Gradation analysis via dry sieving and cohesion test to assess the potential activity of the asphalt binder within the RAS was conducted.

The collected FDR materials were also characterized through gradation analysis, as well as volumetric analysis to determine the optimum moisture content (OMC) and maximum dry density (MDD). Subsequently, the gradation and volumetric properties of the FDR + RAS blends were assessed. This preliminary characterization enabled the development of appropriate mix designs for specimen preparation and subsequent mechanical testing.

The FDR baselines and the FDR + 5% and 10% processed RAS mixtures from both sources were mechanically characterized using three laboratory tests: indirect tensile strength (ITS), triaxial resilient modulus (MR), and triaxial shear strength (TSS). The MR test results were used as input in MnPAVE to predict pavement performance by modeling the studied mixtures within the cross-sections of the two reference projects. The analysis of processed RAS led to the identification of the "optimal" RAS content. An additional evaluation was conducted to adjust the mixtures and achieve comparable density values between those containing the "optimal" RAS content and the FDR baselines.

The "optimal" RAS content and the corrections were then maintained for the analysis of minimally processed RAS. An initial investigation examined potential gradation changes in mixtures containing these RAS. This was followed by volumetric analysis and mechanical testing using the same three tests: ITS, MR, and TSS. Finally, pavement performance analysis was also conducted for mixtures incorporating minimally processed RAS.

Task 3 (Chapter 8) consisted of an economic and environmental evaluation of incorporating 5% post-consumer (PC) RAS into FDR mixtures for the two reference projects. This task included an initial

material cost comparison based on project contract data, a life-cycle assessment (LCA) to quantify environmental impacts associated with material transportation and production, and a life-cycle cost analysis (LCCA) performed using FHWA RealCost. The LCCA incorporated traffic data from the VTrans Traffic Data Management System and pavement service life predictions obtained from the MnPAVE performance analysis to establish rehabilitation schedules over a 60-year analysis period. This task provided a practical assessment of the feasibility of using RAS in FDR applications by integrating the mechanical performance results from Task 2 with long-term economic and environmental considerations.

Conclusions

The main findings and conclusions based on the research conducted are listed below.

- **Gradation:** the addition of processed PC shingles resulted in minimal change to the overall particle size distribution for the FDR from both M-D and C-J projects. However, the addition of processed MW shingles, especially in high percentage (15%), caused a substantial change in the particle size distribution. The inclusion of 5% minimally processed PC RAS had negligible effects on the gradation of blends with the M-D FDR material, likely due to its already higher fine content. Conversely, in blends with the C-J FDR material, minimally processed RAS slightly modified the gradation by increasing the mid-size fraction, likely due to the detachment of fine particles from the shingles during mixing.
- **Volumetric properties:** the introduction of RAS generally increased the air void content of the mixtures, which in turn affected their mechanical behavior. Mixtures with processed RAS exhibited inferior mechanical behavior compared to the FDR baselines, primarily due to higher air voids (ranging from 1.2 to 3.3% for M-D and from 4 to 5.3% for C-J). However, by applying corrections to the compaction time and final specimen height, it was possible to achieve density and air void levels comparable to those of the baseline mixtures. This behavior also suggests that FDR materials with a relatively higher fine content and well-graded particle size distribution may be more suitable for the incorporation of RAS, as they are less sensitive to gradation changes and air void increases compared to coarser blends.
- **Indirect tensile strength:** the inclusion of RAS generally led to a reduction in ITS for both M-D and C-J baseline mixtures, with the decrease becoming more pronounced as the RAS content increased, regardless of type. For the M-D baseline, reductions reached up to 40% with processed PC RAS and 15% with processed MW RAS, corresponding to an increase in air voids ranging between 1.2% and 3.3%. As a result, none of the M-D mixtures met the minimum ITS requirement of 40 psi set by the new VAOT specifications. For the C-J baseline, ITS values decreased by up to 35% with both PC and MW processed RAS, associated with an increase in air void contents ranging between 4% and 5.3%. However, unlike the M-D blends, mixtures prepared with the C-J baseline met the new VAOT specification up to 5% RAS content. Notably, the incorporation of 5% minimally processed PC RAS yielded higher ITS values than mixtures containing 5% processed RAS, though still lower than the baseline FDR mixtures.
- **Triaxial resilient modulus:** the inclusion of 5% of both processed and minimally processed RAS did not cause statistically significant changes in the resilient modulus of FDR mixtures from the C-J project. Conversely, mixtures from the M-D project exhibited a reduction in resilient modulus with the addition of RAS, with a drop ranging between 15% and 40% incorporating the processed RAS, and 20% and 33% incorporating the minimally processed RAS. In the M-D mixtures, 5% minimally processed PC RAS led to an increase in stiffness comparable to that of the FDR baseline only under high confining pressures (5.8 psi).

- Shear properties: in general, shear strength decreased with increasing content of RAS. Cohesion drop is likely due to increased surface area not compensated with added emulsion; friction angle drop is likely due to gradation change effects. The incorporation of 5% minimally processed PC RAS resulted in higher cohesion values compared to mixtures containing 5% processed RAS, although cohesion remained well below that of the baseline FDR mixtures. Importantly, the internal friction angle increased incorporating 5% minimally processed PC RAS, suggesting an overall improvement in shear resistance.
- Pavement performance: preliminary results suggest that the addition of RAS may reduce pavement life, with the effect being more evident in the M-D blends. In contrast, mixtures prepared with the C-J FDR material demonstrated performance comparable to the baseline, regardless of whether processed or minimally processed RAS was used. Notably, the incorporation of 5% minimally processed PC RAS provided better service life than mixtures with 5% processed PC RAS.
- LCA and LCCA: overall, the findings indicate that the feasibility of incorporating 5% MPPC RAS in FDR mixtures depends primarily on pavement performance and material logistics. If the inclusion of RAS does not reduce service life and transport distances are comparable to or shorter than those of conventional aggregate sources, its use can be considered an environmentally and economically viable alternative. Conversely, any reductions in service life may outweigh the modest savings in initial material costs, potentially resulting in higher long-term project costs.

Overall, this research has demonstrated first and foremost that the mechanical results are very specific to each individual project. Results indicated that the use of up to 5% RAS as a mechanical stabilizer in FDR processes is feasible, as it leads to acceptable mechanical properties and pavement performance without compromising quality standards. At higher contents, however, a loss in mechanical properties and performance was observed. As concluded above, the gradation of material plays a very important role with respect to accommodation of RAS, a starting FDR gradation that is more receptive to RAS incorporation is one where gradation is not substantially altered from its well-graded nature with the addition of RAS. Furthermore, laboratory testing showed that minimally processed RAS provided better mechanical behavior and performance than processed RAS, particularly when limited to 5% by weight. LCA and LCCA analyses further suggested that the use of 5% RAS is environmentally and economically viable when it does not reduce service life and transport distances are comparable to conventional aggregate sources; otherwise, any modest initial savings may be offset by higher long-term project costs.

Future work

Building on the findings of this research, a natural next step would be to translate these results into practice by constructing a pavement section incorporating an FDR layer with RAS. Long-term monitoring of this pavement would provide valuable data on performance, durability, and maintenance needs under real field conditions, allowing for validation of laboratory results and further optimization of RAS content in FDR mixtures. This project was approached with a hypothesis that the current FDR specification for VAOT would be used in its current form. The outcomes presented in this report align with the original hypothesis. Future efforts can revisit this hypothesis, where material specifications and corresponding requirements can be revisited to explore if changing these thresholds can change the acceptable amount of RAS in FDR.

In addition, it would be of interest to evaluate the transferability of the results to Cold In-Place Recycling (CIR) treatments, especially considering that CIR is expected to be more widely implemented than FDR in

future projects. Although CIR differs from FDR in terms of mixture gradation, construction procedures, and layer behavior, the trends observed in this study, particularly related to air void content, cohesion, and tensile strength, may provide useful indications for CIR applications.

In this context, further research should investigate the potential influence of RAS incorporation on raveling and shear-related distresses in CIR treatments, in order to better assess their durability and long-term field performance, as recommended from a recent NCHRP study (National Academies, 2021).

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Appendix A - Synthetic Precipitation Leaching Procedure (SPLP) results – RAS samples

ANALYTICAL REPORT

PREPARED FOR

Attn: Eshan Dave
University of New Hampshire
Dept. of Civil & Env. Engineering
33 Academic Way
W173 Kingsbury Hall
Durham, New Hampshire 03824

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JOB DESCRIPTION

Asphalt Shingles Testing

JOB NUMBER

620-23136-1

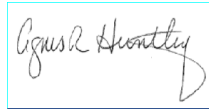
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Job Notes

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Agnes Huntley, Project Manager
Agnes.Huntley@et.eurofinsus.com
(401)267-4374



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Definitions/Glossary

Client: University of New Hampshire
Project/Site: Asphalt Shingles Testing

Job ID: 620-23136-1

Qualifiers

LCMS

Qualifier	Qualifier Description
*+	LCS and/or LCSD is outside acceptance limits, high biased.
*5+	Isotope dilution analyte is outside acceptance limits, high biased.
I	Value is EMPC (estimated maximum possible concentration).

Glossary

Abbreviation	These commonly used abbreviations may or may not be present in this report.
☼	Listed under the "D" column to designate that the result is reported on a dry weight basis
%R	Percent Recovery
CFL	Contains Free Liquid
CFU	Colony Forming Unit
CNF	Contains No Free Liquid
DER	Duplicate Error Ratio (normalized absolute difference)
Dil Fac	Dilution Factor
DL	Detection Limit (DoD/DOE)
DL, RA, RE, IN	Indicates a Dilution, Re-analysis, Re-extraction, or additional Initial metals/anion analysis of the sample
DLC	Decision Level Concentration (Radiochemistry)
EDL	Estimated Detection Limit (Dioxin)
LOD	Limit of Detection (DoD/DOE)
LOQ	Limit of Quantitation (DoD/DOE)
MCL	EPA recommended "Maximum Contaminant Level"
MDA	Minimum Detectable Activity (Radiochemistry)
MDC	Minimum Detectable Concentration (Radiochemistry)
MDL	Method Detection Limit
ML	Minimum Level (Dioxin)
MPN	Most Probable Number
MQL	Method Quantitation Limit
NC	Not Calculated
ND	Not Detected at the reporting limit (or MDL or EDL if shown)
NEG	Negative / Absent
POS	Positive / Present
PQL	Practical Quantitation Limit
PRES	Presumptive
QC	Quality Control
RER	Relative Error Ratio (Radiochemistry)
RL	Reporting Limit or Requested Limit (Radiochemistry)
RPD	Relative Percent Difference, a measure of the relative difference between two points
TEF	Toxicity Equivalent Factor (Dioxin)
TEQ	Toxicity Equivalent Quotient (Dioxin)
TNTC	Too Numerous To Count

Case Narrative

Client: University of New Hampshire
Project: Asphalt Shingles Testing

Job ID: 620-23136-1

Job ID: 620-23136-1

Eurofins Rhode Island

Job Narrative 620-23136-1

Analytical test results meet all requirements of the associated regulatory program listed on the Accreditation/Certification Summary Page unless otherwise noted under the individual analysis. Data qualifiers and/or narrative comments are included to explain any exceptions, if applicable.

- Matrix QC may not be reported if insufficient sample is provided or site-specific QC samples were not submitted. In these situations, to demonstrate precision and accuracy at a batch level, a LCS/LCSD may be performed, unless otherwise specified in the method.
- Surrogate and/or isotope dilution analyte recoveries (if applicable) which are outside of the QC window are confirmed unless attributed to a dilution or otherwise noted in the narrative.

Regulated compliance samples (e.g. SDWA, NPDES) must comply with the associated agency requirements/permits.

Receipt

The samples were received on 12/31/2024 11:52 AM. Unless otherwise noted below, the samples arrived in good condition, and, where required, properly preserved and on ice. The temperature of the cooler at receipt time was 3.6°C.

GC/MS Semi VOA

No additional analytical or quality issues were noted, other than those described above or in the Definitions/ Glossary page.

PCBs

No additional analytical or quality issues were noted, other than those described above or in the Definitions/ Glossary page.

PFAS

Method 1633_Final - SPLP East: Isotope Dilution Analyte (IDA) recovery is above the method recommended limit for the Method Blank (MB), Laboratory Control Sample (LCS), and Low-Level Laboratory Control Sample (LLCS) associated with prep batch 240-640636 and 240-640762. Quantitation by isotope dilution generally precludes any adverse effect on data quality due to elevated IDA recoveries. The MB is non-detect for associated target analytes and the LCS/LLCS are recovering within limits for the associated target analytes, therefore, the associated samples are reported. The following samples are affected: MW1 (620-23136-1) and PC1 (620-23136-2).

Method 1633_Final - SPLP East: Ion abundance ratios are outside criteria for the following sample: PC1 (620-23136-2). Quantitation is based on the theoretical ion abundance ratio; therefore, these analytes have been reported as an estimated maximum possible concentration (EMPC). The affected analytes have been flagged.

Method 1633_Final - SPLP East: Isotope Dilution Analyte (IDA) recovery is above the method recommended limit for the following samples: MW1 (620-23136-1) and PC1 (620-23136-2). Quantitation by isotope dilution generally precludes any adverse effect on data quality due to elevated IDA recoveries.

Method 1633_Final - SPLP East: The low-level continuing calibration verification (CCVL), continuing calibration verification (CCV), and continuing calibration blank (CCB) recovered outside of control limits for IDA compound d5-NEtFOSAA. Section 14.3.3 of the finalized EPA 1633 states that the recovery of target analytes for the CCV must be within 70 - 130%, unless the analyte is not of concern for a given project. Since target analytes associated with this IDA are within spec and the target analytes were below the RL in the CCB, data is reported. The following sample is impacted: (LB 240-640636/4-B).

Method 1633_Final - SPLP East: Isotope Dilution Analyte (IDA) recovery is above the method recommended limit for the following samples: MW1 (620-23136-1) and PC1 (620-23136-2). Quantitation by isotope dilution generally precludes any adverse effect on data quality due to elevated IDA recoveries.

No additional analytical or quality issues were noted, other than those described above or in the Definitions/ Glossary page.

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Detection Summary

Client: University of New Hampshire
Project/Site: Asphalt Shingles Testing

Job ID: 620-23136-1

Client Sample ID: MW1

Lab Sample ID: 620-23136-1

Analyte	Result	Qualifier	RL	Unit	Dil Fac	D	Method	Prep Type
Perfluoropentanoic acid (PFPeA)	2.18		1.91	ng/L	1		1633	SPLP East
Perfluorooctanoic acid (PFOA)	9.39		1.90	ng/L	1		1633	SPLP East
Perfluorooctanesulfonic acid (PFOS)	40.6		1.90	ng/L	1		1633	SPLP East
Perfluorooctanesulfonamide (PFOSA)	4.85		1.90	ng/L	1		1633	SPLP East
N-ethylperfluorooctanesulfonamidoacetic acid (NEtFOSAA)	7.47		1.90	ng/L	1		1633	SPLP East

Client Sample ID: PC1

Lab Sample ID: 620-23136-2

Analyte	Result	Qualifier	RL	Unit	Dil Fac	D	Method	Prep Type
Perfluorohexanoic acid (PFHxA)	1.97		1.86	ng/L	1		1633	SPLP East
Perfluoroheptanoic acid (PFHpA)	3.57		1.89	ng/L	1		1633	SPLP East
Perfluorooctanoic acid (PFOA)	41.5		1.89	ng/L	1		1633	SPLP East
Perfluorononanoic acid (PFNA)	8.54		1.89	ng/L	1		1633	SPLP East
Perfluorodecanoic acid (PFDA)	5.26		1.89	ng/L	1		1633	SPLP East
Perfluorooctanesulfonic acid (PFOS)	226		1.89	ng/L	1		1633	SPLP East
Perfluorooctanesulfonamide (PFOSA)	8.44	I	1.89	ng/L	1		1633	SPLP East
N-ethylperfluorooctanesulfonamidoacetic acid (NEtFOSAA)	32.7		1.89	ng/L	1		1633	SPLP East

This Detection Summary does not include radiochemical test results.

Eurofins Rhode Island

Client Sample Results

Client: University of New Hampshire
Project/Site: Asphalt Shingles Testing

Job ID: 620-23136-1

Client Sample ID: MW1

Lab Sample ID: 620-23136-1

Date Collected: 12/20/24 15:15

Matrix: Solid

Date Received: 12/31/24 11:52

Method: SW846 8270E - Semivolatile Organic Compounds (GC/MS) - SPLP East

Analyte	Result	Qualifier	RL	Unit	D	Prepared	Analyzed	Dil Fac
1-Methylnaphthalene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 21:43	1
2-Methylnaphthalene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 21:43	1
Acenaphthene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 21:43	1
Acenaphthylene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 21:43	1
Anthracene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 21:43	1
Benzo[a]anthracene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 21:43	1
Benzo[a]pyrene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 21:43	1
Benzo[b]fluoranthene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 21:43	1
Benzo[g,h,i]perylene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 21:43	1
Benzo[k]fluoranthene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 21:43	1
Chrysene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 21:43	1
Dibenz(a,h)anthracene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 21:43	1
Fluoranthene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 21:43	1
Fluorene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 21:43	1
Indeno[1,2,3-cd]pyrene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 21:43	1
Naphthalene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 21:43	1
Phenanthrene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 21:43	1
Pyrene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 21:43	1

Surrogate	%Recovery	Qualifier	Limits	Prepared	Analyzed	Dil Fac
Nitrobenzene-d5 (Surr)	64		30 - 130	01/03/25 10:26	01/03/25 21:43	1
2-Fluorobiphenyl (Surr)	65		30 - 130	01/03/25 10:26	01/03/25 21:43	1
Terphenyl-d14 (Surr)	78		30 - 130	01/03/25 10:26	01/03/25 21:43	1

Method: SW846 8082A - Polychlorinated Biphenyls (PCBs) by Gas Chromatography - SPLP East

Analyte	Result	Qualifier	RL	Unit	D	Prepared	Analyzed	Dil Fac
PCB-1016	ND		0.400	ug/L		01/03/25 11:17	01/06/25 14:34	1
PCB-1221	ND		0.400	ug/L		01/03/25 11:17	01/06/25 14:34	1
PCB-1232	ND		0.400	ug/L		01/03/25 11:17	01/06/25 14:34	1
PCB-1242	ND		0.400	ug/L		01/03/25 11:17	01/06/25 14:34	1
PCB-1248	ND		0.400	ug/L		01/03/25 11:17	01/06/25 14:34	1
PCB-1254	ND		0.400	ug/L		01/03/25 11:17	01/06/25 14:34	1
PCB-1260	ND		0.400	ug/L		01/03/25 11:17	01/06/25 14:34	1
PCB-1262	ND		0.400	ug/L		01/03/25 11:17	01/06/25 14:34	1
PCB-1268	ND		0.400	ug/L		01/03/25 11:17	01/06/25 14:34	1

Surrogate	%Recovery	Qualifier	Limits	Prepared	Analyzed	Dil Fac
Tetrachloro-m-xylene	60		30 - 150	01/03/25 11:17	01/06/25 14:34	1
DCB Decachlorobiphenyl (Surr)	67		30 - 150	01/03/25 11:17	01/06/25 14:34	1

Method: EPA 1633 - Per- and Polyfluoroalkyl Substances by LC/MS/MS - SPLP East

Analyte	Result	Qualifier	RL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		3.80	ng/L		01/07/25 08:18	01/07/25 16:41	1
Perfluoropentanoic acid (PFPeA)	2.18		1.91	ng/L		01/09/25 13:58	01/09/25 19:55	1
Perfluorohexanoic acid (PFHxA)	ND		1.91	ng/L		01/09/25 13:58	01/09/25 19:55	1
Perfluoroheptanoic acid (PFHpA)	ND		1.90	ng/L		01/07/25 08:18	01/07/25 16:41	1
Perfluorooctanoic acid (PFOA)	9.39		1.90	ng/L		01/07/25 08:18	01/07/25 16:41	1
Perfluorononanoic acid (PFNA)	ND		1.90	ng/L		01/07/25 08:18	01/07/25 16:41	1
Perfluorodecanoic acid (PFDA)	ND		1.90	ng/L		01/07/25 08:18	01/07/25 16:41	1
Perfluoroundecanoic acid (PFUnA)	ND		1.90	ng/L		01/07/25 08:18	01/07/25 16:41	1

Eurofins Rhode Island

Client Sample Results

Client: University of New Hampshire
Project/Site: Asphalt Shingles Testing

Job ID: 620-23136-1

Client Sample ID: MW1

Lab Sample ID: 620-23136-1

Date Collected: 12/20/24 15:15

Matrix: Solid

Date Received: 12/31/24 11:52

Method: EPA 1633 - Per- and Polyfluoroalkyl Substances by LC/MS/MS - SPLP East (Continued)

Analyte	Result	Qualifier	RL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorododecanoic acid (PFDoA)	ND		1.90	ng/L		01/07/25 08:18	01/07/25 16:41	1
Perfluorotridecanoic acid (PFTrDA)	ND		1.90	ng/L		01/07/25 08:18	01/07/25 16:41	1
Perfluorotetradecanoic acid (PFTeDA)	ND		1.90	ng/L		01/07/25 08:18	01/07/25 16:41	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.90	ng/L		01/07/25 08:18	01/07/25 16:41	1
Perfluoropentanesulfonic acid (PFPeS)	ND		1.90	ng/L		01/07/25 08:18	01/07/25 16:41	1
Perfluorohexanesulfonic acid (PFHxS)	ND		1.90	ng/L		01/07/25 08:18	01/07/25 16:41	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		1.90	ng/L		01/07/25 08:18	01/07/25 16:41	1
Perfluorooctanesulfonic acid (PFOS)	40.6		1.90	ng/L		01/07/25 08:18	01/07/25 16:41	1
Perfluorononanesulfonic acid (PFNS)	ND		1.90	ng/L		01/07/25 08:18	01/07/25 16:41	1
Perfluorododecanesulfonic acid (PFDoS)	ND		1.90	ng/L		01/07/25 08:18	01/07/25 16:41	1
1H,1H,2H,2H-Perfluorohexane sulfonic acid (4:2 FTS)	ND		3.80	ng/L		01/07/25 08:18	01/07/25 16:41	1
1H,1H,2H,2H-Perfluorooctane sulfonic acid (6:2 FTS)	ND		3.81	ng/L		01/09/25 13:58	01/09/25 19:55	1
1H,1H,2H,2H-Perfluorodecane sulfonic acid (8:2 FTS)	ND		3.80	ng/L		01/07/25 08:18	01/07/25 16:41	1
Perfluorooctanesulfonamide (PFOSA)	4.85		1.90	ng/L		01/07/25 08:18	01/07/25 16:41	1
N-methylperfluorooctane sulfonamide (NMeFOSA)	ND		1.90	ng/L		01/07/25 08:18	01/07/25 16:41	1
N-ethylperfluorooctane sulfonamide (NEtFOSA)	ND		1.90	ng/L		01/07/25 08:18	01/07/25 16:41	1
N-methylperfluorooctanesulfonamidoacetic acid (NMeFOSAA)	ND		1.90	ng/L		01/07/25 08:18	01/07/25 16:41	1
N-ethylperfluorooctanesulfonamidoacetic acid (NEtFOSAA)	7.47		1.90	ng/L		01/07/25 08:18	01/07/25 16:41	1
N-methylperfluorooctane sulfonamidoethanol (NMeFOSE)	ND		9.50	ng/L		01/07/25 08:18	01/07/25 16:41	1
N-ethylperfluorooctane sulfonamidoethanol (NEtFOSE)	ND		9.50	ng/L		01/07/25 08:18	01/07/25 16:41	1
Hexafluoropropylene Oxide Dimer Acid (HFPO-DA)	ND		1.42	ng/L		01/07/25 08:18	01/07/25 16:41	1
4,8-Dioxa-3H-perfluorononanoic acid (ADONA)	ND		1.90	ng/L		01/07/25 08:18	01/07/25 16:41	1
Perfluoro-4-methoxybutanoic acid (PFMBA)	ND		1.90	ng/L		01/07/25 08:18	01/07/25 16:41	1
Nonafluoro-3,6-dioxaheptanoic acid (NFDHA)	ND		1.90	ng/L		01/07/25 08:18	01/07/25 16:41	1
9-Chlorohexadecafluoro-3-oxanonane-1-sulfonic acid (9CI-PF3ONS)	ND		1.90	ng/L		01/07/25 08:18	01/07/25 16:41	1
11-Chloroeicosafluoro-3-oxaundecane-1-sulfonic acid (11CI-PF3OUdS)	ND		1.90	ng/L		01/07/25 08:18	01/07/25 16:41	1
Perfluoro (2-ethoxyethane) sulfonic acid (PFEESA)	ND		1.90	ng/L		01/07/25 08:18	01/07/25 16:41	1
3-Perfluoropropylpropanoic acid (3:3 FTCA)	ND		3.80	ng/L		01/07/25 08:18	01/07/25 16:41	1
3-Perfluoropentylpropanoic acid (5:3 FTCA)	ND		9.50	ng/L		01/07/25 08:18	01/07/25 16:41	1
3-Perfluoroheptylpropanoic acid (7:3 FTCA)	ND		9.50	ng/L		01/07/25 08:18	01/07/25 16:41	1
Perfluorodecanesulfonic acid (PFDS)	ND		1.90	ng/L		01/07/25 08:18	01/07/25 16:41	1

Eurofins Rhode Island

Client Sample Results

Client: University of New Hampshire
Project/Site: Asphalt Shingles Testing

Job ID: 620-23136-1

Client Sample ID: MW1

Lab Sample ID: 620-23136-1

Date Collected: 12/20/24 15:15

Matrix: Solid

Date Received: 12/31/24 11:52

Method: EPA 1633 - Per- and Polyfluoroalkyl Substances by LC/MS/MS - SPLP East (Continued)

Analyte	Result	Qualifier	RL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluoro-3-methoxypropanoic acid (PFMPA)	ND		1.90	ng/L		01/07/25 08:18	01/07/25 16:41	1
Isotope Dilution	%Recovery	Qualifier	Limits			Prepared	Analyzed	Dil Fac
13C4 PFBA	95.7		5 - 130			01/07/25 08:18	01/07/25 16:41	1
13C5 PFPeA	87.6		40 - 130			01/07/25 08:18	01/07/25 16:41	1
13C5 PFPeA	145	*5+	40 - 130			01/09/25 13:58	01/09/25 19:55	1
13C5 PFHxA	87.0		40 - 130			01/07/25 08:18	01/07/25 16:41	1
13C5 PFHxA	140	*5+	40 - 130			01/09/25 13:58	01/09/25 19:55	1
13C4 PFHpA	93.1		40 - 130			01/07/25 08:18	01/07/25 16:41	1
13C4 PFHpA	148	*5+	40 - 130			01/09/25 13:58	01/09/25 19:55	1
13C8 PFOA	94.5		40 - 130			01/07/25 08:18	01/07/25 16:41	1
13C8 PFOA	151	*5+	40 - 130			01/09/25 13:58	01/09/25 19:55	1
13C9 PFNA	89.9		40 - 130			01/07/25 08:18	01/07/25 16:41	1
13C9 PFNA	144	*5+	40 - 130			01/09/25 13:58	01/09/25 19:55	1
13C6 PFDA	93.6		40 - 130			01/07/25 08:18	01/07/25 16:41	1
13C6 PFDA	142	*5+	40 - 130			01/09/25 13:58	01/09/25 19:55	1
13C7 PFUnA	87.9		30 - 130			01/07/25 08:18	01/07/25 16:41	1
13C7 PFUnA	130		30 - 130			01/09/25 13:58	01/09/25 19:55	1
13C2 PFTeDA	67.3		10 - 130			01/07/25 08:18	01/07/25 16:41	1
13C2 PFTeDA	88.3		10 - 130			01/09/25 13:58	01/09/25 19:55	1
13C3 PFBS	85.8		40 - 135			01/07/25 08:18	01/07/25 16:41	1
13C3 PFBS	136	*5+	40 - 135			01/09/25 13:58	01/09/25 19:55	1
13C3 PFHxS	94.0		40 - 130			01/07/25 08:18	01/07/25 16:41	1
13C3 PFHxS	151	*5+	40 - 130			01/09/25 13:58	01/09/25 19:55	1
13C8 PFOS	110		40 - 130			01/07/25 08:18	01/07/25 16:41	1
13C8 PFOS	149	*5+	40 - 130			01/09/25 13:58	01/09/25 19:55	1
13C8 PFOSA	145	*5+	40 - 130			01/07/25 08:18	01/07/25 16:41	1
13C8 PFOSA	182	*5+	40 - 130			01/09/25 13:58	01/09/25 19:55	1
d3-NMeFOSAA	154		40 - 170			01/07/25 08:18	01/07/25 16:41	1
d3-NMeFOSAA	197	*5+	40 - 170			01/09/25 13:58	01/09/25 19:55	1
d5-NEtFOSAA	174	*5+	25 - 135			01/07/25 08:18	01/07/25 16:41	1
d5-NEtFOSAA	133		25 - 135			01/09/25 13:58	01/09/25 19:55	1
M2-4:2 FTS	234	*5+	40 - 200			01/07/25 08:18	01/07/25 16:41	1
M2-4:2 FTS	322	*5+	40 - 200			01/09/25 13:58	01/09/25 19:55	1
M2-6:2 FTS	181		40 - 200			01/07/25 08:18	01/07/25 16:41	1
M2-6:2 FTS	264	*5+	40 - 200			01/09/25 13:58	01/09/25 19:55	1
M2-8:2 FTS	193		40 - 300			01/07/25 08:18	01/07/25 16:41	1
M2-8:2 FTS	250		40 - 300			01/09/25 13:58	01/09/25 19:55	1
13C3 HFPO-DA	85.6		40 - 130			01/07/25 08:18	01/07/25 16:41	1
13C3 HFPO-DA	126		40 - 130			01/09/25 13:58	01/09/25 19:55	1
d7-N-MeFOSE-M	78.8		10 - 130			01/07/25 08:18	01/07/25 16:41	1
d7-N-MeFOSE-M	68.6		10 - 130			01/09/25 13:58	01/09/25 19:55	1
d9-N-EtFOSE-M	73.2		10 - 130			01/07/25 08:18	01/07/25 16:41	1
d9-N-EtFOSE-M	58.3		10 - 130			01/09/25 13:58	01/09/25 19:55	1
d5-NEtPFOSA	73.0		10 - 130			01/07/25 08:18	01/07/25 16:41	1
d5-NEtPFOSA	78.2		10 - 130			01/09/25 13:58	01/09/25 19:55	1
D3-NMeFOSA	78.6		10 - 130			01/07/25 08:18	01/07/25 16:41	1
D3-NMeFOSA	96.1		10 - 130			01/09/25 13:58	01/09/25 19:55	1
13C2-PFDoDA	85.0		10 - 130			01/07/25 08:18	01/07/25 16:41	1

Eurofins Rhode Island

Client Sample Results

Client: University of New Hampshire
Project/Site: Asphalt Shingles Testing

Job ID: 620-23136-1

Client Sample ID: MW1

Lab Sample ID: 620-23136-1

Date Collected: 12/20/24 15:15

Matrix: Solid

Date Received: 12/31/24 11:52

Method: EPA 1633 - Per- and Polyfluoroalkyl Substances by LC/MS/MS - SPLP East (Continued)

Isotope Dilution	%Recovery	Qualifier	Limits	Prepared	Analyzed	Dil Fac
13C2-PFDoDA	118		10 - 130	01/09/25 13:58	01/09/25 19:55	1

Client Sample ID: PC1

Lab Sample ID: 620-23136-2

Date Collected: 12/20/24 15:15

Matrix: Solid

Date Received: 12/31/24 11:52

Method: SW846 8270E - Semivolatile Organic Compounds (GC/MS) - SPLP East

Analyte	Result	Qualifier	RL	Unit	D	Prepared	Analyzed	Dil Fac
1-Methylnaphthalene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 22:41	1
2-Methylnaphthalene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 22:41	1
Acenaphthene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 22:41	1
Acenaphthylene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 22:41	1
Anthracene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 22:41	1
Benzo[a]anthracene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 22:41	1
Benzo[a]pyrene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 22:41	1
Benzo[b]fluoranthene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 22:41	1
Benzo[g,h,i]perylene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 22:41	1
Benzo[k]fluoranthene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 22:41	1
Chrysene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 22:41	1
Dibenz(a,h)anthracene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 22:41	1
Fluoranthene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 22:41	1
Fluorene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 22:41	1
Indeno[1,2,3-cd]pyrene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 22:41	1
Naphthalene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 22:41	1
Phenanthrene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 22:41	1
Pyrene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 22:41	1

Surrogate	%Recovery	Qualifier	Limits	Prepared	Analyzed	Dil Fac
Nitrobenzene-d5 (Surr)	61		30 - 130	01/03/25 10:26	01/03/25 22:41	1
2-Fluorobiphenyl (Surr)	62		30 - 130	01/03/25 10:26	01/03/25 22:41	1
Terphenyl-d14 (Surr)	85		30 - 130	01/03/25 10:26	01/03/25 22:41	1

Method: SW846 8082A - Polychlorinated Biphenyls (PCBs) by Gas Chromatography - SPLP East

Analyte	Result	Qualifier	RL	Unit	D	Prepared	Analyzed	Dil Fac
PCB-1016	ND		0.400	ug/L		01/03/25 11:17	01/06/25 14:52	1
PCB-1221	ND		0.400	ug/L		01/03/25 11:17	01/06/25 14:52	1
PCB-1232	ND		0.400	ug/L		01/03/25 11:17	01/06/25 14:52	1
PCB-1242	ND		0.400	ug/L		01/03/25 11:17	01/06/25 14:52	1
PCB-1248	ND		0.400	ug/L		01/03/25 11:17	01/06/25 14:52	1
PCB-1254	ND		0.400	ug/L		01/03/25 11:17	01/06/25 14:52	1
PCB-1260	ND		0.400	ug/L		01/03/25 11:17	01/06/25 14:52	1
PCB-1262	ND		0.400	ug/L		01/03/25 11:17	01/06/25 14:52	1
PCB-1268	ND		0.400	ug/L		01/03/25 11:17	01/06/25 14:52	1

Surrogate	%Recovery	Qualifier	Limits	Prepared	Analyzed	Dil Fac
Tetrachloro-m-xylene	61		30 - 150	01/03/25 11:17	01/06/25 14:52	1
DCB Decachlorobiphenyl (Surr)	69		30 - 150	01/03/25 11:17	01/06/25 14:52	1

Method: EPA 1633 - Per- and Polyfluoroalkyl Substances by LC/MS/MS - SPLP East

Analyte	Result	Qualifier	RL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		3.79	ng/L		01/07/25 08:18	01/07/25 16:58	1

Eurofins Rhode Island

Client Sample Results

Client: University of New Hampshire
Project/Site: Asphalt Shingles Testing

Job ID: 620-23136-1

Client Sample ID: PC1

Lab Sample ID: 620-23136-2

Date Collected: 12/20/24 15:15

Matrix: Solid

Date Received: 12/31/24 11:52

Method: EPA 1633 - Per- and Polyfluoroalkyl Substances by LC/MS/MS - SPLP East (Continued)

Analyte	Result	Qualifier	RL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluoropentanoic acid (PFPeA)	ND		1.86	ng/L		01/09/25 13:58	01/09/25 20:11	1
Perfluorohexanoic acid (PFHxA)	1.97		1.86	ng/L		01/09/25 13:58	01/09/25 20:11	1
Perfluoroheptanoic acid (PFHpA)	3.57		1.89	ng/L		01/07/25 08:18	01/07/25 16:58	1
Perfluorooctanoic acid (PFOA)	41.5		1.89	ng/L		01/07/25 08:18	01/07/25 16:58	1
Perfluorononanoic acid (PFNA)	8.54		1.89	ng/L		01/07/25 08:18	01/07/25 16:58	1
Perfluorodecanoic acid (PFDA)	5.26		1.89	ng/L		01/07/25 08:18	01/07/25 16:58	1
Perfluoroundecanoic acid (PFUnA)	ND		1.89	ng/L		01/07/25 08:18	01/07/25 16:58	1
Perfluorododecanoic acid (PFDoA)	ND		1.89	ng/L		01/07/25 08:18	01/07/25 16:58	1
Perfluorotridecanoic acid (PFTrDA)	ND		1.89	ng/L		01/07/25 08:18	01/07/25 16:58	1
Perfluorotetradecanoic acid (PFTeDA)	ND		1.89	ng/L		01/07/25 08:18	01/07/25 16:58	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.89	ng/L		01/07/25 08:18	01/07/25 16:58	1
Perfluoropentanesulfonic acid (PFPeS)	ND		1.89	ng/L		01/07/25 08:18	01/07/25 16:58	1
Perfluorohexanesulfonic acid (PFHxS)	ND		1.89	ng/L		01/07/25 08:18	01/07/25 16:58	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		1.89	ng/L		01/07/25 08:18	01/07/25 16:58	1
Perfluorooctanesulfonic acid (PFOS)	226		1.89	ng/L		01/07/25 08:18	01/07/25 16:58	1
Perfluorononanesulfonic acid (PFNS)	ND		1.89	ng/L		01/07/25 08:18	01/07/25 16:58	1
Perfluorododecanesulfonic acid (PFDoS)	ND		1.89	ng/L		01/07/25 08:18	01/07/25 16:58	1
1H,1H,2H,2H-Perfluorohexane sulfonic acid (4:2 FTS)	ND		3.79	ng/L		01/07/25 08:18	01/07/25 16:58	1
1H,1H,2H,2H-Perfluorooctane sulfonic acid (6:2 FTS)	ND		3.71	ng/L		01/09/25 13:58	01/09/25 20:11	1
1H,1H,2H,2H-Perfluorodecane sulfonic acid (8:2 FTS)	ND		3.79	ng/L		01/07/25 08:18	01/07/25 16:58	1
Perfluorooctanesulfonamide (PFOSA)	8.44	I	1.89	ng/L		01/07/25 08:18	01/07/25 16:58	1
N-methylperfluorooctane sulfonamide (NMeFOSA)	ND		1.89	ng/L		01/07/25 08:18	01/07/25 16:58	1
N-ethylperfluorooctane sulfonamide (NEtFOSA)	ND		1.89	ng/L		01/07/25 08:18	01/07/25 16:58	1
N-methylperfluorooctanesulfonamidoacetic acid (NMeFOSAA)	ND		1.89	ng/L		01/07/25 08:18	01/07/25 16:58	1
N-ethylperfluorooctanesulfonamidoacetic acid (NEtFOSAA)	32.7		1.89	ng/L		01/07/25 08:18	01/07/25 16:58	1
N-methylperfluorooctane sulfonamidoethanol (NMeFOSE)	ND		9.46	ng/L		01/07/25 08:18	01/07/25 16:58	1
N-ethylperfluorooctane sulfonamidoethanol (NEtFOSE)	ND		9.46	ng/L		01/07/25 08:18	01/07/25 16:58	1
Hexafluoropropylene Oxide Dimer Acid (HFPO-DA)	ND		1.42	ng/L		01/07/25 08:18	01/07/25 16:58	1
4,8-Dioxa-3H-perfluorononanoic acid (ADONA)	ND		1.89	ng/L		01/07/25 08:18	01/07/25 16:58	1
Perfluoro-4-methoxybutanoic acid (PFMBA)	ND		1.89	ng/L		01/07/25 08:18	01/07/25 16:58	1
Nonafluoro-3,6-dioxaheptanoic acid (NFDHA)	ND		1.89	ng/L		01/07/25 08:18	01/07/25 16:58	1
9-Chlorohexadecafluoro-3-oxanonane-1-sulfonic acid (9CI-PF3ONS)	ND		1.89	ng/L		01/07/25 08:18	01/07/25 16:58	1
11-Chloroeicosafluoro-3-oxaundecane-1-sulfonic acid (11CI-PF3OUdS)	ND		1.89	ng/L		01/07/25 08:18	01/07/25 16:58	1
Perfluoro (2-ethoxyethane) sulfonic acid (PFEESA)	ND		1.89	ng/L		01/07/25 08:18	01/07/25 16:58	1

Eurofins Rhode Island

Client Sample Results

Client: University of New Hampshire
Project/Site: Asphalt Shingles Testing

Job ID: 620-23136-1

Client Sample ID: PC1

Lab Sample ID: 620-23136-2

Date Collected: 12/20/24 15:15

Matrix: Solid

Date Received: 12/31/24 11:52

Method: EPA 1633 - Per- and Polyfluoroalkyl Substances by LC/MS/MS - SPLP East (Continued)

Analyte	Result	Qualifier	RL	Unit	D	Prepared	Analyzed	Dil Fac
3-Perfluoropropylpropanoic acid (3:3 FTCA)	ND		3.79	ng/L		01/07/25 08:18	01/07/25 16:58	1
3-Perfluoropentylpropanoic acid (5:3 FTCA)	ND		9.46	ng/L		01/07/25 08:18	01/07/25 16:58	1
3-Perfluoroheptylpropanoic acid (7:3 FTCA)	ND		9.46	ng/L		01/07/25 08:18	01/07/25 16:58	1
Perfluorodecanesulfonic acid (PFDS)	ND		1.89	ng/L		01/07/25 08:18	01/07/25 16:58	1
Perfluoro-3-methoxypropanoic acid (PFMPA)	ND		1.89	ng/L		01/07/25 08:18	01/07/25 16:58	1
Isotope Dilution	%Recovery	Qualifier	Limits			Prepared	Analyzed	Dil Fac
13C4 PFBA	100		5 - 130			01/07/25 08:18	01/07/25 16:58	1
13C5 PFPeA	82.7		40 - 130			01/07/25 08:18	01/07/25 16:58	1
13C5 PFPeA	137	*5+	40 - 130			01/09/25 13:58	01/09/25 20:11	1
13C5 PFHxA	88.7		40 - 130			01/07/25 08:18	01/07/25 16:58	1
13C5 PFHxA	140	*5+	40 - 130			01/09/25 13:58	01/09/25 20:11	1
13C4 PFHpA	103		40 - 130			01/07/25 08:18	01/07/25 16:58	1
13C4 PFHpA	159	*5+	40 - 130			01/09/25 13:58	01/09/25 20:11	1
13C8 PFOA	96.0		40 - 130			01/07/25 08:18	01/07/25 16:58	1
13C8 PFOA	150	*5+	40 - 130			01/09/25 13:58	01/09/25 20:11	1
13C9 PFNA	91.0		40 - 130			01/07/25 08:18	01/07/25 16:58	1
13C9 PFNA	141	*5+	40 - 130			01/09/25 13:58	01/09/25 20:11	1
13C6 PFDA	93.1		40 - 130			01/07/25 08:18	01/07/25 16:58	1
13C6 PFDA	141	*5+	40 - 130			01/09/25 13:58	01/09/25 20:11	1
13C7 PFUnA	85.1		30 - 130			01/07/25 08:18	01/07/25 16:58	1
13C7 PFUnA	127		30 - 130			01/09/25 13:58	01/09/25 20:11	1
13C2 PFTeDA	57.5		10 - 130			01/07/25 08:18	01/07/25 16:58	1
13C2 PFTeDA	79.3		10 - 130			01/09/25 13:58	01/09/25 20:11	1
13C3 PFBS	83.5		40 - 135			01/07/25 08:18	01/07/25 16:58	1
13C3 PFBS	133		40 - 135			01/09/25 13:58	01/09/25 20:11	1
13C3 PFHxS	97.5		40 - 130			01/07/25 08:18	01/07/25 16:58	1
13C3 PFHxS	151	*5+	40 - 130			01/09/25 13:58	01/09/25 20:11	1
13C8 PFOS	100		40 - 130			01/07/25 08:18	01/07/25 16:58	1
13C8 PFOS	136	*5+	40 - 130			01/09/25 13:58	01/09/25 20:11	1
13C8 PFOSA	140	*5+	40 - 130			01/07/25 08:18	01/07/25 16:58	1
13C8 PFOSA	180	*5+	40 - 130			01/09/25 13:58	01/09/25 20:11	1
d3-NMeFOSAA	156		40 - 170			01/07/25 08:18	01/07/25 16:58	1
d3-NMeFOSAA	206	*5+	40 - 170			01/09/25 13:58	01/09/25 20:11	1
d5-NEtFOSAA	163	*5+	25 - 135			01/07/25 08:18	01/07/25 16:58	1
d5-NEtFOSAA	136	*5+	25 - 135			01/09/25 13:58	01/09/25 20:11	1
M2-4:2 FTS	267	*5+	40 - 200			01/07/25 08:18	01/07/25 16:58	1
M2-4:2 FTS	359	*5+	40 - 200			01/09/25 13:58	01/09/25 20:11	1
M2-6:2 FTS	219	*5+	40 - 200			01/07/25 08:18	01/07/25 16:58	1
M2-6:2 FTS	322	*5+	40 - 200			01/09/25 13:58	01/09/25 20:11	1
M2-8:2 FTS	216		40 - 300			01/07/25 08:18	01/07/25 16:58	1
M2-8:2 FTS	286		40 - 300			01/09/25 13:58	01/09/25 20:11	1
13C3 HFPO-DA	77.2		40 - 130			01/07/25 08:18	01/07/25 16:58	1
13C3 HFPO-DA	124		40 - 130			01/09/25 13:58	01/09/25 20:11	1
d7-N-MeFOSE-M	82.1		10 - 130			01/07/25 08:18	01/07/25 16:58	1
d7-N-MeFOSE-M	78.6		10 - 130			01/09/25 13:58	01/09/25 20:11	1
d9-N-EtFOSE-M	73.7		10 - 130			01/07/25 08:18	01/07/25 16:58	1

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Client Sample Results

Client: University of New Hampshire
Project/Site: Asphalt Shingles Testing

Job ID: 620-23136-1

Client Sample ID: PC1

Lab Sample ID: 620-23136-2

Date Collected: 12/20/24 15:15

Matrix: Solid

Date Received: 12/31/24 11:52

Method: EPA 1633 - Per- and Polyfluoroalkyl Substances by LC/MS/MS - SPLP East (Continued)

Isotope Dilution	%Recovery	Qualifier	Limits	Prepared	Analyzed	Dil Fac
d9-N-EtFOSE-M	70.1		10 - 130	01/09/25 13:58	01/09/25 20:11	1
d5-NEtPFOSA	71.2		10 - 130	01/07/25 08:18	01/07/25 16:58	1
d5-NEtPFOSA	73.2		10 - 130	01/09/25 13:58	01/09/25 20:11	1
D3-NMeFOSA	78.8		10 - 130	01/07/25 08:18	01/07/25 16:58	1
D3-NMeFOSA	90.8		10 - 130	01/09/25 13:58	01/09/25 20:11	1
13C2-PFDoDA	84.3		10 - 130	01/07/25 08:18	01/07/25 16:58	1
13C2-PFDoDA	121		10 - 130	01/09/25 13:58	01/09/25 20:11	1

Surrogate Summary

Client: University of New Hampshire
Project/Site: Asphalt Shingles Testing

Job ID: 620-23136-1

Method: 8270E - Semivolatile Organic Compounds (GC/MS)

Matrix: Solid

Prep Type: Total/NA

Lab Sample ID	Client Sample ID	Percent Surrogate Recovery (Acceptance Limits)		
		NBZ (30-130)	FBP (30-130)	TPHL (30-130)
LCS 620-43019/2-A	Lab Control Sample	63	69	83
LCSD 620-43019/3-A	Lab Control Sample Dup	59	62	84
MB 620-43019/1-A	Method Blank	52	54	76
Surrogate Legend				
NBZ = Nitrobenzene-d5 (Surr)				
FBP = 2-Fluorobiphenyl (Surr)				
TPHL = Terphenyl-d14 (Surr)				

Method: 8270E - Semivolatile Organic Compounds (GC/MS)

Matrix: Solid

Prep Type: SPLP East

Lab Sample ID	Client Sample ID	Percent Surrogate Recovery (Acceptance Limits)		
		NBZ (30-130)	FBP (30-130)	TPHL (30-130)
620-23136-1	MW1	64	65	78
620-23136-1 MS	MW1	59	60	76
620-23136-2	PC1	61	62	85
MB 620-42987/1-C	Method Blank	61	65	80
Surrogate Legend				
NBZ = Nitrobenzene-d5 (Surr)				
FBP = 2-Fluorobiphenyl (Surr)				
TPHL = Terphenyl-d14 (Surr)				

Method: 8082A - Polychlorinated Biphenyls (PCBs) by Gas Chromatography

Matrix: Solid

Prep Type: Total/NA

Lab Sample ID	Client Sample ID	Percent Surrogate Recovery (Acceptance Limits)	
		TCX1 (30-150)	DCB1 (30-150)
LCS 620-43020/2-A	Lab Control Sample	81	92
LCSD 620-43020/3-A	Lab Control Sample Dup	64	77
MB 620-43020/1-A	Method Blank	71	86
Surrogate Legend			
TCX = Tetrachloro-m-xylene			
DCB = DCB Decachlorobiphenyl (Surr)			

Method: 8082A - Polychlorinated Biphenyls (PCBs) by Gas Chromatography

Matrix: Solid

Prep Type: SPLP East

Lab Sample ID	Client Sample ID	Percent Surrogate Recovery (Acceptance Limits)	
		TCX1 (30-150)	DCB1 (30-150)
620-23136-1	MW1	60	67
620-23136-2	PC1	61	69
620-23136-2 MS	PC1	53	54
MB 620-42987/1-D	Method Blank	75	83
Surrogate Legend			
TCX = Tetrachloro-m-xylene			
DCB = DCB Decachlorobiphenyl (Surr)			

Eurofins Rhode Island

Isotope Dilution Summary

Client: University of New Hampshire
Project/Site: Asphalt Shingles Testing

Job ID: 620-23136-1

Method: 1633 - Per- and Polyfluoroalkyl Substances by LC/MS/MS

Matrix: Solid

Prep Type: Total/NA

		Percent Isotope Dilution Recovery (Acceptance Limits)							
Lab Sample ID	Client Sample ID	PFBA (5-130)	PFPeA (40-130)	13C5PHA (40-130)	C4PFHA (40-130)	C8PFOA (40-130)	C9PFNA (40-130)	C6PFDA (40-130)	13C7PUA (30-130)
LCS 240-640762/3-A	Lab Control Sample	91.6	91.8	90.2	90.0	90.8	87.1	90.2	91.3
LCS 240-640965/3-A	Lab Control Sample	85.5	91.7	84.9	86.7	91.0	87.2	85.6	83.4
LLCS 240-640762/2-A	Lab Control Sample	94.1	93.2	90.8	93.7	94.4	92.1	91.3	87.8
LLCS 240-640965/2-A	Lab Control Sample	111	125	113	112	119	117	111	110
MB 240-640762/1-A	Method Blank	92.7	92.3	90.2	95.1	94.3	89.4	93.5	88.8
MB 240-640965/1-A	Method Blank	81.6	88.0	80.4	79.6	84.2	83.0	81.1	80.1

		Percent Isotope Dilution Recovery (Acceptance Limits)							
Lab Sample ID	Client Sample ID	PFTDA (10-130)	C3PFBS (40-135)	C3PFHS (40-130)	C8PFOS (40-130)	PFOSA (40-130)	d3NMFOS (40-170)	d5NEFOS (25-135)	M242FTS (40-200)
LCS 240-640762/3-A	Lab Control Sample	77.5	94.3	95.8	98.5	100	103	174 *5+	117
LCS 240-640965/3-A	Lab Control Sample	82.9	88.0	91.6	89.6	88.6	83.8	99.9	94.3
LLCS 240-640762/2-A	Lab Control Sample	77.3	96.5	95.9	98.7	103	103	184 *5+	119
LLCS 240-640965/2-A	Lab Control Sample	99.7	117	121	115	114	104	118	127
MB 240-640762/1-A	Method Blank	79.1	92.2	95.3	96.9	98.8	101	186 *5+	116
MB 240-640965/1-A	Method Blank	80.1	85.5	88.4	84.5	86.3	82.5	92.1	95.5

		Percent Isotope Dilution Recovery (Acceptance Limits)							
Lab Sample ID	Client Sample ID	M262FTS (40-200)	M282FTS (40-300)	HFPODA (40-130)	NMFM (10-130)	NEFM (10-130)	d5NPFSA (10-130)	d3NMFSA (10-130)	PFDODA (10-130)
LCS 240-640762/3-A	Lab Control Sample	103	108	90.9	65.3	56.9	75.3	81.4	83.6
LCS 240-640965/3-A	Lab Control Sample	90.4	93.9	82.7	55.3	53.0	63.7	68.5	82.3
LLCS 240-640762/2-A	Lab Control Sample	109	119	90.6	84.9	79.5	78.0	82.2	87.1
LLCS 240-640965/2-A	Lab Control Sample	120	124	110	74.7	69.2	74.3	82.7	105
MB 240-640762/1-A	Method Blank	107	113	91.0	75.7	72.6	75.0	80.0	89.8
MB 240-640965/1-A	Method Blank	91.7	92.8	81.1	77.1	74.6	63.4	65.4	79.9

Surrogate Legend

PFBA = 13C4 PFBA
PFPeA = 13C5 PFPeA
13C5PHA = 13C5 PFHxA
C4PFHA = 13C4 PFHpA
C8PFOA = 13C8 PFOA
C9PFNA = 13C9 PFNA
C6PFDA = 13C6 PFDA
13C7PUA = 13C7 PFUnA
PFTDA = 13C2 PFTeDA
C3PFBS = 13C3 PFBS
C3PFHS = 13C3 PFHxS
C8PFOS = 13C8 PFOS
PFOSA = 13C8 PFOSA
d3NMFOS = d3-NMeFOSAA
d5NEFOS = d5-NEtFOSAA
M242FTS = M2-4:2 FTS
M262FTS = M2-6:2 FTS
M282FTS = M2-8:2 FTS
HFPODA = 13C3 HFPO-DA
NMFM = d7-N-MeFOSE-M
NEFM = d9-N-EtFOSE-M
d5NPFSA = d5-NEtPFOSA
d3NMFSA = D3-NMeFOSA

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Isotope Dilution Summary

Client: University of New Hampshire
Project/Site: Asphalt Shingles Testing
PFDODA = 13C2-PFDODA

Job ID: 620-23136-1

Method: 1633 - Per- and Polyfluoroalkyl Substances by LC/MS/MS

Matrix: Solid

Prep Type: SPLP East

Percent Isotope Dilution Recovery (Acceptance Limits)

Lab Sample ID	Client Sample ID	PFBA (5-130)	PFPeA (40-130)	13C5PHA (40-130)	C4PFHA (40-130)	C8PFOA (40-130)	C9PFNA (40-130)	C6PFDA (40-130)	13C7PUA (30-130)
620-23136-1	MW1	95.7	87.6	87.0	93.1	94.5	89.9	93.6	87.9
620-23136-1	MW1		145 *5+	140 *5+	148 *5+	151 *5+	144 *5+	142 *5+	130
620-23136-2	PC1	100	82.7	88.7	103	96.0	91.0	93.1	85.1
620-23136-2	PC1		137 *5+	140 *5+	159 *5+	150 *5+	141 *5+	141 *5+	127
LB 240-640636/4-B	Method Blank	88.9	95.8	95.9	96.0	97.9	94.5	91.7	94.9
LB 240-640945/1-B	Method Blank	69.9	76.1	66.7	66.3	69.1	65.9	67.2	66.4

Percent Isotope Dilution Recovery (Acceptance Limits)

Lab Sample ID	Client Sample ID	PFTDA (10-130)	C3PFBS (40-135)	C3PFHS (40-130)	C8PFOS (40-130)	PFOSA (40-130)	d3NMFOS (40-170)	d5NEFOS (25-135)	M242FTS (40-200)
620-23136-1	MW1	67.3	85.8	94.0	110	145 *5+	154	174 *5+	234 *5+
620-23136-1	MW1	88.3	136 *5+	151 *5+	149 *5+	182 *5+	197 *5+	133	322 *5+
620-23136-2	PC1	57.5	83.5	97.5	100	140 *5+	156	163 *5+	267 *5+
620-23136-2	PC1	79.3	133	151 *5+	136 *5+	180 *5+	206 *5+	136 *5+	359 *5+
LB 240-640636/4-B	Method Blank	86.9	94.9	99.0	94.7	94.0	92.7	130	116
LB 240-640945/1-B	Method Blank	59.6	65.9	68.4	65.6	65.8	64.4	62.7	75.3

Percent Isotope Dilution Recovery (Acceptance Limits)

Lab Sample ID	Client Sample ID	M262FTS (40-200)	M282FTS (40-300)	HFPODA (40-130)	NMFM (10-130)	NEFM (10-130)	d5NPFSA (10-130)	d3NMFSA (10-130)	PFDODA (10-130)
620-23136-1	MW1	181	193	85.6	78.8	73.2	73.0	78.6	85.0
620-23136-1	MW1	264 *5+	250	126	68.6	58.3	78.2	96.1	118
620-23136-2	PC1	219 *5+	216	77.2	82.1	73.7	71.2	78.8	84.3
620-23136-2	PC1	322 *5+	286	124	78.6	70.1	73.2	90.8	121
LB 240-640636/4-B	Method Blank	96.4	94.3	75.3	83.7	84.3	71.8	75.5	91.2
LB 240-640945/1-B	Method Blank	72.1	72.1	68.7	43.8	43.3	45.8	51.3	64.0

Surrogate Legend

PFBA = 13C4 PFBA
PFPeA = 13C5 PFPeA
13C5PHA = 13C5 PFHxA
C4PFHA = 13C4 PFHpA
C8PFOA = 13C8 PFOA
C9PFNA = 13C9 PFNA
C6PFDA = 13C6 PFDA
13C7PUA = 13C7 PFUnA
PFTDA = 13C2 PFTeDA
C3PFBS = 13C3 PFBS
C3PFHS = 13C3 PFHxS
C8PFOS = 13C8 PFOS
PFOSA = 13C8 PFOSA
d3NMFOS = d3-NMeFOSAA
d5NEFOS = d5-NEtFOSAA
M242FTS = M2-4:2 FTS
M262FTS = M2-6:2 FTS
M282FTS = M2-8:2 FTS
HFPODA = 13C3 HFPO-DA
NMFM = d7-N-MeFOSE-M
NEFM = d9-N-EtFOSE-M
d5NPFSA = d5-NEtPFOSA

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Isotope Dilution Summary

Client: University of New Hampshire
Project/Site: Asphalt Shingles Testing
d3NMFSA = D3-NMeFOSA
PFDoDA = 13C2-PFDoDA

Job ID: 620-23136-1

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QC Sample Results

Client: University of New Hampshire
Project/Site: Asphalt Shingles Testing

Job ID: 620-23136-1

Method: 8270E - Semivolatile Organic Compounds (GC/MS)

Lab Sample ID: MB 620-43019/1-A

Matrix: Solid

Analysis Batch: 43022

Client Sample ID: Method Blank

Prep Type: Total/NA

Prep Batch: 43019

Analyte	MB Result	MB Qualifier	RL	Unit	D	Prepared	Analyzed	Dil Fac
1-Methylnaphthalene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 13:30	1
2-Methylnaphthalene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 13:30	1
Acenaphthene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 13:30	1
Acenaphthylene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 13:30	1
Anthracene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 13:30	1
Benzo[a]anthracene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 13:30	1
Benzo[a]pyrene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 13:30	1
Benzo[b]fluoranthene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 13:30	1
Benzo[g,h,i]perylene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 13:30	1
Benzo[k]fluoranthene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 13:30	1
Chrysene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 13:30	1
Dibenz(a,h)anthracene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 13:30	1
Fluoranthene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 13:30	1
Fluorene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 13:30	1
Indeno[1,2,3-cd]pyrene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 13:30	1
Naphthalene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 13:30	1
Phenanthrene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 13:30	1
Pyrene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 13:30	1

Surrogate	MB %Recovery	MB Qualifier	Limits	Prepared	Analyzed	Dil Fac
Nitrobenzene-d5 (Surr)	52		30 - 130	01/03/25 10:26	01/03/25 13:30	1
2-Fluorobiphenyl (Surr)	54		30 - 130	01/03/25 10:26	01/03/25 13:30	1
Terphenyl-d14 (Surr)	76		30 - 130	01/03/25 10:26	01/03/25 13:30	1

Lab Sample ID: LCS 620-43019/2-A

Matrix: Solid

Analysis Batch: 43022

Client Sample ID: Lab Control Sample

Prep Type: Total/NA

Prep Batch: 43019

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec Limits
1-Methylnaphthalene	40.0	25.05		ug/L		63	33 - 83
2-Methylnaphthalene	40.0	25.07		ug/L		63	32 - 88
Acenaphthene	40.0	24.10		ug/L		60	34 - 87
Acenaphthylene	40.0	23.87		ug/L		60	34 - 86
Anthracene	40.0	33.62		ug/L		84	54 - 102
Benzo[a]anthracene	40.0	33.72		ug/L		84	65 - 110
Benzo[a]pyrene	40.0	34.17		ug/L		85	60 - 103
Benzo[b]fluoranthene	40.0	31.86		ug/L		80	56 - 121
Benzo[g,h,i]perylene	40.0	29.91		ug/L		75	57 - 114
Benzo[k]fluoranthene	40.0	32.69		ug/L		82	40 - 111
Chrysene	40.0	34.25		ug/L		86	63 - 105
Dibenz(a,h)anthracene	40.0	30.58		ug/L		76	56 - 109
Fluoranthene	40.0	32.60		ug/L		81	59 - 110
Fluorene	40.0	25.14		ug/L		63	39 - 90
Indeno[1,2,3-cd]pyrene	40.0	29.55		ug/L		74	54 - 107
Naphthalene	40.0	23.32		ug/L		58	29 - 84
Phenanthrene	40.0	31.20		ug/L		78	52 - 99
Pyrene	40.0	33.88		ug/L		85	63 - 105

Eurofins Rhode Island

QC Sample Results

Client: University of New Hampshire
Project/Site: Asphalt Shingles Testing

Job ID: 620-23136-1

Method: 8270E - Semivolatile Organic Compounds (GC/MS) (Continued)

Lab Sample ID: LCS 620-43019/2-A

Matrix: Solid

Analysis Batch: 43022

Client Sample ID: Lab Control Sample

Prep Type: Total/NA

Prep Batch: 43019

	LCS	LCS	
Surrogate	%Recovery	Qualifier	Limits
Nitrobenzene-d5 (Surr)	63		30 - 130
2-Fluorobiphenyl (Surr)	69		30 - 130
Terphenyl-d14 (Surr)	83		30 - 130

Lab Sample ID: LCSD 620-43019/3-A

Matrix: Solid

Analysis Batch: 43022

Client Sample ID: Lab Control Sample Dup

Prep Type: Total/NA

Prep Batch: 43019

Analyte	Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec Limits	RPD	RPD Limit
1-Methylnaphthalene	40.0	24.84		ug/L		62	33 - 83	1	20
2-Methylnaphthalene	40.0	25.29		ug/L		63	32 - 88	1	20
Acenaphthene	40.0	23.20		ug/L		58	34 - 87	4	20
Acenaphthylene	40.0	23.02		ug/L		58	34 - 86	4	20
Anthracene	40.0	31.68		ug/L		79	54 - 102	6	20
Benzo[a]anthracene	40.0	34.99		ug/L		87	65 - 110	4	20
Benzo[a]pyrene	40.0	35.20		ug/L		88	60 - 103	3	20
Benzo[b]fluoranthene	40.0	33.43		ug/L		84	56 - 121	5	20
Benzo[g,h,i]perylene	40.0	34.73		ug/L		87	57 - 114	15	20
Benzo[k]fluoranthene	40.0	34.31		ug/L		86	40 - 111	5	20
Chrysene	40.0	34.88		ug/L		87	63 - 105	2	20
Dibenz[a,h]anthracene	40.0	31.75		ug/L		79	56 - 109	4	20
Fluoranthene	40.0	32.25		ug/L		81	59 - 110	1	20
Fluorene	40.0	24.76		ug/L		62	39 - 90	2	20
Indeno[1,2,3-cd]pyrene	40.0	30.81		ug/L		77	54 - 107	4	20
Naphthalene	40.0	22.83		ug/L		57	29 - 84	2	20
Phenanthrene	40.0	29.31		ug/L		73	52 - 99	6	20
Pyrene	40.0	34.30		ug/L		86	63 - 105	1	20

	LCSD	LCSD	
Surrogate	%Recovery	Qualifier	Limits
Nitrobenzene-d5 (Surr)	59		30 - 130
2-Fluorobiphenyl (Surr)	62		30 - 130
Terphenyl-d14 (Surr)	84		30 - 130

Lab Sample ID: MB 620-42987/1-C

Matrix: Solid

Analysis Batch: 43022

Client Sample ID: Method Blank

Prep Type: SPLP East

Prep Batch: 43019

Analyte	MB Result	MB Qualifier	RL	Unit	D	Prepared	Analyzed	Dil Fac
1-Methylnaphthalene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 14:58	1
2-Methylnaphthalene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 14:58	1
Acenaphthene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 14:58	1
Acenaphthylene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 14:58	1
Anthracene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 14:58	1
Benzo[a]anthracene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 14:58	1
Benzo[a]pyrene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 14:58	1
Benzo[b]fluoranthene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 14:58	1
Benzo[g,h,i]perylene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 14:58	1
Benzo[k]fluoranthene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 14:58	1

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QC Sample Results

Client: University of New Hampshire
Project/Site: Asphalt Shingles Testing

Job ID: 620-23136-1

Method: 8270E - Semivolatile Organic Compounds (GC/MS) (Continued)

Lab Sample ID: MB 620-42987/1-C

Matrix: Solid

Analysis Batch: 43022

Client Sample ID: Method Blank

Prep Type: SPLP East

Prep Batch: 43019

Analyte	MB Result	MB Qualifier	RL	Unit	D	Prepared	Analyzed	Dil Fac
Chrysene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 14:58	1
Dibenz(a,h)anthracene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 14:58	1
Fluoranthene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 14:58	1
Fluorene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 14:58	1
Indeno[1,2,3-cd]pyrene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 14:58	1
Naphthalene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 14:58	1
Phenanthrene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 14:58	1
Pyrene	ND		5.00	ug/L		01/03/25 10:26	01/03/25 14:58	1

Surrogate	MB %Recovery	MB Qualifier	Limits	Prepared	Analyzed	Dil Fac
Nitrobenzene-d5 (Surr)	61		30 - 130	01/03/25 10:26	01/03/25 14:58	1
2-Fluorobiphenyl (Surr)	65		30 - 130	01/03/25 10:26	01/03/25 14:58	1
Terphenyl-d14 (Surr)	80		30 - 130	01/03/25 10:26	01/03/25 14:58	1

Lab Sample ID: 620-23136-1 MS

Matrix: Solid

Analysis Batch: 43022

Client Sample ID: MW1

Prep Type: SPLP East

Prep Batch: 43019

Analyte	Sample Result	Sample Qualifier	Spike Added	MS Result	MS Qualifier	Unit	D	%Rec	%Rec Limits
1-Methylnaphthalene	ND		40.0	22.15		ug/L		55	40 - 140
2-Methylnaphthalene	ND		40.0	20.97		ug/L		52	40 - 140
Acenaphthene	ND		40.0	20.08		ug/L		50	40 - 140
Acenaphthylene	ND		40.0	19.61		ug/L		49	40 - 140
Anthracene	ND		40.0	28.99		ug/L		72	40 - 140
Benzo[a]anthracene	ND		40.0	29.02		ug/L		73	40 - 140
Benzo[a]pyrene	ND		40.0	28.45		ug/L		71	40 - 140
Benzo[b]fluoranthene	ND		40.0	26.81		ug/L		67	40 - 140
Benzo[g,h,i]perylene	ND		40.0	27.52		ug/L		69	40 - 140
Benzo[k]fluoranthene	ND		40.0	26.51		ug/L		66	40 - 140
Chrysene	ND		40.0	30.08		ug/L		75	40 - 140
Dibenz(a,h)anthracene	ND		40.0	25.78		ug/L		64	40 - 140
Fluoranthene	ND		40.0	27.20		ug/L		68	40 - 140
Fluorene	ND		40.0	21.66		ug/L		54	40 - 140
Indeno[1,2,3-cd]pyrene	ND		40.0	24.69		ug/L		62	40 - 140
Naphthalene	ND		40.0	21.06		ug/L		53	40 - 140
Phenanthrene	ND		40.0	26.97		ug/L		67	40 - 140
Pyrene	ND		40.0	30.01		ug/L		75	40 - 140

Surrogate	MS %Recovery	MS Qualifier	Limits
Nitrobenzene-d5 (Surr)	59		30 - 130
2-Fluorobiphenyl (Surr)	60		30 - 130
Terphenyl-d14 (Surr)	76		30 - 130

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QC Sample Results

Client: University of New Hampshire
Project/Site: Asphalt Shingles Testing

Job ID: 620-23136-1

Method: 8082A - Polychlorinated Biphenyls (PCBs) by Gas Chromatography

Lab Sample ID: MB 620-43020/1-A

Matrix: Solid

Analysis Batch: 43052

Client Sample ID: Method Blank

Prep Type: Total/NA

Prep Batch: 43020

Analyte	MB Result	MB Qualifier	RL	Unit	D	Prepared	Analyzed	Dil Fac
PCB-1016	ND		0.400	ug/L		01/03/25 11:17	01/06/25 13:43	1
PCB-1221	ND		0.400	ug/L		01/03/25 11:17	01/06/25 13:43	1
PCB-1232	ND		0.400	ug/L		01/03/25 11:17	01/06/25 13:43	1
PCB-1242	ND		0.400	ug/L		01/03/25 11:17	01/06/25 13:43	1
PCB-1248	ND		0.400	ug/L		01/03/25 11:17	01/06/25 13:43	1
PCB-1254	ND		0.400	ug/L		01/03/25 11:17	01/06/25 13:43	1
PCB-1260	ND		0.400	ug/L		01/03/25 11:17	01/06/25 13:43	1
PCB-1262	ND		0.400	ug/L		01/03/25 11:17	01/06/25 13:43	1
PCB-1268	ND		0.400	ug/L		01/03/25 11:17	01/06/25 13:43	1

Surrogate	MB %Recovery	MB Qualifier	Limits	Prepared	Analyzed	Dil Fac
Tetrachloro-m-xylene	71		30 - 150	01/03/25 11:17	01/06/25 13:43	1
DCB Decachlorobiphenyl (Surr)	86		30 - 150	01/03/25 11:17	01/06/25 13:43	1

Lab Sample ID: LCS 620-43020/2-A

Matrix: Solid

Analysis Batch: 43052

Client Sample ID: Lab Control Sample

Prep Type: Total/NA

Prep Batch: 43020

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec Limits
PCB-1016	4.00	3.326		ug/L		83	40 - 132
PCB-1260	4.00	3.075		ug/L		77	44 - 140

Surrogate	LCS %Recovery	LCS Qualifier	Limits
Tetrachloro-m-xylene	81		30 - 150
DCB Decachlorobiphenyl (Surr)	92		30 - 150

Lab Sample ID: LCSD 620-43020/3-A

Matrix: Solid

Analysis Batch: 43052

Client Sample ID: Lab Control Sample Dup

Prep Type: Total/NA

Prep Batch: 43020

Analyte	Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec Limits	RPD	RPD Limit
PCB-1016	4.00	2.877		ug/L		72	40 - 132	14	20
PCB-1260	4.00	2.738		ug/L		68	44 - 140	12	20

Surrogate	LCSD %Recovery	LCSD Qualifier	Limits
Tetrachloro-m-xylene	64		30 - 150
DCB Decachlorobiphenyl (Surr)	77		30 - 150

Lab Sample ID: MB 620-42987/1-D

Matrix: Solid

Analysis Batch: 43052

Client Sample ID: Method Blank

Prep Type: SPLP East

Prep Batch: 43020

Analyte	MB Result	MB Qualifier	RL	Unit	D	Prepared	Analyzed	Dil Fac
PCB-1016	ND		0.400	ug/L		01/03/25 11:17	01/06/25 16:11	1
PCB-1221	ND		0.400	ug/L		01/03/25 11:17	01/06/25 16:11	1
PCB-1232	ND		0.400	ug/L		01/03/25 11:17	01/06/25 16:11	1
PCB-1242	ND		0.400	ug/L		01/03/25 11:17	01/06/25 16:11	1
PCB-1248	ND		0.400	ug/L		01/03/25 11:17	01/06/25 16:11	1

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QC Sample Results

Client: University of New Hampshire
Project/Site: Asphalt Shingles Testing

Job ID: 620-23136-1

Method: 8082A - Polychlorinated Biphenyls (PCBs) by Gas Chromatography (Continued)

Lab Sample ID: MB 620-42987/1-D

Matrix: Solid

Analysis Batch: 43052

Client Sample ID: Method Blank

Prep Type: SPLP East

Prep Batch: 43020

Analyte	MB Result	MB Qualifier	RL	Unit	D	Prepared	Analyzed	Dil Fac
PCB-1254	ND		0.400	ug/L		01/03/25 11:17	01/06/25 16:11	1
PCB-1260	ND		0.400	ug/L		01/03/25 11:17	01/06/25 16:11	1
PCB-1262	ND		0.400	ug/L		01/03/25 11:17	01/06/25 16:11	1
PCB-1268	ND		0.400	ug/L		01/03/25 11:17	01/06/25 16:11	1

Surrogate	MB %Recovery	MB Qualifier	Limits	Prepared	Analyzed	Dil Fac
Tetrachloro-m-xylene	75		30 - 150	01/03/25 11:17	01/06/25 16:11	1
DCB Decachlorobiphenyl (Surr)	83		30 - 150	01/03/25 11:17	01/06/25 16:11	1

Lab Sample ID: 620-23136-2 MS

Matrix: Solid

Analysis Batch: 43052

Client Sample ID: PC1

Prep Type: SPLP East

Prep Batch: 43020

Analyte	Sample Result	Sample Qualifier	Spike Added	MS Result	MS Qualifier	Unit	D	%Rec	%Rec Limits
PCB-1016	ND		4.00	2.699		ug/L		67	40 - 140
PCB-1260	ND		4.00	2.507		ug/L		63	40 - 140

Surrogate	MS %Recovery	MS Qualifier	Limits
Tetrachloro-m-xylene	53		30 - 150
DCB Decachlorobiphenyl (Surr)	54		30 - 150

Method: 1633 - Per- and Polyfluoroalkyl Substances by LC/MS/MS

Lab Sample ID: MB 240-640762/1-A

Matrix: Solid

Analysis Batch: 640803

Client Sample ID: Method Blank

Prep Type: Total/NA

Prep Batch: 640762

Analyte	MB Result	MB Qualifier	RL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		4.00	ng/L		01/07/25 08:18	01/07/25 15:18	1
Perfluoropentanoic acid (PFPeA)	ND		2.00	ng/L		01/07/25 08:18	01/07/25 15:18	1
Perfluorohexanoic acid (PFHxA)	2.916		2.00	ng/L		01/07/25 08:18	01/07/25 15:18	1
Perfluoroheptanoic acid (PFHpA)	ND		2.00	ng/L		01/07/25 08:18	01/07/25 15:18	1
Perfluorooctanoic acid (PFOA)	ND		2.00	ng/L		01/07/25 08:18	01/07/25 15:18	1
Perfluorononanoic acid (PFNA)	ND		2.00	ng/L		01/07/25 08:18	01/07/25 15:18	1
Perfluorodecanoic acid (PFDA)	ND		2.00	ng/L		01/07/25 08:18	01/07/25 15:18	1
Perfluoroundecanoic acid (PFUnA)	ND		2.00	ng/L		01/07/25 08:18	01/07/25 15:18	1
Perfluorododecanoic acid (PFDoA)	ND		2.00	ng/L		01/07/25 08:18	01/07/25 15:18	1
Perfluorotridecanoic acid (PFTTrDA)	ND		2.00	ng/L		01/07/25 08:18	01/07/25 15:18	1
Perfluorotetradecanoic acid (PFTeDA)	ND		2.00	ng/L		01/07/25 08:18	01/07/25 15:18	1
Perfluorobutanesulfonic acid (PFBS)	ND		2.00	ng/L		01/07/25 08:18	01/07/25 15:18	1
Perfluoropentanesulfonic acid (PFPeS)	ND		2.00	ng/L		01/07/25 08:18	01/07/25 15:18	1
Perfluorohexanesulfonic acid (PFHxS)	ND		2.00	ng/L		01/07/25 08:18	01/07/25 15:18	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		2.00	ng/L		01/07/25 08:18	01/07/25 15:18	1
Perfluorooctanesulfonic acid (PFOS)	ND		2.00	ng/L		01/07/25 08:18	01/07/25 15:18	1
Perfluorononanesulfonic acid (PFNS)	ND		2.00	ng/L		01/07/25 08:18	01/07/25 15:18	1
Perfluorododecanesulfonic acid (PFDoS)	ND		2.00	ng/L		01/07/25 08:18	01/07/25 15:18	1

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QC Sample Results

Client: University of New Hampshire
Project/Site: Asphalt Shingles Testing

Job ID: 620-23136-1

Method: 1633 - Per- and Polyfluoroalkyl Substances by LC/MS/MS (Continued)

Lab Sample ID: MB 240-640762/1-A

Matrix: Solid

Analysis Batch: 640803

Client Sample ID: Method Blank

Prep Type: Total/NA

Prep Batch: 640762

Analyte	MB Result	MB Qualifier	RL	Unit	D	Prepared	Analyzed	Dil Fac
1H,1H,2H,2H-Perfluorohexane sulfonic acid (4:2 FTS)	ND		4.00	ng/L		01/07/25 08:18	01/07/25 15:18	1
1H,1H,2H,2H-Perfluorooctane sulfonic acid (6:2 FTS)	4.846		4.00	ng/L		01/07/25 08:18	01/07/25 15:18	1
1H,1H,2H,2H-Perfluorodecane sulfonic acid (8:2 FTS)	ND		4.00	ng/L		01/07/25 08:18	01/07/25 15:18	1
Perfluorooctanesulfonamide (PFOSA)	ND		2.00	ng/L		01/07/25 08:18	01/07/25 15:18	1
N-methylperfluorooctane sulfonamide (NMeFOSA)	ND		2.00	ng/L		01/07/25 08:18	01/07/25 15:18	1
N-ethylperfluorooctane sulfonamide (NEtFOSA)	ND		2.00	ng/L		01/07/25 08:18	01/07/25 15:18	1
N-methylperfluorooctanesulfonamidoacetic acid (NMeFOSAA)	ND		2.00	ng/L		01/07/25 08:18	01/07/25 15:18	1
N-ethylperfluorooctanesulfonamidoacetic acid (NEtFOSAA)	ND		2.00	ng/L		01/07/25 08:18	01/07/25 15:18	1
N-methylperfluorooctane sulfonamidoethanol (NMeFOSE)	ND		10.0	ng/L		01/07/25 08:18	01/07/25 15:18	1
N-ethylperfluorooctane sulfonamidoethanol (NEtFOSE)	ND		10.0	ng/L		01/07/25 08:18	01/07/25 15:18	1
Hexafluoropropylene Oxide Dimer Acid (HFPO-DA)	ND		1.50	ng/L		01/07/25 08:18	01/07/25 15:18	1
4,8-Dioxo-3H-perfluorononanoic acid (ADONA)	ND		2.00	ng/L		01/07/25 08:18	01/07/25 15:18	1
Perfluoro-4-methoxybutanoic acid (PFMBA)	ND		2.00	ng/L		01/07/25 08:18	01/07/25 15:18	1
Nonafluoro-3,6-dioxaheptanoic acid (NFDHA)	ND		2.00	ng/L		01/07/25 08:18	01/07/25 15:18	1
9-Chlorohexadecafluoro-3-oxanonane-1-sulfonic acid (9Cl-PF3ONS)	ND		2.00	ng/L		01/07/25 08:18	01/07/25 15:18	1
11-Chloroeicosafluoro-3-oxaundecane-1-sulfonic acid (11Cl-PF3OUdS)	ND		2.00	ng/L		01/07/25 08:18	01/07/25 15:18	1
Perfluoro (2-ethoxyethane) sulfonic acid (PFEESA)	ND		2.00	ng/L		01/07/25 08:18	01/07/25 15:18	1
3-Perfluoropropylpropanoic acid (3:3 FTCA)	ND		4.00	ng/L		01/07/25 08:18	01/07/25 15:18	1
3-Perfluoropentylpropanoic acid (5:3 FTCA)	ND		10.0	ng/L		01/07/25 08:18	01/07/25 15:18	1
3-Perfluoroheptylpropanoic acid (7:3 FTCA)	ND		10.0	ng/L		01/07/25 08:18	01/07/25 15:18	1
Perfluorodecanesulfonic acid (PFDS)	ND		2.00	ng/L		01/07/25 08:18	01/07/25 15:18	1
Perfluoro-3-methoxypropanoic acid (PFMPA)	ND		2.00	ng/L		01/07/25 08:18	01/07/25 15:18	1

Isotope Dilution	MB %Recovery	MB Qualifier	Limits	Prepared	Analyzed	Dil Fac
13C4 PFBA	92.7		5 - 130	01/07/25 08:18	01/07/25 15:18	1
13C5 PFPeA	92.3		40 - 130	01/07/25 08:18	01/07/25 15:18	1
13C5 PFHxA	90.2		40 - 130	01/07/25 08:18	01/07/25 15:18	1
13C4 PFHpA	95.1		40 - 130	01/07/25 08:18	01/07/25 15:18	1
13C8 PFOA	94.3		40 - 130	01/07/25 08:18	01/07/25 15:18	1
13C9 PFNA	89.4		40 - 130	01/07/25 08:18	01/07/25 15:18	1
13C6 PFDA	93.5		40 - 130	01/07/25 08:18	01/07/25 15:18	1
13C7 PFUnA	88.8		30 - 130	01/07/25 08:18	01/07/25 15:18	1
13C2 PFTeDA	79.1		10 - 130	01/07/25 08:18	01/07/25 15:18	1
13C3 PFBS	92.2		40 - 135	01/07/25 08:18	01/07/25 15:18	1

Eurofins Rhode Island

QC Sample Results

Client: University of New Hampshire
Project/Site: Asphalt Shingles Testing

Job ID: 620-23136-1

Method: 1633 - Per- and Polyfluoroalkyl Substances by LC/MS/MS (Continued)

Lab Sample ID: MB 240-640762/1-A

Matrix: Solid

Analysis Batch: 640803

Client Sample ID: Method Blank

Prep Type: Total/NA

Prep Batch: 640762

Isotope Dilution	MB %Recovery	MB Qualifier	Limits	Prepared	Analyzed	Dil Fac
13C3 PFHxS	95.3		40 - 130	01/07/25 08:18	01/07/25 15:18	1
13C8 PFOS	96.9		40 - 130	01/07/25 08:18	01/07/25 15:18	1
13C8 PFOSA	98.8		40 - 130	01/07/25 08:18	01/07/25 15:18	1
d3-NMeFOSAA	101		40 - 170	01/07/25 08:18	01/07/25 15:18	1
d5-NEtFOSAA	186	*5+	25 - 135	01/07/25 08:18	01/07/25 15:18	1
M2-4:2 FTS	116		40 - 200	01/07/25 08:18	01/07/25 15:18	1
M2-6:2 FTS	107		40 - 200	01/07/25 08:18	01/07/25 15:18	1
M2-8:2 FTS	113		40 - 300	01/07/25 08:18	01/07/25 15:18	1
13C3 HFPO-DA	91.0		40 - 130	01/07/25 08:18	01/07/25 15:18	1
d7-N-MeFOSE-M	75.7		10 - 130	01/07/25 08:18	01/07/25 15:18	1
d9-N-EtFOSE-M	72.6		10 - 130	01/07/25 08:18	01/07/25 15:18	1
d5-NEtPFOSA	75.0		10 - 130	01/07/25 08:18	01/07/25 15:18	1
D3-NMeFOSA	80.0		10 - 130	01/07/25 08:18	01/07/25 15:18	1
13C2-PFDoDA	89.8		10 - 130	01/07/25 08:18	01/07/25 15:18	1

Lab Sample ID: LCS 240-640762/3-A

Matrix: Solid

Analysis Batch: 640803

Client Sample ID: Lab Control Sample

Prep Type: Total/NA

Prep Batch: 640762

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec Limits
Perfluorobutanoic acid (PFBA)	80.0	104.1		ng/L		130	70 - 140
Perfluoropentanoic acid (PFPeA)	40.0	48.85		ng/L		122	65 - 135
Perfluorohexanoic acid (PFHxA)	40.0	48.92		ng/L		122	70 - 145
Perfluoroheptanoic acid (PFHpA)	40.0	51.03		ng/L		128	70 - 150
Perfluorooctanoic acid (PFOA)	40.0	52.12		ng/L		130	70 - 150
Perfluorononanoic acid (PFNA)	40.0	53.48		ng/L		134	70 - 150
Perfluorodecanoic acid (PFDA)	40.0	48.17		ng/L		120	70 - 140
Perfluoroundecanoic acid (PFUnA)	40.0	46.40		ng/L		116	70 - 145
Perfluorododecanoic acid (PFDoA)	40.0	49.73		ng/L		124	70 - 140
Perfluorotridecanoic acid (PFTTrDA)	40.0	50.36		ng/L		126	65 - 140
Perfluorotetradecanoic acid (PFTeDA)	40.0	49.56		ng/L		124	60 - 140
Perfluorobutanesulfonic acid (PFBS)	35.4	48.47		ng/L		137	60 - 145
Perfluoropentanesulfonic acid (PFPeS)	37.5	49.13		ng/L		131	65 - 140
Perfluorohexanesulfonic acid (PFHxS)	36.4	44.46		ng/L		122	65 - 145
Perfluoroheptanesulfonic acid (PFHpS)	38.1	54.32		ng/L		143	70 - 150
Perfluorooctanesulfonic acid (PFOS)	37.1	45.28		ng/L		122	55 - 150
Perfluorononanesulfonic acid (PFNS)	38.4	54.11		ng/L		141	65 - 145
Perfluorododecanesulfonic acid (PFDoS)	38.7	47.46		ng/L		123	50 - 145
1H,1H,2H,2H-Perfluorohexane sulfonic acid (4:2 FTS)	74.7	95.55		ng/L		128	70 - 145

Eurofins Rhode Island

QC Sample Results

Client: University of New Hampshire
Project/Site: Asphalt Shingles Testing

Job ID: 620-23136-1

Method: 1633 - Per- and Polyfluoroalkyl Substances by LC/MS/MS (Continued)

Lab Sample ID: LCS 240-640762/3-A

Matrix: Solid

Analysis Batch: 640803

Client Sample ID: Lab Control Sample

Prep Type: Total/NA

Prep Batch: 640762

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec Limits
1H,1H,2H,2H-Perfluorooctane sulfonic acid (6:2 FTS)	75.8	98.54		ng/L		130	65 - 155
1H,1H,2H,2H-Perfluorodecane sulfonic acid (8:2 FTS)	76.6	95.97		ng/L		125	60 - 150
Perfluorooctanesulfonamide (PFOSA)	40.0	51.71		ng/L		129	70 - 145
N-methylperfluorooctane sulfonamide (NMeFOSA)	40.0	56.21		ng/L		141	60 - 150
N-ethylperfluorooctane sulfonamide (NEtFOSA)	40.0	54.71		ng/L		137	65 - 145
N-methylperfluorooctanesulfonamidoacetic acid (NMeFOSAA)	40.0	51.60		ng/L		129	50 - 140
N-ethylperfluorooctanesulfonamidoacetic acid (NEtFOSAA)	40.0	46.24		ng/L		116	70 - 145
N-methylperfluorooctane sulfonamidoethanol (NMeFOSE)	200	264.4		ng/L		132	70 - 145
N-ethylperfluorooctane sulfonamidoethanol (NEtFOSE)	200	258.2		ng/L		129	70 - 135
Hexafluoropropylene Oxide Dimer Acid (HFPO-DA)	30.0	40.20		ng/L		134	70 - 140
4,8-Dioxa-3H-perfluorononanoic acid (ADONA)	37.7	49.32		ng/L		131	65 - 145
Perfluoro-4-methoxybutanoic acid (PFMBA)	40.0	52.24		ng/L		131	60 - 150
Nonafluoro-3,6-dioxaheptanoic acid (NFDHA)	40.0	49.04		ng/L		123	50 - 150
9-Chlorohexadecafluoro-3-oxanonane-1-sulfonic acid (9Cl-PF3ONS)	37.3	47.82		ng/L		128	70 - 155
11-Chloroeicosafluoro-3-oxaundecane-1-sulfonic acid (11Cl-PF3OUdS)	37.7	44.95		ng/L		119	55 - 160
Perfluoro (2-ethoxyethane) sulfonic acid (PFEEESA)	35.6	45.99		ng/L		129	70 - 140
3-Perfluoropropylpropanoic acid (3:3 FTCA)	80.0	93.12		ng/L		116	65 - 130
3-Perfluoropentylpropanoic acid (5:3 FTCA)	200	236.0		ng/L		118	70 - 135
3-Perfluoroheptylpropanoic acid (7:3 FTCA)	200	219.4		ng/L		110	50 - 145
Perfluorodecanesulfonic acid (PFDS)	38.6	51.44		ng/L		133	60 - 145
Perfluoro-3-methoxypropanoic acid (PFMPA)	40.0	48.38		ng/L		121	55 - 140

Isotope Dilution	LCS		Limits
	%Recovery	Qualifier	
13C4 PFBA	91.6		5 - 130
13C5 PFPeA	91.8		40 - 130
13C5 PFHxA	90.2		40 - 130
13C4 PFHpA	90.0		40 - 130
13C8 PFOA	90.8		40 - 130
13C9 PFNA	87.1		40 - 130
13C6 PFDA	90.2		40 - 130
13C7 PFUnA	91.3		30 - 130

Eurofins Rhode Island

QC Sample Results

Client: University of New Hampshire
Project/Site: Asphalt Shingles Testing

Job ID: 620-23136-1

Method: 1633 - Per- and Polyfluoroalkyl Substances by LC/MS/MS (Continued)

Lab Sample ID: LCS 240-640762/3-A

Matrix: Solid

Analysis Batch: 640803

Client Sample ID: Lab Control Sample

Prep Type: Total/NA

Prep Batch: 640762

Isotope Dilution	LCS LCS		Limits
	%Recovery	Qualifier	
13C2 PFTeDA	77.5		10 - 130
13C3 PFBS	94.3		40 - 135
13C3 PFHxS	95.8		40 - 130
13C8 PFOS	98.5		40 - 130
13C8 PFOSA	100		40 - 130
d3-NMeFOSAA	103		40 - 170
d5-NEtFOSAA	174	*5+	25 - 135
M2-4:2 FTS	117		40 - 200
M2-6:2 FTS	103		40 - 200
M2-8:2 FTS	108		40 - 300
13C3 HFPO-DA	90.9		40 - 130
d7-N-MeFOSE-M	65.3		10 - 130
d9-N-EtFOSE-M	56.9		10 - 130
d5-NEtPFOSA	75.3		10 - 130
D3-NMeFOSA	81.4		10 - 130
13C2-PFDoDA	83.6		10 - 130

Lab Sample ID: LLCS 240-640762/2-A

Matrix: Solid

Analysis Batch: 640803

Client Sample ID: Lab Control Sample

Prep Type: Total/NA

Prep Batch: 640762

Analyte	Spike Added	LLCS Result	LLCS Qualifier	Unit	D	%Rec	%Rec Limits
Perfluorobutanoic acid (PFBA)	8.00	10.00		ng/L		125	70 - 140
Perfluoropentanoic acid (PFPeA)	4.00	5.744	*+	ng/L		144	65 - 135
Perfluorohexanoic acid (PFHxA)	4.00	8.254	*+	ng/L		206	70 - 145
Perfluoroheptanoic acid (PFHpA)	4.00	5.038		ng/L		126	70 - 150
Perfluorooctanoic acid (PFOA)	4.00	5.266		ng/L		132	70 - 150
Perfluorononanoic acid (PFNA)	4.00	5.538		ng/L		138	70 - 150
Perfluorodecanoic acid (PFDA)	4.00	4.981		ng/L		125	70 - 140
Perfluoroundecanoic acid (PFUnA)	4.00	4.808		ng/L		120	70 - 145
Perfluorododecanoic acid (PFDoA)	4.00	4.720		ng/L		118	70 - 140
Perfluorotridecanoic acid (PFTriDA)	4.00	4.715		ng/L		118	65 - 140
Perfluorotetradecanoic acid (PFTeDA)	4.00	4.542		ng/L		114	60 - 140
Perfluorobutanesulfonic acid (PFBS)	3.54	4.853		ng/L		137	60 - 145
Perfluoropentanesulfonic acid (PFPeS)	3.75	4.814		ng/L		128	65 - 140
Perfluorohexanesulfonic acid (PFHxS)	3.64	4.489		ng/L		123	65 - 145
Perfluoroheptanesulfonic acid (PFHpS)	3.81	5.574		ng/L		146	70 - 150
Perfluorooctanesulfonic acid (PFOS)	3.71	4.468		ng/L		120	55 - 150
Perfluorononanesulfonic acid (PFNS)	3.84	5.536		ng/L		144	65 - 145
Perfluorododecanesulfonic acid (PFDoS)	3.87	4.667		ng/L		121	50 - 145

Eurofins Rhode Island

QC Sample Results

Client: University of New Hampshire
Project/Site: Asphalt Shingles Testing

Job ID: 620-23136-1

Method: 1633 - Per- and Polyfluoroalkyl Substances by LC/MS/MS (Continued)

Lab Sample ID: LLCS 240-640762/2-A

Matrix: Solid

Analysis Batch: 640803

Client Sample ID: Lab Control Sample

Prep Type: Total/NA

Prep Batch: 640762

Analyte	Spike Added	LLCS Result	LLCS Qualifier	Unit	D	%Rec	%Rec Limits
1H,1H,2H,2H-Perfluorohexane sulfonic acid (4:2 FTS)	7.47	9.197		ng/L		123	70 - 145
1H,1H,2H,2H-Perfluorooctane sulfonic acid (6:2 FTS)	7.58	15.84	*+	ng/L		209	65 - 155
1H,1H,2H,2H-Perfluorodecane sulfonic acid (8:2 FTS)	7.66	9.004		ng/L		117	60 - 150
Perfluorooctanesulfonamide (PFOSA)	4.00	4.734		ng/L		118	70 - 145
N-methylperfluorooctane sulfonamide (NMeFOSA)	4.00	5.045		ng/L		126	60 - 150
N-ethylperfluorooctane sulfonamide (NEtFOSA)	4.00	5.045		ng/L		126	65 - 145
N-methylperfluorooctanesulfonamidoacetic acid (NMeFOSAA)	4.00	4.965		ng/L		124	50 - 140
N-ethylperfluorooctanesulfonamidoacetic acid (NEtFOSAA)	4.00	4.743		ng/L		119	70 - 145
N-methylperfluorooctane sulfonamidoethanol (NMeFOSE)	20.0	26.07		ng/L		130	70 - 145
N-ethylperfluorooctane sulfonamidoethanol (NEtFOSE)	20.0	26.33		ng/L		132	70 - 135
Hexafluoropropylene Oxide Dimer Acid (HFPO-DA)	3.00	3.714		ng/L		124	70 - 140
4,8-Dioxa-3H-perfluorononanoic acid (ADONA)	3.77	4.696		ng/L		125	65 - 145
Perfluoro-4-methoxybutanoic acid (PFMBA)	4.00	4.988		ng/L		125	60 - 150
Nonafluoro-3,6-dioxaheptanoic acid (NFDHA)	4.00	4.683		ng/L		117	50 - 150
9-Chlorohexadecafluoro-3-oxanonane-1-sulfonic acid (9Cl-PF3ONS)	3.73	4.656		ng/L		125	70 - 155
11-Chloroeicosafluoro-3-oxaundecane-1-sulfonic acid (11Cl-PF3OUdS)	3.77	4.402		ng/L		117	55 - 160
Perfluoro (2-ethoxyethane) sulfonic acid (PFEEA)	3.56	4.590		ng/L		129	70 - 140
3-Perfluoropropylpropanoic acid (3:3 FTCA)	8.00	8.500		ng/L		106	65 - 130
3-Perfluoropentylpropanoic acid (5:3 FTCA)	20.0	21.13		ng/L		106	70 - 135
3-Perfluoroheptylpropanoic acid (7:3 FTCA)	20.0	19.95		ng/L		100	50 - 145
Perfluorodecanesulfonic acid (PFDS)	3.86	5.049		ng/L		131	60 - 145
Perfluoro-3-methoxypropanoic acid (PFMPA)	4.00	4.635		ng/L		116	55 - 140

Isotope Dilution	LLCS %Recovery	LLCS Qualifier	Limits
13C4 PFBA	94.1		5 - 130
13C5 PFPeA	93.2		40 - 130
13C5 PFHxA	90.8		40 - 130
13C4 PFHpA	93.7		40 - 130
13C8 PFOA	94.4		40 - 130
13C9 PFNA	92.1		40 - 130

Eurofins Rhode Island

QC Sample Results

Client: University of New Hampshire
Project/Site: Asphalt Shingles Testing

Job ID: 620-23136-1

Method: 1633 - Per- and Polyfluoroalkyl Substances by LC/MS/MS (Continued)

Lab Sample ID: LLCS 240-640762/2-A

Matrix: Solid

Analysis Batch: 640803

Client Sample ID: Lab Control Sample

Prep Type: Total/NA

Prep Batch: 640762

Isotope Dilution	LLCS LLCS		Limits
	%Recovery	Qualifier	
13C6 PFDA	91.3		40 - 130
13C7 PFUnA	87.8		30 - 130
13C2 PFTeDA	77.3		10 - 130
13C3 PFBS	96.5		40 - 135
13C3 PFHxS	95.9		40 - 130
13C8 PFOS	98.7		40 - 130
13C8 PFOSA	103		40 - 130
d3-NMeFOSAA	103		40 - 170
d5-NEtFOSAA	184	*5+	25 - 135
M2-4:2 FTS	119		40 - 200
M2-6:2 FTS	109		40 - 200
M2-8:2 FTS	119		40 - 300
13C3 HFPO-DA	90.6		40 - 130
d7-N-MeFOSE-M	84.9		10 - 130
d9-N-EtFOSE-M	79.5		10 - 130
d5-NEtPFOSA	78.0		10 - 130
D3-NMeFOSA	82.2		10 - 130
13C2-PFDoDA	87.1		10 - 130

Lab Sample ID: MB 240-640965/1-A

Matrix: Solid

Analysis Batch: 641035

Client Sample ID: Method Blank

Prep Type: Total/NA

Prep Batch: 640965

Analyte	MB MB		RL	Unit	D	Prepared	Analyzed	Dil Fac
	Result	Qualifier						
Perfluorobutanoic acid (PFBA)	ND		4.00	ng/L		01/09/25 08:30	01/09/25 17:09	1
Perfluoropentanoic acid (PFPeA)	ND		2.00	ng/L		01/09/25 08:30	01/09/25 17:09	1
Perfluorohexanoic acid (PFHxA)	ND		2.00	ng/L		01/09/25 08:30	01/09/25 17:09	1
Perfluoroheptanoic acid (PFHpA)	ND		2.00	ng/L		01/09/25 08:30	01/09/25 17:09	1
Perfluorooctanoic acid (PFOA)	ND		2.00	ng/L		01/09/25 08:30	01/09/25 17:09	1
Perfluorononanoic acid (PFNA)	ND		2.00	ng/L		01/09/25 08:30	01/09/25 17:09	1
Perfluorodecanoic acid (PFDA)	ND		2.00	ng/L		01/09/25 08:30	01/09/25 17:09	1
Perfluoroundecanoic acid (PFUnA)	ND		2.00	ng/L		01/09/25 08:30	01/09/25 17:09	1
Perfluorododecanoic acid (PFDoA)	ND		2.00	ng/L		01/09/25 08:30	01/09/25 17:09	1
Perfluorotridecanoic acid (PFTrDA)	ND		2.00	ng/L		01/09/25 08:30	01/09/25 17:09	1
Perfluorotetradecanoic acid (PFTeDA)	ND		2.00	ng/L		01/09/25 08:30	01/09/25 17:09	1
Perfluorobutanesulfonic acid (PFBS)	ND		2.00	ng/L		01/09/25 08:30	01/09/25 17:09	1
Perfluoropentanesulfonic acid (PFPeS)	ND		2.00	ng/L		01/09/25 08:30	01/09/25 17:09	1
Perfluorohexanesulfonic acid (PFHxS)	ND		2.00	ng/L		01/09/25 08:30	01/09/25 17:09	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		2.00	ng/L		01/09/25 08:30	01/09/25 17:09	1
Perfluorooctanesulfonic acid (PFOS)	ND		2.00	ng/L		01/09/25 08:30	01/09/25 17:09	1
Perfluorononanesulfonic acid (PFNS)	ND		2.00	ng/L		01/09/25 08:30	01/09/25 17:09	1
Perfluorododecanesulfonic acid (PFDoS)	ND		2.00	ng/L		01/09/25 08:30	01/09/25 17:09	1
1H,1H,2H,2H-Perfluorohexane sulfonic acid (4:2 FTS)	ND		4.00	ng/L		01/09/25 08:30	01/09/25 17:09	1
1H,1H,2H,2H-Perfluorooctane sulfonic acid (6:2 FTS)	ND		4.00	ng/L		01/09/25 08:30	01/09/25 17:09	1

Eurofins Rhode Island

QC Sample Results

Client: University of New Hampshire
Project/Site: Asphalt Shingles Testing

Job ID: 620-23136-1

Method: 1633 - Per- and Polyfluoroalkyl Substances by LC/MS/MS (Continued)

Lab Sample ID: MB 240-640965/1-A

Matrix: Solid

Analysis Batch: 641035

Client Sample ID: Method Blank

Prep Type: Total/NA

Prep Batch: 640965

Analyte	MB Result	MB Qualifier	RL	Unit	D	Prepared	Analyzed	Dil Fac
1H,1H,2H,2H-Perfluorodecane sulfonic acid (8:2 FTS)	ND		4.00	ng/L		01/09/25 08:30	01/09/25 17:09	1
Perfluorooctanesulfonamide (PFOSA)	ND		2.00	ng/L		01/09/25 08:30	01/09/25 17:09	1
N-methylperfluorooctane sulfonamide (NMeFOSA)	ND		2.00	ng/L		01/09/25 08:30	01/09/25 17:09	1
N-ethylperfluorooctane sulfonamide (NEtFOSA)	ND		2.00	ng/L		01/09/25 08:30	01/09/25 17:09	1
N-methylperfluorooctanesulfonamidoacetic acid (NMeFOSAA)	ND		2.00	ng/L		01/09/25 08:30	01/09/25 17:09	1
N-ethylperfluorooctanesulfonamidoacetic acid (NEtFOSAA)	ND		2.00	ng/L		01/09/25 08:30	01/09/25 17:09	1
N-methylperfluorooctane sulfonamidoethanol (NMeFOSE)	ND		10.0	ng/L		01/09/25 08:30	01/09/25 17:09	1
N-ethylperfluorooctane sulfonamidoethanol (NEtFOSE)	ND		10.0	ng/L		01/09/25 08:30	01/09/25 17:09	1
Hexafluoropropylene Oxide Dimer Acid (HFPO-DA)	ND		1.50	ng/L		01/09/25 08:30	01/09/25 17:09	1
4,8-Dioxa-3H-perfluorononanoic acid (ADONA)	ND		2.00	ng/L		01/09/25 08:30	01/09/25 17:09	1
Perfluoro-4-methoxybutanoic acid (PFMBA)	ND		2.00	ng/L		01/09/25 08:30	01/09/25 17:09	1
Nonafluoro-3,6-dioxaheptanoic acid (NFDHA)	ND		2.00	ng/L		01/09/25 08:30	01/09/25 17:09	1
9-Chlorohexadecafluoro-3-oxanonane-1-sulfonic acid (9Cl-PF3ONS)	ND		2.00	ng/L		01/09/25 08:30	01/09/25 17:09	1
11-Chloroeicosafluoro-3-oxaundecane-1-sulfonic acid (11Cl-PF3OUdS)	ND		2.00	ng/L		01/09/25 08:30	01/09/25 17:09	1
Perfluoro (2-ethoxyethane) sulfonic acid (PFEESA)	ND		2.00	ng/L		01/09/25 08:30	01/09/25 17:09	1
3-Perfluoropropylpropanoic acid (3:3 FTCA)	ND		4.00	ng/L		01/09/25 08:30	01/09/25 17:09	1
3-Perfluoropentylpropanoic acid (5:3 FTCA)	ND		10.0	ng/L		01/09/25 08:30	01/09/25 17:09	1
3-Perfluoroheptylpropanoic acid (7:3 FTCA)	ND		10.0	ng/L		01/09/25 08:30	01/09/25 17:09	1
Perfluorodecanesulfonic acid (PFDS)	ND		2.00	ng/L		01/09/25 08:30	01/09/25 17:09	1
Perfluoro-3-methoxypropanoic acid (PFMPA)	ND		2.00	ng/L		01/09/25 08:30	01/09/25 17:09	1

Isotope Dilution	MB %Recovery	MB Qualifier	Limits	Prepared	Analyzed	Dil Fac
13C4 PFBA	81.6		5 - 130	01/09/25 08:30	01/09/25 17:09	1
13C5 PFPeA	88.0		40 - 130	01/09/25 08:30	01/09/25 17:09	1
13C5 PFHxA	80.4		40 - 130	01/09/25 08:30	01/09/25 17:09	1
13C4 PFHpA	79.6		40 - 130	01/09/25 08:30	01/09/25 17:09	1
13C8 PFOA	84.2		40 - 130	01/09/25 08:30	01/09/25 17:09	1
13C9 PFNA	83.0		40 - 130	01/09/25 08:30	01/09/25 17:09	1
13C6 PFDA	81.1		40 - 130	01/09/25 08:30	01/09/25 17:09	1
13C7 PFUnA	80.1		30 - 130	01/09/25 08:30	01/09/25 17:09	1
13C2 PFTeDA	80.1		10 - 130	01/09/25 08:30	01/09/25 17:09	1
13C3 PFBS	85.5		40 - 135	01/09/25 08:30	01/09/25 17:09	1
13C3 PFHxS	88.4		40 - 130	01/09/25 08:30	01/09/25 17:09	1
13C8 PFOS	84.5		40 - 130	01/09/25 08:30	01/09/25 17:09	1
13C8 PFOSA	86.3		40 - 130	01/09/25 08:30	01/09/25 17:09	1

Eurofins Rhode Island

QC Sample Results

Client: University of New Hampshire
Project/Site: Asphalt Shingles Testing

Job ID: 620-23136-1

Method: 1633 - Per- and Polyfluoroalkyl Substances by LC/MS/MS (Continued)

Lab Sample ID: MB 240-640965/1-A

Matrix: Solid

Analysis Batch: 641035

Client Sample ID: Method Blank

Prep Type: Total/NA

Prep Batch: 640965

Isotope Dilution	MB MB		Limits	Prepared	Analyzed	Dil Fac
	%Recovery	Qualifier				
d3-NMeFOSAA	82.5		40 - 170	01/09/25 08:30	01/09/25 17:09	1
d5-NEtFOSAA	92.1		25 - 135	01/09/25 08:30	01/09/25 17:09	1
M2-4:2 FTS	95.5		40 - 200	01/09/25 08:30	01/09/25 17:09	1
M2-6:2 FTS	91.7		40 - 200	01/09/25 08:30	01/09/25 17:09	1
M2-8:2 FTS	92.8		40 - 300	01/09/25 08:30	01/09/25 17:09	1
13C3 HFPO-DA	81.1		40 - 130	01/09/25 08:30	01/09/25 17:09	1
d7-N-MeFOSE-M	77.1		10 - 130	01/09/25 08:30	01/09/25 17:09	1
d9-N-EtFOSE-M	74.6		10 - 130	01/09/25 08:30	01/09/25 17:09	1
d5-NEtPFOSA	63.4		10 - 130	01/09/25 08:30	01/09/25 17:09	1
D3-NMeFOSA	65.4		10 - 130	01/09/25 08:30	01/09/25 17:09	1
13C2-PFDoDA	79.9		10 - 130	01/09/25 08:30	01/09/25 17:09	1

Lab Sample ID: LCS 240-640965/3-A

Matrix: Solid

Analysis Batch: 641035

Client Sample ID: Lab Control Sample

Prep Type: Total/NA

Prep Batch: 640965

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec Limits
Perfluorobutanoic acid (PFBA)	80.0	102.4		ng/L		128	70 - 140
Perfluoropentanoic acid (PFPeA)	40.0	48.58		ng/L		121	65 - 135
Perfluorohexanoic acid (PFHxA)	40.0	46.79		ng/L		117	70 - 145
Perfluoroheptanoic acid (PFHpA)	40.0	48.19		ng/L		120	70 - 150
Perfluorooctanoic acid (PFOA)	40.0	49.08		ng/L		123	70 - 150
Perfluorononanoic acid (PFNA)	40.0	49.01		ng/L		123	70 - 150
Perfluorodecanoic acid (PFDA)	40.0	46.28		ng/L		116	70 - 140
Perfluoroundecanoic acid (PFUnA)	40.0	47.67		ng/L		119	70 - 145
Perfluorododecanoic acid (PFDoA)	40.0	48.27		ng/L		121	70 - 140
Perfluorotridecanoic acid (PFTrDA)	40.0	48.03		ng/L		120	65 - 140
Perfluorotetradecanoic acid (PFTeDA)	40.0	47.53		ng/L		119	60 - 140
Perfluorobutanesulfonic acid (PFBS)	35.4	47.22		ng/L		134	60 - 145
Perfluoropentanesulfonic acid (PFPeS)	37.5	48.27		ng/L		129	65 - 140
Perfluorohexanesulfonic acid (PFHxS)	36.4	41.30		ng/L		113	65 - 145
Perfluoroheptanesulfonic acid (PFHpS)	38.1	50.24		ng/L		132	70 - 150
Perfluorooctanesulfonic acid (PFOS)	37.1	43.61		ng/L		117	55 - 150
Perfluorononanesulfonic acid (PFNS)	38.4	52.15		ng/L		136	65 - 145
Perfluorododecanesulfonic acid (PFDoS)	38.7	47.87		ng/L		124	50 - 145
1H,1H,2H,2H-Perfluorohexane sulfonic acid (4:2 FTS)	74.7	97.36		ng/L		130	70 - 145
1H,1H,2H,2H-Perfluorooctane sulfonic acid (6:2 FTS)	75.8	90.87		ng/L		120	65 - 155
1H,1H,2H,2H-Perfluorodecane sulfonic acid (8:2 FTS)	76.6	98.75		ng/L		129	60 - 150

Eurofins Rhode Island

QC Sample Results

Client: University of New Hampshire
Project/Site: Asphalt Shingles Testing

Job ID: 620-23136-1

Method: 1633 - Per- and Polyfluoroalkyl Substances by LC/MS/MS (Continued)

Lab Sample ID: LCS 240-640965/3-A

Matrix: Solid

Analysis Batch: 641035

Client Sample ID: Lab Control Sample

Prep Type: Total/NA

Prep Batch: 640965

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec Limits
Perfluorooctanesulfonamide (PFOSA)	40.0	51.31		ng/L		128	70 - 145
N-methylperfluorooctane sulfonamide (NMeFOSA)	40.0	59.89		ng/L		150	60 - 150
N-ethylperfluorooctane sulfonamide (NEtFOSA)	40.0	55.31		ng/L		138	65 - 145
N-methylperfluorooctanesulfonamidoacetic acid (NMeFOSAA)	40.0	49.27		ng/L		123	50 - 140
N-ethylperfluorooctanesulfonamidoacetic acid (NEtFOSAA)	40.0	50.41		ng/L		126	70 - 145
N-methylperfluorooctane sulfonamidoethanol (NMeFOSE)	200	263.8		ng/L		132	70 - 145
N-ethylperfluorooctane sulfonamidoethanol (NEtFOSE)	200	261.5		ng/L		131	70 - 135
Hexafluoropropylene Oxide Dimer Acid (HFPO-DA)	30.0	40.59		ng/L		135	70 - 140
4,8-Dioxa-3H-perfluorononanoic acid (ADONA)	37.7	51.62		ng/L		137	65 - 145
Perfluoro-4-methoxybutanoic acid (PFMBA)	40.0	47.51		ng/L		119	60 - 150
Nonafluoro-3,6-dioxaheptanoic acid (NFDHA)	40.0	50.37		ng/L		126	50 - 150
9-Chlorohexadecafluoro-3-oxanonane-1-sulfonic acid (9Cl-PF3ONS)	37.3	49.96		ng/L		134	70 - 155
11-Chloroeicosafluoro-3-oxaundecane-1-sulfonic acid (11Cl-PF3OUdS)	37.7	48.47		ng/L		129	55 - 160
Perfluoro (2-ethoxyethane) sulfonic acid (PFEEA)	35.6	45.11		ng/L		127	70 - 140
3-Perfluoropropylpropanoic acid (3:3 FTCA)	80.0	92.04		ng/L		115	65 - 130
3-Perfluoropentylpropanoic acid (5:3 FTCA)	200	246.1		ng/L		123	70 - 135
3-Perfluoroheptylpropanoic acid (7:3 FTCA)	200	239.8		ng/L		120	50 - 145
Perfluorodecanesulfonic acid (PFDS)	38.6	47.54		ng/L		123	60 - 145
Perfluoro-3-methoxypropanoic acid (PFMPA)	40.0	48.02		ng/L		120	55 - 140

Isotope Dilution	LCS		Limits
	%Recovery	Qualifier	
13C4 PFBA	85.5		5 - 130
13C5 PFPeA	91.7		40 - 130
13C5 PFHxA	84.9		40 - 130
13C4 PFHpA	86.7		40 - 130
13C8 PFOA	91.0		40 - 130
13C9 PFNA	87.2		40 - 130
13C6 PFDA	85.6		40 - 130
13C7 PFUnA	83.4		30 - 130
13C2 PFTeDA	82.9		10 - 130
13C3 PFBS	88.0		40 - 135
13C3 PFHxS	91.6		40 - 130
13C8 PFOS	89.6		40 - 130

Eurofins Rhode Island

QC Sample Results

Client: University of New Hampshire
Project/Site: Asphalt Shingles Testing

Job ID: 620-23136-1

Method: 1633 - Per- and Polyfluoroalkyl Substances by LC/MS/MS (Continued)

Lab Sample ID: LCS 240-640965/3-A

Matrix: Solid

Analysis Batch: 641035

Client Sample ID: Lab Control Sample

Prep Type: Total/NA

Prep Batch: 640965

Isotope Dilution	LCS LCS		Limits
	%Recovery	Qualifier	
13C8 PFOSA	88.6		40 - 130
d3-NMeFOSAA	83.8		40 - 170
d5-NEtFOSAA	99.9		25 - 135
M2-4:2 FTS	94.3		40 - 200
M2-6:2 FTS	90.4		40 - 200
M2-8:2 FTS	93.9		40 - 300
13C3 HFPO-DA	82.7		40 - 130
d7-N-MeFOSE-M	55.3		10 - 130
d9-N-EtFOSE-M	53.0		10 - 130
d5-NEtPFOSA	63.7		10 - 130
D3-NMeFOSA	68.5		10 - 130
13C2-PFDoDA	82.3		10 - 130

Lab Sample ID: LLCS 240-640965/2-A

Matrix: Solid

Analysis Batch: 641035

Client Sample ID: Lab Control Sample

Prep Type: Total/NA

Prep Batch: 640965

Analyte	Spike Added	LLCS Result	LLCS Qualifier	Unit	D	%Rec	%Rec Limits
Perfluorobutanoic acid (PFBA)	8.00	9.083		ng/L		114	70 - 140
Perfluoropentanoic acid (PFPeA)	4.00	4.732		ng/L		118	65 - 135
Perfluorohexanoic acid (PFHxA)	4.00	4.602		ng/L		115	70 - 145
Perfluoroheptanoic acid (PFHpA)	4.00	4.725		ng/L		118	70 - 150
Perfluorooctanoic acid (PFOA)	4.00	4.689		ng/L		117	70 - 150
Perfluorononanoic acid (PFNA)	4.00	4.389		ng/L		110	70 - 150
Perfluorodecanoic acid (PFDA)	4.00	4.752		ng/L		119	70 - 140
Perfluoroundecanoic acid (PFUnA)	4.00	4.548		ng/L		114	70 - 145
Perfluorododecanoic acid (PFDoA)	4.00	4.502		ng/L		113	70 - 140
Perfluorotridecanoic acid (PFTrDA)	4.00	3.990		ng/L		100	65 - 140
Perfluorotetradecanoic acid (PFTeDA)	4.00	4.381		ng/L		110	60 - 140
Perfluorobutanesulfonic acid (PFBS)	3.54	4.170		ng/L		118	60 - 145
Perfluoropentanesulfonic acid (PFPeS)	3.75	4.521		ng/L		120	65 - 140
Perfluorohexanesulfonic acid (PFHxS)	3.64	3.892		ng/L		107	65 - 145
Perfluoroheptanesulfonic acid (PFHpS)	3.81	4.644		ng/L		122	70 - 150
Perfluorooctanesulfonic acid (PFOS)	3.71	4.392		ng/L		118	55 - 150
Perfluorononanesulfonic acid (PFNS)	3.84	4.462		ng/L		116	65 - 145
Perfluorododecanesulfonic acid (PFDoS)	3.87	4.089		ng/L		106	50 - 145
1H,1H,2H,2H-Perfluorohexane sulfonic acid (4:2 FTS)	7.47	8.916		ng/L		119	70 - 145
1H,1H,2H,2H-Perfluorooctane sulfonic acid (6:2 FTS)	7.58	9.015		ng/L		119	65 - 155

Eurofins Rhode Island

QC Sample Results

Client: University of New Hampshire
Project/Site: Asphalt Shingles Testing

Job ID: 620-23136-1

Method: 1633 - Per- and Polyfluoroalkyl Substances by LC/MS/MS (Continued)

Lab Sample ID: LLCS 240-640965/2-A

Matrix: Solid

Analysis Batch: 641035

Client Sample ID: Lab Control Sample

Prep Type: Total/NA

Prep Batch: 640965

Analyte	Spike Added	LLCS Result	LLCS Qualifier	Unit	D	%Rec	%Rec Limits
1H,1H,2H,2H-Perfluorodecane sulfonic acid (8:2 FTS)	7.66	8.864		ng/L		116	60 - 150
Perfluorooctanesulfonamide (PFOSA)	4.00	4.425		ng/L		111	70 - 145
N-methylperfluorooctane sulfonamide (NMeFOSA)	4.00	4.453		ng/L		111	60 - 150
N-ethylperfluorooctane sulfonamide (NEtFOSA)	4.00	4.835		ng/L		121	65 - 145
N-methylperfluorooctanesulfonamidoacetic acid (NMeFOSAA)	4.00	4.358		ng/L		109	50 - 140
N-ethylperfluorooctanesulfonamidoacetic acid (NEtFOSAA)	4.00	4.527		ng/L		113	70 - 145
N-methylperfluorooctane sulfonamidoethanol (NMeFOSE)	20.0	23.45		ng/L		117	70 - 145
N-ethylperfluorooctane sulfonamidoethanol (NEtFOSE)	20.0	23.74		ng/L		119	70 - 135
Hexafluoropropylene Oxide Dimer Acid (HFPO-DA)	3.00	3.403		ng/L		113	70 - 140
4,8-Dioxa-3H-perfluorononanoic acid (ADONA)	3.77	4.392		ng/L		117	65 - 145
Perfluoro-4-methoxybutanoic acid (PFMBA)	4.00	4.269		ng/L		107	60 - 150
Nonafluoro-3,6-dioxaheptanoic acid (NFDHA)	4.00	4.971		ng/L		124	50 - 150
9-Chlorohexadecafluoro-3-oxanonane-1-sulfonic acid (9Cl-PF3ONS)	3.73	4.153		ng/L		111	70 - 155
11-Chloroeicosafluoro-3-oxaundecane-1-sulfonic acid (11Cl-PF3OUdS)	3.77	4.085		ng/L		108	55 - 160
Perfluoro (2-ethoxyethane) sulfonic acid (PFEEA)	3.56	4.073		ng/L		114	70 - 140
3-Perfluoropropylpropanoic acid (3:3 FTCA)	8.00	8.170		ng/L		102	65 - 130
3-Perfluoropentylpropanoic acid (5:3 FTCA)	20.0	22.19		ng/L		111	70 - 135
3-Perfluoroheptylpropanoic acid (7:3 FTCA)	20.0	20.54		ng/L		103	50 - 145
Perfluorodecanesulfonic acid (PFDS)	3.86	4.253		ng/L		110	60 - 145
Perfluoro-3-methoxypropanoic acid (PFMPA)	4.00	4.176		ng/L		104	55 - 140

Isotope Dilution	LLCS		Limits
	%Recovery	Qualifier	
13C4 PFBA	111		5 - 130
13C5 PFPeA	125		40 - 130
13C5 PFHxA	113		40 - 130
13C4 PFHpA	112		40 - 130
13C8 PFOA	119		40 - 130
13C9 PFNA	117		40 - 130
13C6 PFDA	111		40 - 130
13C7 PFUnA	110		30 - 130
13C2 PFTeDA	99.7		10 - 130
13C3 PFBS	117		40 - 135

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QC Sample Results

Client: University of New Hampshire
Project/Site: Asphalt Shingles Testing

Job ID: 620-23136-1

Method: 1633 - Per- and Polyfluoroalkyl Substances by LC/MS/MS (Continued)

Lab Sample ID: LLCS 240-640965/2-A

Matrix: Solid

Analysis Batch: 641035

Client Sample ID: Lab Control Sample

Prep Type: Total/NA

Prep Batch: 640965

Isotope Dilution	LLCS LLCS		Limits
	%Recovery	Qualifier	
13C3 PFHxS	121		40 - 130
13C8 PFOS	115		40 - 130
13C8 PFOSA	114		40 - 130
d3-NMeFOSAA	104		40 - 170
d5-NEtFOSAA	118		25 - 135
M2-4:2 FTS	127		40 - 200
M2-6:2 FTS	120		40 - 200
M2-8:2 FTS	124		40 - 300
13C3 HFPO-DA	110		40 - 130
d7-N-MeFOSE-M	74.7		10 - 130
d9-N-EtFOSE-M	69.2		10 - 130
d5-NEtPFOSA	74.3		10 - 130
D3-NMeFOSA	82.7		10 - 130
13C2-PFDoDA	105		10 - 130

Lab Sample ID: LB 240-640636/4-B

Matrix: Solid

Analysis Batch: 640904

Client Sample ID: Method Blank

Prep Type: SPLP East

Prep Batch: 640762

Analyte	LB LB		RL	Unit	D	Prepared	Analyzed	Dil Fac
	Result	Qualifier						
Perfluorobutanoic acid (PFBA)	ND		3.81	ng/L		01/07/25 14:23	01/08/25 16:07	1
Perfluoropentanoic acid (PFPeA)	ND		1.90	ng/L		01/07/25 14:23	01/08/25 16:07	1
Perfluorohexanoic acid (PFHxA)	ND		1.90	ng/L		01/07/25 14:23	01/08/25 16:07	1
Perfluoroheptanoic acid (PFHpA)	ND		1.90	ng/L		01/07/25 14:23	01/08/25 16:07	1
Perfluorooctanoic acid (PFOA)	ND		1.90	ng/L		01/07/25 14:23	01/08/25 16:07	1
Perfluorononanoic acid (PFNA)	ND		1.90	ng/L		01/07/25 14:23	01/08/25 16:07	1
Perfluorodecanoic acid (PFDA)	ND		1.90	ng/L		01/07/25 14:23	01/08/25 16:07	1
Perfluoroundecanoic acid (PFUnA)	ND		1.90	ng/L		01/07/25 14:23	01/08/25 16:07	1
Perfluorododecanoic acid (PFDoA)	ND		1.90	ng/L		01/07/25 14:23	01/08/25 16:07	1
Perfluorotridecanoic acid (PFTriDA)	ND		1.90	ng/L		01/07/25 14:23	01/08/25 16:07	1
Perfluorotetradecanoic acid (PFTeDA)	ND		1.90	ng/L		01/07/25 14:23	01/08/25 16:07	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.90	ng/L		01/07/25 14:23	01/08/25 16:07	1
Perfluoropentanesulfonic acid (PFPeS)	ND		1.90	ng/L		01/07/25 14:23	01/08/25 16:07	1
Perfluorohexanesulfonic acid (PFHxS)	ND		1.90	ng/L		01/07/25 14:23	01/08/25 16:07	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		1.90	ng/L		01/07/25 14:23	01/08/25 16:07	1
Perfluorooctanesulfonic acid (PFOS)	ND		1.90	ng/L		01/07/25 14:23	01/08/25 16:07	1
Perfluorononanesulfonic acid (PFNS)	ND		1.90	ng/L		01/07/25 14:23	01/08/25 16:07	1
Perfluorododecanesulfonic acid (PFDoS)	ND		1.90	ng/L		01/07/25 14:23	01/08/25 16:07	1
1H,1H,2H,2H-Perfluorohexane sulfonic acid (4:2 FTS)	ND		3.81	ng/L		01/07/25 14:23	01/08/25 16:07	1
1H,1H,2H,2H-Perfluorooctane sulfonic acid (6:2 FTS)	ND		3.81	ng/L		01/07/25 14:23	01/08/25 16:07	1
1H,1H,2H,2H-Perfluorodecane sulfonic acid (8:2 FTS)	ND		3.81	ng/L		01/07/25 14:23	01/08/25 16:07	1
Perfluorooctanesulfonamide (PFOSA)	ND		1.90	ng/L		01/07/25 14:23	01/08/25 16:07	1
N-methylperfluorooctane sulfonamide (NMeFOSA)	ND		1.90	ng/L		01/07/25 14:23	01/08/25 16:07	1

Eurofins Rhode Island

QC Sample Results

Client: University of New Hampshire
Project/Site: Asphalt Shingles Testing

Job ID: 620-23136-1

Method: 1633 - Per- and Polyfluoroalkyl Substances by LC/MS/MS (Continued)

Lab Sample ID: LB 240-640636/4-B

Matrix: Solid

Analysis Batch: 640904

Client Sample ID: Method Blank

Prep Type: SPLP East

Prep Batch: 640762

Analyte	LB Result	LB Qualifier	RL	Unit	D	Prepared	Analyzed	Dil Fac
N-ethylperfluorooctane sulfonamide (NEtFOSA)	ND		1.90	ng/L		01/07/25 14:23	01/08/25 16:07	1
N-methylperfluorooctanesulfonamidoacetic acid (NMeFOSAA)	ND		1.90	ng/L		01/07/25 14:23	01/08/25 16:07	1
N-ethylperfluorooctanesulfonamidoacetic acid (NEtFOSAA)	ND		1.90	ng/L		01/07/25 14:23	01/08/25 16:07	1
N-methylperfluorooctane sulfonamidoethanol (NMeFOSE)	ND		9.52	ng/L		01/07/25 14:23	01/08/25 16:07	1
N-ethylperfluorooctane sulfonamidoethanol (NEtFOSE)	ND		9.52	ng/L		01/07/25 14:23	01/08/25 16:07	1
Hexafluoropropylene Oxide Dimer Acid (HFPO-DA)	ND		1.43	ng/L		01/07/25 14:23	01/08/25 16:07	1
4,8-Dioxa-3H-perfluorononanoic acid (ADONA)	ND		1.90	ng/L		01/07/25 14:23	01/08/25 16:07	1
Perfluoro-4-methoxybutanoic acid (PFMBA)	ND		1.90	ng/L		01/07/25 14:23	01/08/25 16:07	1
Nonafluoro-3,6-dioxaheptanoic acid (NFDHA)	ND		1.90	ng/L		01/07/25 14:23	01/08/25 16:07	1
9-Chlorohexadecafluoro-3-oxanonane-1-sulfonic acid (9Cl-PF3ONS)	ND		1.90	ng/L		01/07/25 14:23	01/08/25 16:07	1
11-Chloroeicosafluoro-3-oxaundecane-1-sulfonic acid (11Cl-PF3OUdS)	ND		1.90	ng/L		01/07/25 14:23	01/08/25 16:07	1
Perfluoro (2-ethoxyethane) sulfonic acid (PFEESA)	ND		1.90	ng/L		01/07/25 14:23	01/08/25 16:07	1
3-Perfluoropropylpropanoic acid (3:3 FTCA)	ND		3.81	ng/L		01/07/25 14:23	01/08/25 16:07	1
3-Perfluoropentylpropanoic acid (5:3 FTCA)	ND		9.52	ng/L		01/07/25 14:23	01/08/25 16:07	1
3-Perfluoroheptylpropanoic acid (7:3 FTCA)	ND		9.52	ng/L		01/07/25 14:23	01/08/25 16:07	1
Perfluorodecanesulfonic acid (PFDS)	ND		1.90	ng/L		01/07/25 14:23	01/08/25 16:07	1
Perfluoro-3-methoxypropanoic acid (PFMPA)	ND		1.90	ng/L		01/07/25 14:23	01/08/25 16:07	1

Isotope Dilution	LB %Recovery	LB Qualifier	Limits	Prepared	Analyzed	Dil Fac
13C4 PFBA	88.9		5 - 130	01/07/25 14:23	01/08/25 16:07	1
13C5 PFPeA	95.8		40 - 130	01/07/25 14:23	01/08/25 16:07	1
13C5 PFHxA	95.9		40 - 130	01/07/25 14:23	01/08/25 16:07	1
13C4 PFHpA	96.0		40 - 130	01/07/25 14:23	01/08/25 16:07	1
13C8 PFOA	97.9		40 - 130	01/07/25 14:23	01/08/25 16:07	1
13C9 PFNA	94.5		40 - 130	01/07/25 14:23	01/08/25 16:07	1
13C6 PFDA	91.7		40 - 130	01/07/25 14:23	01/08/25 16:07	1
13C7 PFUnA	94.9		30 - 130	01/07/25 14:23	01/08/25 16:07	1
13C2 PFTeDA	86.9		10 - 130	01/07/25 14:23	01/08/25 16:07	1
13C3 PFBS	94.9		40 - 135	01/07/25 14:23	01/08/25 16:07	1
13C3 PFHxS	99.0		40 - 130	01/07/25 14:23	01/08/25 16:07	1
13C8 PFOS	94.7		40 - 130	01/07/25 14:23	01/08/25 16:07	1
13C8 PFOSA	94.0		40 - 130	01/07/25 14:23	01/08/25 16:07	1
d3-NMeFOSAA	92.7		40 - 170	01/07/25 14:23	01/08/25 16:07	1
d5-NEtFOSAA	130		25 - 135	01/07/25 14:23	01/08/25 16:07	1
M2-4:2 FTS	116		40 - 200	01/07/25 14:23	01/08/25 16:07	1
M2-6:2 FTS	96.4		40 - 200	01/07/25 14:23	01/08/25 16:07	1
M2-8:2 FTS	94.3		40 - 300	01/07/25 14:23	01/08/25 16:07	1

Eurofins Rhode Island

QC Sample Results

Client: University of New Hampshire
Project/Site: Asphalt Shingles Testing

Job ID: 620-23136-1

Method: 1633 - Per- and Polyfluoroalkyl Substances by LC/MS/MS (Continued)

Lab Sample ID: LB 240-640636/4-B

Matrix: Solid

Analysis Batch: 640904

Client Sample ID: Method Blank

Prep Type: SPLP East

Prep Batch: 640762

Isotope Dilution	LB LB		Limits	Prepared	Analyzed	Dil Fac
	%Recovery	Qualifier				
13C3 HFPO-DA	75.3		40 - 130	01/07/25 14:23	01/08/25 16:07	1
d7-N-MeFOSE-M	83.7		10 - 130	01/07/25 14:23	01/08/25 16:07	1
d9-N-EtFOSE-M	84.3		10 - 130	01/07/25 14:23	01/08/25 16:07	1
d5-NEtPFOSA	71.8		10 - 130	01/07/25 14:23	01/08/25 16:07	1
D3-NMeFOSA	75.5		10 - 130	01/07/25 14:23	01/08/25 16:07	1
13C2-PFDoDA	91.2		10 - 130	01/07/25 14:23	01/08/25 16:07	1

Lab Sample ID: LB 240-640945/1-B

Matrix: Solid

Analysis Batch: 641035

Client Sample ID: Method Blank

Prep Type: SPLP East

Prep Batch: 640965

Analyte	LB LB		RL	Unit	D	Prepared	Analyzed	Dil Fac
	Result	Qualifier						
Perfluorobutanoic acid (PFBA)	ND		3.82	ng/L		01/09/25 13:58	01/09/25 19:21	1
Perfluoropentanoic acid (PFPeA)	ND		1.91	ng/L		01/09/25 13:58	01/09/25 19:21	1
Perfluorohexanoic acid (PFHxA)	ND		1.91	ng/L		01/09/25 13:58	01/09/25 19:21	1
Perfluoroheptanoic acid (PFHpA)	ND		1.91	ng/L		01/09/25 13:58	01/09/25 19:21	1
Perfluorooctanoic acid (PFOA)	ND		1.91	ng/L		01/09/25 13:58	01/09/25 19:21	1
Perfluorononanoic acid (PFNA)	ND		1.91	ng/L		01/09/25 13:58	01/09/25 19:21	1
Perfluorodecanoic acid (PFDA)	ND		1.91	ng/L		01/09/25 13:58	01/09/25 19:21	1
Perfluoroundecanoic acid (PFUnA)	ND		1.91	ng/L		01/09/25 13:58	01/09/25 19:21	1
Perfluorododecanoic acid (PFDoA)	ND		1.91	ng/L		01/09/25 13:58	01/09/25 19:21	1
Perfluorotridecanoic acid (PFTTrDA)	ND		1.91	ng/L		01/09/25 13:58	01/09/25 19:21	1
Perfluorotetradecanoic acid (PFTeDA)	ND		1.91	ng/L		01/09/25 13:58	01/09/25 19:21	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.91	ng/L		01/09/25 13:58	01/09/25 19:21	1
Perfluoropentanesulfonic acid (PFPeS)	ND		1.91	ng/L		01/09/25 13:58	01/09/25 19:21	1
Perfluorohexanesulfonic acid (PFHxS)	ND		1.91	ng/L		01/09/25 13:58	01/09/25 19:21	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		1.91	ng/L		01/09/25 13:58	01/09/25 19:21	1
Perfluorooctanesulfonic acid (PFOS)	ND		1.91	ng/L		01/09/25 13:58	01/09/25 19:21	1
Perfluorononanesulfonic acid (PFNS)	ND		1.91	ng/L		01/09/25 13:58	01/09/25 19:21	1
Perfluorododecanesulfonic acid (PFDoS)	ND		1.91	ng/L		01/09/25 13:58	01/09/25 19:21	1
1H,1H,2H,2H-Perfluorohexane sulfonic acid (4:2 FTS)	ND		3.82	ng/L		01/09/25 13:58	01/09/25 19:21	1
1H,1H,2H,2H-Perfluorooctane sulfonic acid (6:2 FTS)	ND		3.82	ng/L		01/09/25 13:58	01/09/25 19:21	1
1H,1H,2H,2H-Perfluorodecane sulfonic acid (8:2 FTS)	ND		3.82	ng/L		01/09/25 13:58	01/09/25 19:21	1
Perfluorooctanesulfonamide (PFOSA)	ND		1.91	ng/L		01/09/25 13:58	01/09/25 19:21	1
N-methylperfluorooctane sulfonamide (NMeFOSA)	ND		1.91	ng/L		01/09/25 13:58	01/09/25 19:21	1
N-ethylperfluorooctane sulfonamide (NEtFOSA)	ND		1.91	ng/L		01/09/25 13:58	01/09/25 19:21	1
N-methylperfluorooctanesulfonamidoacetic acid (NMeFOSAA)	ND		1.91	ng/L		01/09/25 13:58	01/09/25 19:21	1
N-ethylperfluorooctanesulfonamidoacetic acid (NEtFOSAA)	ND		1.91	ng/L		01/09/25 13:58	01/09/25 19:21	1
N-methylperfluorooctane sulfonamidoethanol (NMeFOSE)	ND		9.56	ng/L		01/09/25 13:58	01/09/25 19:21	1
N-ethylperfluorooctane sulfonamidoethanol (NEtFOSE)	ND		9.56	ng/L		01/09/25 13:58	01/09/25 19:21	1

Eurofins Rhode Island

QC Sample Results

Client: University of New Hampshire
Project/Site: Asphalt Shingles Testing

Job ID: 620-23136-1

Method: 1633 - Per- and Polyfluoroalkyl Substances by LC/MS/MS (Continued)

Lab Sample ID: LB 240-640945/1-B

Matrix: Solid

Analysis Batch: 641035

Client Sample ID: Method Blank

Prep Type: SPLP East

Prep Batch: 640965

Analyte	LB Result	LB Qualifier	RL	Unit	D	Prepared	Analyzed	Dil Fac
Hexafluoropropylene Oxide Dimer Acid (HFPO-DA)	ND		1.43	ng/L		01/09/25 13:58	01/09/25 19:21	1
4,8-Dioxa-3H-perfluorononanoic acid (ADONA)	ND		1.91	ng/L		01/09/25 13:58	01/09/25 19:21	1
Perfluoro-4-methoxybutanoic acid (PFMBA)	ND		1.91	ng/L		01/09/25 13:58	01/09/25 19:21	1
Nonafluoro-3,6-dioxaheptanoic acid (NFDHA)	ND		1.91	ng/L		01/09/25 13:58	01/09/25 19:21	1
9-Chlorohexadecafluoro-3-oxanonan e-1-sulfonic acid (9Cl-PF3ONS)	ND		1.91	ng/L		01/09/25 13:58	01/09/25 19:21	1
11-Chloroeicosafluoro-3-oxaundecan e-1-sulfonic acid (11Cl-PF3OUdS)	ND		1.91	ng/L		01/09/25 13:58	01/09/25 19:21	1
Perfluoro (2-ethoxyethane) sulfonic acid (PFEESA)	ND		1.91	ng/L		01/09/25 13:58	01/09/25 19:21	1
3-Perfluoropropylpropanoic acid (3:3 FTCA)	ND		3.82	ng/L		01/09/25 13:58	01/09/25 19:21	1
3-Perfluoropentylpropanoic acid (5:3 FTCA)	ND		9.56	ng/L		01/09/25 13:58	01/09/25 19:21	1
3-Perfluoroheptylpropanoic acid (7:3 FTCA)	ND		9.56	ng/L		01/09/25 13:58	01/09/25 19:21	1
Perfluorodecanesulfonic acid (PFDS)	ND		1.91	ng/L		01/09/25 13:58	01/09/25 19:21	1
Perfluoro-3-methoxypropanoic acid (PFMPA)	ND		1.91	ng/L		01/09/25 13:58	01/09/25 19:21	1

Isotope Dilution	LB %Recovery	LB Qualifier	Limits	Prepared	Analyzed	Dil Fac
13C4 PFBA	69.9		5 - 130	01/09/25 13:58	01/09/25 19:21	1
13C5 PFPeA	76.1		40 - 130	01/09/25 13:58	01/09/25 19:21	1
13C5 PFHxA	66.7		40 - 130	01/09/25 13:58	01/09/25 19:21	1
13C4 PFHpA	66.3		40 - 130	01/09/25 13:58	01/09/25 19:21	1
13C8 PFOA	69.1		40 - 130	01/09/25 13:58	01/09/25 19:21	1
13C9 PFNA	65.9		40 - 130	01/09/25 13:58	01/09/25 19:21	1
13C6 PFDA	67.2		40 - 130	01/09/25 13:58	01/09/25 19:21	1
13C7 PFUnA	66.4		30 - 130	01/09/25 13:58	01/09/25 19:21	1
13C2 PFTeDA	59.6		10 - 130	01/09/25 13:58	01/09/25 19:21	1
13C3 PFBS	65.9		40 - 135	01/09/25 13:58	01/09/25 19:21	1
13C3 PFHxS	68.4		40 - 130	01/09/25 13:58	01/09/25 19:21	1
13C8 PFOS	65.6		40 - 130	01/09/25 13:58	01/09/25 19:21	1
13C8 PFOSA	65.8		40 - 130	01/09/25 13:58	01/09/25 19:21	1
d3-NMeFOSAA	64.4		40 - 170	01/09/25 13:58	01/09/25 19:21	1
d5-NEtFOSAA	62.7		25 - 135	01/09/25 13:58	01/09/25 19:21	1
M2-4:2 FTS	75.3		40 - 200	01/09/25 13:58	01/09/25 19:21	1
M2-6:2 FTS	72.1		40 - 200	01/09/25 13:58	01/09/25 19:21	1
M2-8:2 FTS	72.1		40 - 300	01/09/25 13:58	01/09/25 19:21	1
13C3 HFPO-DA	68.7		40 - 130	01/09/25 13:58	01/09/25 19:21	1
d7-N-MeFOSE-M	43.8		10 - 130	01/09/25 13:58	01/09/25 19:21	1
d9-N-EtFOSE-M	43.3		10 - 130	01/09/25 13:58	01/09/25 19:21	1
d5-NEtPFOSA	45.8		10 - 130	01/09/25 13:58	01/09/25 19:21	1
D3-NMeFOSA	51.3		10 - 130	01/09/25 13:58	01/09/25 19:21	1
13C2-PFDoDA	64.0		10 - 130	01/09/25 13:58	01/09/25 19:21	1

Eurofins Rhode Island

QC Association Summary

Client: University of New Hampshire
Project/Site: Asphalt Shingles Testing

Job ID: 620-23136-1

GC/MS Semi VOA

Leach Batch: 42987

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
620-23136-1	MW1	SPLP East	Solid	1312	
620-23136-2	PC1	SPLP East	Solid	1312	
MB 620-42987/1-C	Method Blank	SPLP East	Solid	1312	
620-23136-1 MS	MW1	SPLP East	Solid	1312	

Prep Batch: 43019

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
620-23136-1	MW1	SPLP East	Solid	3510C	42987
620-23136-2	PC1	SPLP East	Solid	3510C	42987
MB 620-42987/1-C	Method Blank	SPLP East	Solid	3510C	42987
MB 620-43019/1-A	Method Blank	Total/NA	Solid	3510C	
LCS 620-43019/2-A	Lab Control Sample	Total/NA	Solid	3510C	
LCSD 620-43019/3-A	Lab Control Sample Dup	Total/NA	Solid	3510C	
620-23136-1 MS	MW1	SPLP East	Solid	3510C	42987

Analysis Batch: 43022

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
620-23136-1	MW1	SPLP East	Solid	8270E	43019
620-23136-2	PC1	SPLP East	Solid	8270E	43019
MB 620-42987/1-C	Method Blank	SPLP East	Solid	8270E	43019
MB 620-43019/1-A	Method Blank	Total/NA	Solid	8270E	43019
LCS 620-43019/2-A	Lab Control Sample	Total/NA	Solid	8270E	43019
LCSD 620-43019/3-A	Lab Control Sample Dup	Total/NA	Solid	8270E	43019
620-23136-1 MS	MW1	SPLP East	Solid	8270E	43019

GC Semi VOA

Leach Batch: 42987

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
620-23136-1	MW1	SPLP East	Solid	1312	
620-23136-2	PC1	SPLP East	Solid	1312	
MB 620-42987/1-D	Method Blank	SPLP East	Solid	1312	
620-23136-2 MS	PC1	SPLP East	Solid	1312	

Prep Batch: 43020

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
620-23136-1	MW1	SPLP East	Solid	3510C	42987
620-23136-2	PC1	SPLP East	Solid	3510C	42987
MB 620-42987/1-D	Method Blank	SPLP East	Solid	3510C	42987
MB 620-43020/1-A	Method Blank	Total/NA	Solid	3510C	
LCS 620-43020/2-A	Lab Control Sample	Total/NA	Solid	3510C	
LCSD 620-43020/3-A	Lab Control Sample Dup	Total/NA	Solid	3510C	
620-23136-2 MS	PC1	SPLP East	Solid	3510C	42987

Analysis Batch: 43052

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
620-23136-1	MW1	SPLP East	Solid	8082A	43020
620-23136-2	PC1	SPLP East	Solid	8082A	43020
MB 620-42987/1-D	Method Blank	SPLP East	Solid	8082A	43020
MB 620-43020/1-A	Method Blank	Total/NA	Solid	8082A	43020
LCS 620-43020/2-A	Lab Control Sample	Total/NA	Solid	8082A	43020

Eurofins Rhode Island

QC Association Summary

Client: University of New Hampshire
Project/Site: Asphalt Shingles Testing

Job ID: 620-23136-1

GC Semi VOA (Continued)

Analysis Batch: 43052 (Continued)

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
LCSD 620-43020/3-A	Lab Control Sample Dup	Total/NA	Solid	8082A	43020
620-23136-2 MS	PC1	SPLP East	Solid	8082A	43020

LCMS

Leach Batch: 640636

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
620-23136-1	MW1	SPLP East	Solid	1312	
620-23136-2	PC1	SPLP East	Solid	1312	
LB 240-640636/4-B	Method Blank	SPLP East	Solid	1312	

Prep Batch: 640762

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
620-23136-1	MW1	SPLP East	Solid	1633	640636
620-23136-2	PC1	SPLP East	Solid	1633	640636
LB 240-640636/4-B	Method Blank	SPLP East	Solid	1633	640636
MB 240-640762/1-A	Method Blank	Total/NA	Solid	1633	
LCS 240-640762/3-A	Lab Control Sample	Total/NA	Solid	1633	
LLCS 240-640762/2-A	Lab Control Sample	Total/NA	Solid	1633	

Analysis Batch: 640803

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
620-23136-1	MW1	SPLP East	Solid	1633	640762
620-23136-2	PC1	SPLP East	Solid	1633	640762
MB 240-640762/1-A	Method Blank	Total/NA	Solid	1633	640762
LCS 240-640762/3-A	Lab Control Sample	Total/NA	Solid	1633	640762
LLCS 240-640762/2-A	Lab Control Sample	Total/NA	Solid	1633	640762

Analysis Batch: 640904

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
LB 240-640636/4-B	Method Blank	SPLP East	Solid	1633	640762

Leach Batch: 640945

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
620-23136-1	MW1	SPLP East	Solid	1312	
620-23136-2	PC1	SPLP East	Solid	1312	
LB 240-640945/1-B	Method Blank	SPLP East	Solid	1312	

Prep Batch: 640965

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
620-23136-1	MW1	SPLP East	Solid	1633	640945
620-23136-2	PC1	SPLP East	Solid	1633	640945
LB 240-640945/1-B	Method Blank	SPLP East	Solid	1633	640945
MB 240-640965/1-A	Method Blank	Total/NA	Solid	1633	
LCS 240-640965/3-A	Lab Control Sample	Total/NA	Solid	1633	
LLCS 240-640965/2-A	Lab Control Sample	Total/NA	Solid	1633	

Analysis Batch: 641035

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
620-23136-1	MW1	SPLP East	Solid	1633	640965
620-23136-2	PC1	SPLP East	Solid	1633	640965

Eurofins Rhode Island

QC Association Summary

Client: University of New Hampshire
Project/Site: Asphalt Shingles Testing

Job ID: 620-23136-1

LCMS (Continued)

Analysis Batch: 641035 (Continued)

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
LB 240-640945/1-B	Method Blank	SPLP East	Solid	1633	640965
MB 240-640965/1-A	Method Blank	Total/NA	Solid	1633	640965
LCS 240-640965/3-A	Lab Control Sample	Total/NA	Solid	1633	640965
LLCS 240-640965/2-A	Lab Control Sample	Total/NA	Solid	1633	640965

Lab Chronicle

Client: University of New Hampshire
Project/Site: Asphalt Shingles Testing

Job ID: 620-23136-1

Client Sample ID: MW1

Lab Sample ID: 620-23136-1

Date Collected: 12/20/24 15:15

Matrix: Solid

Date Received: 12/31/24 11:52

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Analyst	Lab	Prepared or Analyzed
SPLP East	Leach	1312			42987	DJW	EET RI	01/02/25 10:34
SPLP East	Prep	3510C			43019	AAH	EET RI	01/03/25 10:26
SPLP East	Analysis	8270E		1	43022	BJJ	EET RI	01/03/25 21:43
SPLP East	Leach	1312			42987	DJW	EET RI	01/02/25 10:34
SPLP East	Prep	3510C			43020	CAC	EET RI	01/03/25 11:17
SPLP East	Analysis	8082A		1	43052	BMH	EET RI	01/06/25 14:34
SPLP East	Leach	1312			640636	KLE	EET CLE	01/05/25 14:55
SPLP East	Prep	1633			640762	KML	EET CLE	01/07/25 08:18
SPLP East	Analysis	1633		1	640803	C4KB	EET CLE	01/07/25 16:41
SPLP East	Leach	1312			640945	VFF2	EET CLE	01/08/25 16:25
SPLP East	Prep	1633			640965	JVB4	EET CLE	01/09/25 13:58
SPLP East	Analysis	1633		1	641035	C4KB	EET CLE	01/09/25 19:55

Client Sample ID: PC1

Lab Sample ID: 620-23136-2

Date Collected: 12/20/24 15:15

Matrix: Solid

Date Received: 12/31/24 11:52

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Analyst	Lab	Prepared or Analyzed
SPLP East	Leach	1312			42987	DJW	EET RI	01/02/25 10:34
SPLP East	Prep	3510C			43019	AAH	EET RI	01/03/25 10:26
SPLP East	Analysis	8270E		1	43022	BJJ	EET RI	01/03/25 22:41
SPLP East	Leach	1312			42987	DJW	EET RI	01/02/25 10:34
SPLP East	Prep	3510C			43020	CAC	EET RI	01/03/25 11:17
SPLP East	Analysis	8082A		1	43052	BMH	EET RI	01/06/25 14:52
SPLP East	Leach	1312			640636	KLE	EET CLE	01/05/25 14:55
SPLP East	Prep	1633			640762	KML	EET CLE	01/07/25 08:18
SPLP East	Analysis	1633		1	640803	C4KB	EET CLE	01/07/25 16:58
SPLP East	Leach	1312			640945	VFF2	EET CLE	01/08/25 16:25
SPLP East	Prep	1633			640965	JVB4	EET CLE	01/09/25 13:58
SPLP East	Analysis	1633		1	641035	C4KB	EET CLE	01/09/25 20:11

Laboratory References:

EET CLE = Eurofins Cleveland, 180 S. Van Buren Avenue, Barberton, OH 44203, TEL (330)497-9396

EET RI = Eurofins Rhode Island, 646 Camp Ave, North Kingstown, RI 02852, TEL (413)789-9018

Accreditation/Certification Summary

Client: University of New Hampshire
Project/Site: Asphalt Shingles Testing

Job ID: 620-23136-1

Laboratory: Eurofins Rhode Island

Unless otherwise noted, all analytes for this laboratory were covered under each accreditation/certification below.

Authority	Program	Identification Number	Expiration Date
New Hampshire	NELAP	2245	09-17-25

The following analytes are included in this report, but the laboratory is not certified by the governing authority. This list may include analytes for which the agency does not offer certification.

Analysis Method	Prep Method	Matrix	Analyte
8270E	3510C	Solid	1-Methylnaphthalene

Laboratory: Eurofins Cleveland

The accreditations/certifications listed below are applicable to this report.

Authority	Program	Identification Number	Expiration Date
New Hampshire	NELAP	225024	09-30-25

Method Summary

Client: University of New Hampshire
Project/Site: Asphalt Shingles Testing

Job ID: 620-23136-1

Method	Method Description	Protocol	Laboratory
8270E	Semivolatile Organic Compounds (GC/MS)	SW846	EET RI
8082A	Polychlorinated Biphenyls (PCBs) by Gas Chromatography	SW846	EET RI
1633	Per- and Polyfluoroalkyl Substances by LC/MS/MS	EPA	EET CLE
1312	SPLP Extraction	SW846	EET CLE
1312	SPLP Extraction	SW846	EET RI
1633	Solid-Phase Extraction (SPE)	EPA	EET CLE
3510C	Liquid-Liquid Extraction (Separatory Funnel)	SW846	EET RI

Protocol References:

EPA = US Environmental Protection Agency

SW846 = "Test Methods For Evaluating Solid Waste, Physical/Chemical Methods", Third Edition, November 1986 And Its Updates.

Laboratory References:

EET CLE = Eurofins Cleveland, 180 S. Van Buren Avenue, Barberton, OH 44203, TEL (330)497-9396

EET RI = Eurofins Rhode Island, 646 Camp Ave, North Kingstown, RI 02852, TEL (413)789-9018

Sample Summary

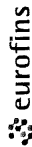
Client: University of New Hampshire
Project/Site: Asphalt Shingles Testing

Job ID: 620-23136-1

Lab Sample ID	Client Sample ID	Matrix	Collected	Received
620-23136-1	MW1	Solid	12/20/24 15:15	12/31/24 11:52
620-23136-2	PC1	Solid	12/20/24 15:15	12/31/24 11:52

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Chain of Custody Record



Client Information		Sampler F. BISANTI		Lab PM Huntley, Agnes R		Carrier Tracking No(s)		COC No 620-21136-3140 1	
Client Contact Eshan Dave		Phone 603 862 5268		E-Mail Agnes.Huntley@eurofins.com		State of Origin NH		Page Page 1 of 1	
Company University of New Hampshire		PWSID		Analysis Requested		Job #			
Address Dept of Civil & Env Engineering 33 Academic Way W173 Kings		Due Date Requested:		1633_Final - 1633 Standard List 40		Preservation Codes: N - None			
City Durham		TAT Requested (days):		Field Filtered Sample (Yes or No)		Total Number of Containers		Special Instructions/Note:	
State, Zip NH, 03824		Compliance Project: ☐ Yes ☐ No		8082A, 8270E					
Phone 603-862-5268(Tel)		PO #		Preservation Code					
Email Eshan.Dave@unh.edu		Advance Payment Required		Sample Type (C=Comp, G=grab)					
Project Name Asphalt Shingles Testing		WO #		Sample Date					
Site		SSOW#		Sample Time					
Sample Identification		Sample Date		Sample Time		Sample Type (C=Comp, G=grab)		Matrix (Weater, Sealed, Open/soil)	
MW1		12/20		3:15		G		Solid	
PC1		12/20		3:15		G		Solid	
									
620-23136 Chain of Custody									
Possible Hazard Identification		☒ Non-Hazard		☐ Flammable		☐ Skin Irritant		☐ Poison B	
Deliverable Requested I, II, III, IV, Other (specify)		☐ Unknown		☐ Radiological					
Empty Kit Relinquished by ESHAN DAVE		Date: 12/20/24		Time: 11:00 am		Method of Shipment: FEDEX			
Relinquished by ESHAN DAVE		Date/Time: 12/30/24		Company: UNH		Received by:		Date/Time	
Relinquished by FedEx		Date/Time: 12/31/24		Company: -		Received by: Samuel Buda		Date/Time: 12/31/24	
Relinquished by		Date/Time		Company		Received by:		Date/Time	
Custody Seals Intact.		Custody Seal No		Cooler Temperature(s) °C and Other Remarks		3.4 + 0.2		3.6 #6	
☐ Yes ☐ No									

- 1
- 2
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- 8
- 9
- 10
- 11
- 12
- 13
- 14
- 15
- 16

Client Indeck E.I.

Site Name _____

Cooler unpacked by _____

Cooler Received on 11/3/25Opened on 11/3/25TFFedEx: 1st Grd (Exp)

UPS FAS Waypoint

Client Drop Off

Eurofins Courier

Other _____

Receipt After-hours Drop-off Date/Time _____

Storage Location _____

Eurofins Cooler # 4C

Foam Box

Client Cooler

Box

Other _____

Packing material used: Bubble Wrap

Foam

Plastic Bag

(None)

Other _____

COOLANT: (Wet Ice)

Blue Ice

Dry Ice

Water

None

1 Cooler temperature upon receipt _____

☐ See Multiple Cooler FormIR GUN # 13

(CF +0.0 °C)

Observed Cooler Temp 0.4 °CCorrected Cooler Temp 0.4 °C2. Were tamper/custody seals on the outside of the cooler(s)? If Yes Quantity 1☒ Yes ☒ No ☐ NA

-Were the seals on the outside of the cooler(s) signed & dated?

☒ Yes ☒ No ☐ NA

-Were tamper/custody seals on the bottle(s) or bottle kits (LLHg/MeHg)?

☒ Yes ☒ No ☐ NA

-Were tamper/custody seals intact and uncompromised?

☒ Yes ☒ No ☐ NA

3 Shippers' packing slip attached to the cooler(s)?

☒ Yes ☒ No ☐ NA

4 Did custody papers accompany the sample(s)?

☒ Yes ☒ No ☐ NA

5 Were the custody papers relinquished & signed in the appropriate place?

☒ Yes ☒ No ☐ NA

6 Was/were the person(s) who collected the samples clearly identified on the COC?

☒ Yes ☒ No ☐ NA

7 Did all bottles arrive in good condition (Unbroken)?

☒ Yes ☒ No ☐ NA

8 Could all bottle labels (ID/Date/Time) be reconciled with the COC?

☒ Yes ☒ No ☐ NA

9 For each sample, does the COC specify preservatives (Y/N), # of containers (N), and sample type of grab/comp (N)?

☒ Yes ☒ No ☐ NA

10 Were correct bottle(s) used for the test(s) indicated?

☒ Yes ☒ No ☐ NA

11 Sufficient quantity received to perform indicated analyses?

☒ Yes ☒ No ☐ NA

12 Are these work share samples and all listed on the COC?

☒ Yes ☒ No ☐ NA

If yes, Questions 13-17 have been checked at the originating laboratory

13 Were all preserved sample(s) at the correct pH upon receipt?

☒ Yes ☒ No ☐ NA

14 Were VOAs on the COC?

☒ Yes ☒ No ☐ NA15 Were air bubbles >6 mm in any VOA vials?  Larger than this.☒ Yes ☒ No ☐ NA

16 Was a VOA trip blank present in the cooler(s)? Trip Blank Lot # _____

☒ Yes ☒ No ☐ NA

17 Was a LL Hg or Me Hg trip blank present? _____

☒ Yes ☒ No ☐ NA

Contacted PM _____ Date _____ by _____ via Verbal Voice Mail Other _____

Concerning _____

18. CHAIN OF CUSTODY & SAMPLE DISCREPANCIES

☐ additional next page

Samples processed by _____

19. SAMPLE CONDITION

Sample(s) _____ were received after the recommended holding time had expired.

Sample(s) _____ were received in a broken container

Sample(s) _____ were received with bubble >6 mm in diameter (Notify PM)

20. SAMPLE PRESERVATION

Sample(s) _____ were further preserved in the laboratory

Time preserved. _____ Preservative(s) added/Lot number(s). _____

VOA Sample Preservation - Date/Time VOAs Frozen. _____

1
2
3
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7
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11
12
13
14
15
16

UNIQUE ID: 123456789
SAMPLE RECEIVING
EUROFINS NEW ENGLAND
646 CAMP AVE
NORTH KINGSTOWN, RI 02881
UNITED STATES

ONE PASS ONLY
ACTIVATED
CAP: 100282METAB55

BLK SENDER

TO: **SAMPLE RECEIVING**
EUROFINS ENVIRONMENT CLEVELAND
180 S. VAN BUREN AVENUE

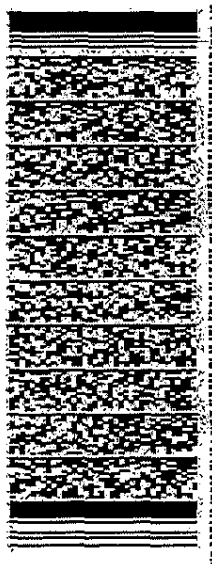
BARBERTON OH 44203

REF: WORKSHARE 1.2

PO:

DEPT:

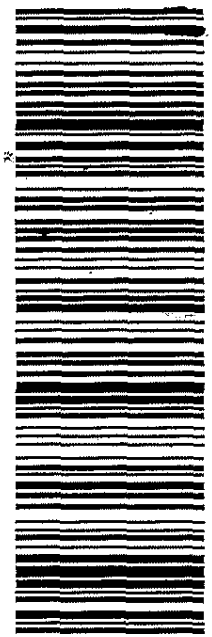
58CJ5/49B9/C8C4



TRK# 7711 6816 7520
0201

FRI - 03 JAN 12:00P
PRIORITY OVERNIGHT

XS CAKA
44203
OH-US CLE



Login Sample Receipt Checklist

Client: Cash in Advance (Rhode Island)

Job Number: 620-23136-1

Login Number: 23136

List Source: Eurofins Rhode Island

List Number: 1

Creator: Makhoul, Elie

Question	Answer	Comment
Radioactivity wasn't checked or is $\leq$ background as measured by a survey meter.	N/A	
The cooler's custody seal, if present, is intact.	N/A	
Sample custody seals, if present, are intact.	N/A	
The cooler or samples do not appear to have been compromised or tampered with.	True	
Samples were received on ice.	True	
Cooler Temperature is acceptable.	True	
Cooler Temperature is recorded.	True	
COC is present.	True	
COC is filled out in ink and legible.	True	
COC is filled out with all pertinent information.	True	
Is the Field Sampler's name present on COC?	True	
There are no discrepancies between the containers received and the COC.	True	
Samples are received within Holding Time (excluding tests with immediate HTs)	True	
Sample containers have legible labels.	True	
Containers are not broken or leaking.	True	
Sample collection date/times are provided.	True	
Appropriate sample containers are used.	True	
Sample bottles are completely filled.	True	
Sample Preservation Verified.	True	
There is sufficient vol. for all requested analyses, incl. any requested MS/MSDs	True	
Containers requiring zero headspace have no headspace or bubble is $<6\text{mm}$ (1/4").	True	
Multiphasic samples are not present.	True	
Samples do not require splitting or compositing.	True	
Residual Chlorine Checked.	N/A	

Appendix B - Synthetic Precipitation Leaching Procedure (SPLP) results – C-J FDR and C-J + 5% PC RAS

ANALYTICAL REPORT

PREPARED FOR

Attn: Eshan Dave
University of New Hampshire
Dept. of Civil & Env. Engineering
33 Academic Way
W173 Kingsbury Hall
Durham, New Hampshire 03824

Generated 1/7/2026 4:08:26 AM

JOB DESCRIPTION

YT 01 OT FDR

JOB NUMBER

620-32232-1

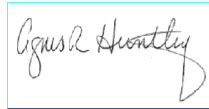
Eurofins Rhode Island

Job Notes

This report may not be reproduced except in full, and with written approval from the laboratory. The results relate only to the samples tested. For questions please contact the Project Manager at the e-mail address or telephone number listed on this page.

The test results in this report relate only to the samples as received by the laboratory and will meet all requirements of the methodology, with any exceptions noted. This report shall not be reproduced except in full, without the express written approval of the laboratory. All questions should be directed to the Eurofins Environment Testing Northeast, LLC Project Manager.

Authorization



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1/7/2026 4:08:26 AM

Authorized for release by
Agnes Huntley, Project Manager
Agnes.Huntley@et.eurofinsus.com
(401)267-4374

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Definitions/Glossary

Client: University of New Hampshire
Project/Site: YT 01 OT FDR

Job ID: 620-32232-1

Qualifiers

LCMS

Qualifier	Qualifier Description
*+	LCS and/or LCSD is outside acceptance limits, high biased.
*5+	Isotope dilution analyte is outside acceptance limits, high biased.

Glossary

Abbreviation	These commonly used abbreviations may or may not be present in this report.
☼	Listed under the "D" column to designate that the result is reported on a dry weight basis
%R	Percent Recovery
CFL	Contains Free Liquid
CFU	Colony Forming Unit
CNF	Contains No Free Liquid
DER	Duplicate Error Ratio (normalized absolute difference)
Dil Fac	Dilution Factor
DL	Detection Limit (DoD/DOE)
DL, RA, RE, IN	Indicates a Dilution, Re-analysis, Re-extraction, or additional Initial metals/anion analysis of the sample
DLC	Decision Level Concentration (Radiochemistry)
EDL	Estimated Detection Limit (Dioxin)
LOD	Limit of Detection (DoD/DOE)
LOQ	Limit of Quantitation (DoD/DOE)
MCL	EPA recommended "Maximum Contaminant Level"
MDA	Minimum Detectable Activity (Radiochemistry)
MDC	Minimum Detectable Concentration (Radiochemistry)
MDL	Method Detection Limit
ML	Minimum Level (Dioxin)
MPN	Most Probable Number
MQL	Method Quantitation Limit
NC	Not Calculated
ND	Not Detected at the reporting limit (or MDL or EDL if shown)
NEG	Negative / Absent
POS	Positive / Present
PQL	Practical Quantitation Limit
PRES	Presumptive
QC	Quality Control
RER	Relative Error Ratio (Radiochemistry)
RL	Reporting Limit or Requested Limit (Radiochemistry)
RPD	Relative Percent Difference, a measure of the relative difference between two points
TEF	Toxicity Equivalent Factor (Dioxin)
TEQ	Toxicity Equivalent Quotient (Dioxin)
TNTC	Too Numerous To Count

Case Narrative

Client: University of New Hampshire
Project: YT 01 OT FDR

Job ID: 620-32232-1

Job ID: 620-32232-1

Eurofins Rhode Island

Job Narrative 620-32232-1

The analytical test results presented in this report meet all requirements of the associated regulatory program listed on the Accreditation/Certification Summary Page, unless otherwise noted. Data qualifiers and/or narrative comments are included to explain any exceptions, if applicable. Regulated compliance samples (e.g. SDWA, NPDES) must comply with associated agency requirements/permits.

- Matrix-specific batch QC (e.g., MS, MSD, SD) may not be reported when insufficient sample volume is available or when site-specific QC samples are not submitted. In such cases, a Laboratory Control Sample Duplicate (LCSD) may be analyzed to provide precision data for the batch.
- For samples analyzed using surrogate and/or isotope dilution analytes, any recoveries falling outside of established acceptance criteria are re-prepared and/or re-analyzed to confirm results, unless the deviation is due to sample dilution or otherwise explained in the case narrative.

Receipt

The samples were received on 12/26/2025 11:30 AM. Unless otherwise noted below, the samples arrived in good condition, and, where required, properly preserved and on ice. The temperature of the cooler at receipt time was 0.7°C.

PCBs

No additional analytical or quality issues were noted, other than those described above or in the Definitions/ Glossary page.

PFAS

Method 1633_Final - SPLP East: The recovery for a target analyte(s) N-methylperfluorooctanesulfonamidoacetic acid (NMeFOSAA) in the laboratory control spike samples associated with the following samples: FDR-Labelled-1&-2 (620-32232-1) and PCRAS-Labelled-1&-2 (620-32232-2) is outside the QC acceptance limits. Since the recovery is high and the native analyte is not detected in the sample, the data is reported.

Method 1633_Final - SPLP East: The labeled isotopes 13C2 4:2 FTS and 13C2 6:2 FTS are outside QC acceptance limits. Since the recovery in sample FDR-Labelled-1&-2 (620-32232-1) is less than 350%, the data is reported.

No additional analytical or quality issues were noted, other than those described above or in the Definitions/ Glossary page.

Eurofins Rhode Island

Detection Summary

Client: University of New Hampshire
Project/Site: YT 01 OT FDR

Job ID: 620-32232-1

Client Sample ID: FDR-Labelled-1&-2

Lab Sample ID: 620-32232-1

No Detections.

Client Sample ID: PCRAS-Labelled-1&-2

Lab Sample ID: 620-32232-2

Analyte	Result	Qualifier	RL	Unit	Dil Fac	D	Method	Prep Type
Perfluorooctanesulfonic acid (PFOS)	5.17		1.90	ng/L	1		1633	SPLP East

Client Sample Results

Client: University of New Hampshire
Project/Site: YT 01 OT FDR

Job ID: 620-32232-1

Client Sample ID: FDR-Labelled-1&-2

Lab Sample ID: 620-32232-1

Date Collected: 12/18/25 16:00

Matrix: Solid

Date Received: 12/26/25 11:30

Method: SW846 8082A - Polychlorinated Biphenyls (PCBs) by Gas Chromatography - SPLP East

Analyte	Result	Qualifier	RL	Unit	D	Prepared	Analyzed	Dil Fac
PCB-1016	ND		0.400	ug/L		12/31/25 10:40	12/31/25 16:48	1
PCB-1221	ND		0.400	ug/L		12/31/25 10:40	12/31/25 16:48	1
PCB-1232	ND		0.400	ug/L		12/31/25 10:40	12/31/25 16:48	1
PCB-1242	ND		0.400	ug/L		12/31/25 10:40	12/31/25 16:48	1
PCB-1248	ND		0.400	ug/L		12/31/25 10:40	12/31/25 16:48	1
PCB-1254	ND		0.400	ug/L		12/31/25 10:40	12/31/25 16:48	1
PCB-1260	ND		0.400	ug/L		12/31/25 10:40	12/31/25 16:48	1
PCB-1262	ND		0.400	ug/L		12/31/25 10:40	12/31/25 16:48	1
PCB-1268	ND		0.400	ug/L		12/31/25 10:40	12/31/25 16:48	1

Surrogate	%Recovery	Qualifier	Limits	Prepared	Analyzed	Dil Fac
Tetrachloro-m-xylene	84		30 - 150	12/31/25 10:40	12/31/25 16:48	1
DCB Decachlorobiphenyl (Surr)	74		30 - 150	12/31/25 10:40	12/31/25 16:48	1

Method: EPA 1633 - Per- and Polyfluoroalkyl Substances by LC/MS/MS - SPLP East

Analyte	Result	Qualifier	RL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		3.82	ng/L		12/31/25 12:30	01/01/26 01:47	1
Perfluoropentanoic acid (PFPeA)	ND		1.91	ng/L		12/31/25 12:30	01/01/26 01:47	1
Perfluorohexanoic acid (PFHxA)	ND		1.91	ng/L		12/31/25 12:30	01/01/26 01:47	1
Perfluoroheptanoic acid (PFHpA)	ND		1.91	ng/L		12/31/25 12:30	01/01/26 01:47	1
Perfluorooctanoic acid (PFOA)	ND		1.91	ng/L		12/31/25 12:30	01/01/26 01:47	1
Perfluorononanoic acid (PFNA)	ND		1.91	ng/L		12/31/25 12:30	01/01/26 01:47	1
Perfluorodecanoic acid (PFDA)	ND		1.91	ng/L		12/31/25 12:30	01/01/26 01:47	1
Perfluoroundecanoic acid (PFUnA)	ND		1.91	ng/L		12/31/25 12:30	01/01/26 01:47	1
Perfluorododecanoic acid (PFDoA)	ND		1.91	ng/L		12/31/25 12:30	01/01/26 01:47	1
Perfluorotridecanoic acid (PFTriDA)	ND		1.91	ng/L		12/31/25 12:30	01/01/26 01:47	1
Perfluorotetradecanoic acid (PFTeDA)	ND		1.91	ng/L		12/31/25 12:30	01/01/26 01:47	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.91	ng/L		12/31/25 12:30	01/01/26 01:47	1
Perfluoropentanesulfonic acid (PFPeS)	ND		1.91	ng/L		12/31/25 12:30	01/01/26 01:47	1
Perfluorohexanesulfonic acid (PFHxS)	ND		1.91	ng/L		12/31/25 12:30	01/01/26 01:47	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		1.91	ng/L		12/31/25 12:30	01/01/26 01:47	1
Perfluorooctanesulfonic acid (PFOS)	ND		1.91	ng/L		12/31/25 12:30	01/01/26 01:47	1
Perfluorononanesulfonic acid (PFNS)	ND		1.91	ng/L		12/31/25 12:30	01/01/26 01:47	1
Perfluorodecanesulfonic acid (PFDS)	ND		1.91	ng/L		12/31/25 12:30	01/01/26 01:47	1
Perfluorododecanesulfonic acid (PFDoS)	ND		1.91	ng/L		12/31/25 12:30	01/01/26 01:47	1
1H,1H,2H,2H-Perfluorohexane sulfonic acid (4:2 FTS)	ND		3.82	ng/L		12/31/25 12:30	01/01/26 01:47	1
1H,1H,2H,2H-Perfluorooctane sulfonic acid (6:2 FTS)	ND		3.82	ng/L		12/31/25 12:30	01/01/26 01:47	1
1H,1H,2H,2H-Perfluorodecane sulfonic acid (8:2 FTS)	ND		3.82	ng/L		12/31/25 12:30	01/01/26 01:47	1
Perfluorooctanesulfonamide (PFOSA)	ND		1.91	ng/L		12/31/25 12:30	01/01/26 01:47	1
N-methylperfluorooctane sulfonamide (NMeFOSA)	ND		1.91	ng/L		12/31/25 12:30	01/01/26 01:47	1
N-ethylperfluorooctane sulfonamide (NEtFOSA)	ND		1.91	ng/L		12/31/25 12:30	01/01/26 01:47	1
N-methylperfluorooctanesulfonamidoacetic acid (NMeFOSAA)	ND	*+	1.91	ng/L		12/31/25 12:30	01/01/26 01:47	1

Eurofins Rhode Island

Client Sample Results

Client: University of New Hampshire
Project/Site: YT 01 OT FDR

Job ID: 620-32232-1

Client Sample ID: FDR-Labelled-1&-2

Lab Sample ID: 620-32232-1

Date Collected: 12/18/25 16:00

Matrix: Solid

Date Received: 12/26/25 11:30

Method: EPA 1633 - Per- and Polyfluoroalkyl Substances by LC/MS/MS - SPLP East (Continued)

Analyte	Result	Qualifier	RL	Unit	D	Prepared	Analyzed	Dil Fac
N-ethylperfluorooctanesulfonamidoacetic acid (NEtFOSAA)	ND		1.91	ng/L		12/31/25 12:30	01/01/26 01:47	1
N-methylperfluorooctane sulfonamidoethanol (NMeFOSE)	ND		9.55	ng/L		12/31/25 12:30	01/01/26 01:47	1
N-ethylperfluorooctane sulfonamidoethanol (NEtFOSE)	ND		9.55	ng/L		12/31/25 12:30	01/01/26 01:47	1
Hexafluoropropylene Oxide Dimer Acid (HFPO-DA)	ND		1.91	ng/L		12/31/25 12:30	01/01/26 01:47	1
4,8-Dioxa-3H-perfluorononanoic acid (ADONA)	ND		1.91	ng/L		12/31/25 12:30	01/01/26 01:47	1
Perfluoro-3-methoxypropanoic acid (PFMPA)	ND		1.91	ng/L		12/31/25 12:30	01/01/26 01:47	1
Perfluoro-4-methoxybutanoic acid (PFMBA)	ND		1.91	ng/L		12/31/25 12:30	01/01/26 01:47	1
Nonafluoro-3,6-dioxaheptanoic acid (NFDHA)	ND		1.91	ng/L		12/31/25 12:30	01/01/26 01:47	1
9-Chlorohexadecafluoro-3-oxanonane-1-sulfonic acid (9Cl-PF3ONS)	ND		1.91	ng/L		12/31/25 12:30	01/01/26 01:47	1
11-Chloroeicosafluoro-3-oxaundecane-1-sulfonic acid (11Cl-PF3OUdS)	ND		1.91	ng/L		12/31/25 12:30	01/01/26 01:47	1
Perfluoro (2-ethoxyethane) sulfonic acid (PFEESA)	ND		1.91	ng/L		12/31/25 12:30	01/01/26 01:47	1
3-Perfluoropropylpropanoic acid (3:3 FTCA)	ND		3.82	ng/L		12/31/25 12:30	01/01/26 01:47	1
3-Perfluoropentylpropanoic acid (5:3 FTCA)	ND		9.55	ng/L		12/31/25 12:30	01/01/26 01:47	1
3-Perfluoroheptylpropanoic acid (7:3 FTCA)	ND		9.55	ng/L		12/31/25 12:30	01/01/26 01:47	1

Isotope Dilution	%Recovery	Qualifier	Limits	Prepared	Analyzed	Dil Fac
13C4-PFBA	92.5		5 - 130	12/31/25 12:30	01/01/26 01:47	1
13C5-PFPeA	102		40 - 130	12/31/25 12:30	01/01/26 01:47	1
13C5-PFHxA	100		40 - 130	12/31/25 12:30	01/01/26 01:47	1
13C4-PFHpA	93.1		40 - 130	12/31/25 12:30	01/01/26 01:47	1
13C8-PFOA	94.0		40 - 130	12/31/25 12:30	01/01/26 01:47	1
13C9-PFNA	105		40 - 130	12/31/25 12:30	01/01/26 01:47	1
13C6-PFDA	100		40 - 130	12/31/25 12:30	01/01/26 01:47	1
13C7-PFUnA	100		30 - 130	12/31/25 12:30	01/01/26 01:47	1
13C2-PFTeDA	98.7		10 - 130	12/31/25 12:30	01/01/26 01:47	1
13C3-PFBS	109		40 - 135	12/31/25 12:30	01/01/26 01:47	1
13C3-PFHxS	111		40 - 130	12/31/25 12:30	01/01/26 01:47	1
13C8-PFOS	89.1		40 - 130	12/31/25 12:30	01/01/26 01:47	1
13C8-PFOSA	104		40 - 130	12/31/25 12:30	01/01/26 01:47	1
d3-NMeFOSAA	111		40 - 170	12/31/25 12:30	01/01/26 01:47	1
d5-NEtFOSAA	118		25 - 135	12/31/25 12:30	01/01/26 01:47	1
13C2 4:2 FTS	226	*5+	40 - 200	12/31/25 12:30	01/01/26 01:47	1
13C2 6:2 FTS	206	*5+	40 - 200	12/31/25 12:30	01/01/26 01:47	1
13C2 8:2 FTS	199		40 - 300	12/31/25 12:30	01/01/26 01:47	1
13C3-HFPO-DA	89.4		40 - 130	12/31/25 12:30	01/01/26 01:47	1
D7-NMeFOSE	89.6		10 - 130	12/31/25 12:30	01/01/26 01:47	1
D9-NEtFOSE	80.8		10 - 130	12/31/25 12:30	01/01/26 01:47	1
d5-NEtPFOSA	68.9		10 - 130	12/31/25 12:30	01/01/26 01:47	1
d3-NMePFOSA	81.6		10 - 130	12/31/25 12:30	01/01/26 01:47	1
13C2 PFDoA	95.2		10 - 130	12/31/25 12:30	01/01/26 01:47	1

Eurofins Rhode Island

Client Sample Results

Client: University of New Hampshire
Project/Site: YT 01 OT FDR

Job ID: 620-32232-1

Client Sample ID: PCRAS-Labelled-1&-2

Lab Sample ID: 620-32232-2

Date Collected: 12/18/25 16:00

Matrix: Solid

Date Received: 12/26/25 11:30

Method: SW846 8082A - Polychlorinated Biphenyls (PCBs) by Gas Chromatography - SPLP East

Analyte	Result	Qualifier	RL	Unit	D	Prepared	Analyzed	Dil Fac
PCB-1016	ND		0.400	ug/L		12/31/25 10:40	12/31/25 17:05	1
PCB-1221	ND		0.400	ug/L		12/31/25 10:40	12/31/25 17:05	1
PCB-1232	ND		0.400	ug/L		12/31/25 10:40	12/31/25 17:05	1
PCB-1242	ND		0.400	ug/L		12/31/25 10:40	12/31/25 17:05	1
PCB-1248	ND		0.400	ug/L		12/31/25 10:40	12/31/25 17:05	1
PCB-1254	ND		0.400	ug/L		12/31/25 10:40	12/31/25 17:05	1
PCB-1260	ND		0.400	ug/L		12/31/25 10:40	12/31/25 17:05	1
PCB-1262	ND		0.400	ug/L		12/31/25 10:40	12/31/25 17:05	1
PCB-1268	ND		0.400	ug/L		12/31/25 10:40	12/31/25 17:05	1

Surrogate	%Recovery	Qualifier	Limits	Prepared	Analyzed	Dil Fac
Tetrachloro-m-xylene	88		30 - 150	12/31/25 10:40	12/31/25 17:05	1
DCB Decachlorobiphenyl (Surr)	77		30 - 150	12/31/25 10:40	12/31/25 17:05	1

Method: EPA 1633 - Per- and Polyfluoroalkyl Substances by LC/MS/MS - SPLP East

Analyte	Result	Qualifier	RL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		3.79	ng/L		12/31/25 12:30	01/01/26 02:01	1
Perfluoropentanoic acid (PFPeA)	ND		1.90	ng/L		12/31/25 12:30	01/01/26 02:01	1
Perfluorohexanoic acid (PFHxA)	ND		1.90	ng/L		12/31/25 12:30	01/01/26 02:01	1
Perfluoroheptanoic acid (PFHpA)	ND		1.90	ng/L		12/31/25 12:30	01/01/26 02:01	1
Perfluorooctanoic acid (PFOA)	ND		1.90	ng/L		12/31/25 12:30	01/01/26 02:01	1
Perfluorononanoic acid (PFNA)	ND		1.90	ng/L		12/31/25 12:30	01/01/26 02:01	1
Perfluorodecanoic acid (PFDA)	ND		1.90	ng/L		12/31/25 12:30	01/01/26 02:01	1
Perfluoroundecanoic acid (PFUnA)	ND		1.90	ng/L		12/31/25 12:30	01/01/26 02:01	1
Perfluorododecanoic acid (PFDoA)	ND		1.90	ng/L		12/31/25 12:30	01/01/26 02:01	1
Perfluorotridecanoic acid (PFTrDA)	ND		1.90	ng/L		12/31/25 12:30	01/01/26 02:01	1
Perfluorotetradecanoic acid (PFTeDA)	ND		1.90	ng/L		12/31/25 12:30	01/01/26 02:01	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.90	ng/L		12/31/25 12:30	01/01/26 02:01	1
Perfluoropentanesulfonic acid (PFPeS)	ND		1.90	ng/L		12/31/25 12:30	01/01/26 02:01	1
Perfluorohexanesulfonic acid (PFHxS)	ND		1.90	ng/L		12/31/25 12:30	01/01/26 02:01	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		1.90	ng/L		12/31/25 12:30	01/01/26 02:01	1
Perfluorooctanesulfonic acid (PFOS)	5.17		1.90	ng/L		12/31/25 12:30	01/01/26 02:01	1
Perfluorononanesulfonic acid (PFNS)	ND		1.90	ng/L		12/31/25 12:30	01/01/26 02:01	1
Perfluorodecanesulfonic acid (PFDS)	ND		1.90	ng/L		12/31/25 12:30	01/01/26 02:01	1
Perfluorododecanesulfonic acid (PFDoS)	ND		1.90	ng/L		12/31/25 12:30	01/01/26 02:01	1
1H,1H,2H,2H-Perfluorohexane sulfonic acid (4:2 FTS)	ND		3.79	ng/L		12/31/25 12:30	01/01/26 02:01	1
1H,1H,2H,2H-Perfluorooctane sulfonic acid (6:2 FTS)	ND		3.79	ng/L		12/31/25 12:30	01/01/26 02:01	1
1H,1H,2H,2H-Perfluorodecane sulfonic acid (8:2 FTS)	ND		3.79	ng/L		12/31/25 12:30	01/01/26 02:01	1
Perfluorooctanesulfonamide (PFOSA)	ND		1.90	ng/L		12/31/25 12:30	01/01/26 02:01	1
N-methylperfluorooctane sulfonamide (NMeFOSA)	ND		1.90	ng/L		12/31/25 12:30	01/01/26 02:01	1
N-ethylperfluorooctane sulfonamide (NEtFOSA)	ND		1.90	ng/L		12/31/25 12:30	01/01/26 02:01	1
N-methylperfluorooctanesulfonamidoacetic acid (NMeFOSAA)	ND	+	1.90	ng/L		12/31/25 12:30	01/01/26 02:01	1

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Client Sample Results

Client: University of New Hampshire
Project/Site: YT 01 OT FDR

Job ID: 620-32232-1

Client Sample ID: PCRAS-Labelled-1&-2

Lab Sample ID: 620-32232-2

Date Collected: 12/18/25 16:00

Matrix: Solid

Date Received: 12/26/25 11:30

Method: EPA 1633 - Per- and Polyfluoroalkyl Substances by LC/MS/MS - SPLP East (Continued)

Analyte	Result	Qualifier	RL	Unit	D	Prepared	Analyzed	Dil Fac
N-ethylperfluorooctanesulfonamidoacetic acid (NEtFOSAA)	ND		1.90	ng/L		12/31/25 12:30	01/01/26 02:01	1
N-methylperfluorooctane sulfonamidoethanol (NMeFOSE)	ND		9.48	ng/L		12/31/25 12:30	01/01/26 02:01	1
N-ethylperfluorooctane sulfonamidoethanol (NEtFOSE)	ND		9.48	ng/L		12/31/25 12:30	01/01/26 02:01	1
Hexafluoropropylene Oxide Dimer Acid (HFPO-DA)	ND		1.90	ng/L		12/31/25 12:30	01/01/26 02:01	1
4,8-Dioxo-3H-perfluorononanoic acid (ADONA)	ND		1.90	ng/L		12/31/25 12:30	01/01/26 02:01	1
Perfluoro-3-methoxypropanoic acid (PFMPA)	ND		1.90	ng/L		12/31/25 12:30	01/01/26 02:01	1
Perfluoro-4-methoxybutanoic acid (PFMBA)	ND		1.90	ng/L		12/31/25 12:30	01/01/26 02:01	1
Nonafluoro-3,6-dioxaheptanoic acid (NFDHA)	ND		1.90	ng/L		12/31/25 12:30	01/01/26 02:01	1
9-Chlorohexadecafluoro-3-oxanonane-1-sulfonic acid (9Cl-PF3ONS)	ND		1.90	ng/L		12/31/25 12:30	01/01/26 02:01	1
11-Chloroeicosafluoro-3-oxaundecane-1-sulfonic acid (11Cl-PF3OUdS)	ND		1.90	ng/L		12/31/25 12:30	01/01/26 02:01	1
Perfluoro (2-ethoxyethane) sulfonic acid (PFEESA)	ND		1.90	ng/L		12/31/25 12:30	01/01/26 02:01	1
3-Perfluoropropylpropanoic acid (3:3 FTCA)	ND		3.79	ng/L		12/31/25 12:30	01/01/26 02:01	1
3-Perfluoropentylpropanoic acid (5:3 FTCA)	ND		9.48	ng/L		12/31/25 12:30	01/01/26 02:01	1
3-Perfluoroheptylpropanoic acid (7:3 FTCA)	ND		9.48	ng/L		12/31/25 12:30	01/01/26 02:01	1

Isotope Dilution	%Recovery	Qualifier	Limits	Prepared	Analyzed	Dil Fac
13C4-PFBA	87.5		5 - 130	12/31/25 12:30	01/01/26 02:01	1
13C5-PFPeA	90.2		40 - 130	12/31/25 12:30	01/01/26 02:01	1
13C5-PFHxA	90.1		40 - 130	12/31/25 12:30	01/01/26 02:01	1
13C4-PFHpA	82.1		40 - 130	12/31/25 12:30	01/01/26 02:01	1
13C8-PFOA	87.7		40 - 130	12/31/25 12:30	01/01/26 02:01	1
13C9-PFNA	102		40 - 130	12/31/25 12:30	01/01/26 02:01	1
13C6-PFDA	93.4		40 - 130	12/31/25 12:30	01/01/26 02:01	1
13C7-PFUnA	95.4		30 - 130	12/31/25 12:30	01/01/26 02:01	1
13C2-PFTeDA	89.7		10 - 130	12/31/25 12:30	01/01/26 02:01	1
13C3-PFBS	97.3		40 - 135	12/31/25 12:30	01/01/26 02:01	1
13C3-PFHxS	96.1		40 - 130	12/31/25 12:30	01/01/26 02:01	1
13C8-PFOS	84.1		40 - 130	12/31/25 12:30	01/01/26 02:01	1
13C8-PFOSA	98.0		40 - 130	12/31/25 12:30	01/01/26 02:01	1
d3-NMeFOSAA	107		40 - 170	12/31/25 12:30	01/01/26 02:01	1
d5-NEtFOSAA	113		25 - 135	12/31/25 12:30	01/01/26 02:01	1
13C2 4:2 FTS	183		40 - 200	12/31/25 12:30	01/01/26 02:01	1
13C2 6:2 FTS	185		40 - 200	12/31/25 12:30	01/01/26 02:01	1
13C2 8:2 FTS	177		40 - 300	12/31/25 12:30	01/01/26 02:01	1
13C3-HFPO-DA	85.4		40 - 130	12/31/25 12:30	01/01/26 02:01	1
D7-NMeFOSE	65.9		10 - 130	12/31/25 12:30	01/01/26 02:01	1
D9-NEtFOSE	59.6		10 - 130	12/31/25 12:30	01/01/26 02:01	1
d5-NEtPFOSA	67.4		10 - 130	12/31/25 12:30	01/01/26 02:01	1
d3-NMePFOSA	79.2		10 - 130	12/31/25 12:30	01/01/26 02:01	1
13C2 PFDoA	91.0		10 - 130	12/31/25 12:30	01/01/26 02:01	1

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Surrogate Summary

Client: University of New Hampshire
Project/Site: YT 01 OT FDR

Job ID: 620-32232-1

Method: 8082A - Polychlorinated Biphenyls (PCBs) by Gas Chromatography

Matrix: Solid

Prep Type: Total/NA

Percent Surrogate Recovery (Acceptance Limits)

Lab Sample ID	Client Sample ID	TCX1 (30-150)	DCB1 (30-150)
LCS 620-57586/2-A	Lab Control Sample	78	83
LCSD 620-57586/3-A	Lab Control Sample Dup	73	85

Surrogate Legend

TCX = Tetrachloro-m-xylene

DCB = DCB Decachlorobiphenyl (Surr)

Method: 8082A - Polychlorinated Biphenyls (PCBs) by Gas Chromatography

Matrix: Solid

Prep Type: SPLP East

Percent Surrogate Recovery (Acceptance Limits)

Lab Sample ID	Client Sample ID	TCX1 (30-150)	DCB1 (30-150)
620-32232-1	FDR-Labelled-1&-2	84	74
620-32232-2	PCRAS-Labelled-1&-2	88	77
620-32232-2 MS	PCRAS-Labelled-1&-2	92	82
MB 620-56880/1-C	Method Blank	67	70
MB 620-57457/1-B	Method Blank	91	84

Surrogate Legend

TCX = Tetrachloro-m-xylene

DCB = DCB Decachlorobiphenyl (Surr)

Isotope Dilution Summary

Client: University of New Hampshire
Project/Site: YT 01 OT FDR

Job ID: 620-32232-1

Method: 1633 - Per- and Polyfluoroalkyl Substances by LC/MS/MS

Matrix: Solid

Prep Type: Total/NA

Percent Isotope Dilution Recovery (Acceptance Limits)

Lab Sample ID	Client Sample ID	PFBA (5-130)	PFPeA (40-130)	13C5PHA (40-130)	C4PFHA (40-130)	C8PFOA (40-130)	C9PFNA (40-130)	C6PFDA (40-130)	13C7PUA (30-130)
LCS 410-751084/21-A	Lab Control Sample	80.5	81.5	78.8	81.9	81.0	89.1	86.1	93.8
LCSD 410-751084/1-A	Lab Control Sample Dup	109	110	108	106	110	114	103	106
LLCS 410-751084/2-A	Lab Control Sample	98.1	103	100	100	95.3	105	96.3	104
MB 410-751084/20-A	Method Blank	105	114	108	107	105	109	101	106

Percent Isotope Dilution Recovery (Acceptance Limits)

Lab Sample ID	Client Sample ID	PFTDA (10-130)	C3PFBS (40-135)	C3PFHS (40-130)	C8PFOS (40-130)	PFOSA (40-130)	d3NMFOS (40-170)	d5NEFOS (25-135)	M242FTS (40-200)
LCS 410-751084/21-A	Lab Control Sample	78.3	89.3	89.0	81.4	86.1	83.4	89.2	75.5
LCSD 410-751084/1-A	Lab Control Sample Dup	94.2	109	111	92.5	101	85.2	95.4	100
LLCS 410-751084/2-A	Lab Control Sample	90.7	101	103	90.2	99.0	82.2	91.3	91.4
MB 410-751084/20-A	Method Blank	89.0	108	107	92.2	111	96.9	103	97.9

Percent Isotope Dilution Recovery (Acceptance Limits)

Lab Sample ID	Client Sample ID	M262FTS (40-200)	M282FTS (40-300)	HFPODA (40-130)	NMFM (10-130)	NEFM (10-130)	d5NPFSA (10-130)	d3NMFSA (10-130)	PFDaA (10-130)
LCS 410-751084/21-A	Lab Control Sample	86.2	77.2	77.8	82.8	76.7	71.0	70.9	89.5
LCSD 410-751084/1-A	Lab Control Sample Dup	106	99.2	106	90.7	83.2	74.0	78.8	95.5
LLCS 410-751084/2-A	Lab Control Sample	98.9	90.6	92.9	88.4	82.9	79.2	84.5	95.3
MB 410-751084/20-A	Method Blank	107	87.4	102	92.9	85.8	78.7	81.3	95.2

Surrogate Legend

PFBA = 13C4-PFBA
PFPeA = 13C5-PFPeA
13C5PHA = 13C5-PFHxA
C4PFHA = 13C4-PFHpA
C8PFOA = 13C8-PFOA
C9PFNA = 13C9-PFNA
C6PFDA = 13C6-PFDA
13C7PUA = 13C7-PFUnA
PFTDA = 13C2-PFTeDA
C3PFBS = 13C3-PFBS
C3PFHS = 13C3-PFHxS
C8PFOS = 13C8-PFOS
PFOSA = 13C8-PFOSA
d3NMFOS = d3-NMeFOSAA
d5NEFOS = d5-NEtFOSAA
M242FTS = 13C2 4:2 FTS
M262FTS = 13C2 6:2 FTS
M282FTS = 13C2 8:2 FTS
HFPODA = 13C3-HFPO-DA
NMFM = D7-NMeFOSE
NEFM = D9-NEtFOSE
d5NPFSA = d5-NEtPFOSA
d3NMFSA = d3-NMePFOSA
PFDaA = 13C2 PFDaA

Isotope Dilution Summary

Client: University of New Hampshire

Job ID: 620-32232-1

Project/Site: YT 01 OT FDR

Method: 1633 - Per- and Polyfluoroalkyl Substances by LC/MS/MS

Matrix: Solid

Prep Type: SPLP East

		Percent Isotope Dilution Recovery (Acceptance Limits)							
Lab Sample ID	Client Sample ID	PFBA (5-130)	PFPeA (40-130)	13C5PHA (40-130)	C4PFHA (40-130)	C8PFOA (40-130)	C9PFNA (40-130)	C6PFDA (40-130)	13C7PUA (30-130)
620-32232-1	FDR-Labelled-1&-2	92.5	102	100	93.1	94.0	105	100	100
620-32232-2	PCRAS-Labelled-1&-2	87.5	90.2	90.1	82.1	87.7	102	93.4	95.4
LB 410-750430/1-C	Method Blank	100	107	106	103	99.2	108	104	107
		Percent Isotope Dilution Recovery (Acceptance Limits)							
Lab Sample ID	Client Sample ID	PFTDA (10-130)	C3PFBS (40-135)	C3PFHS (40-130)	C8PFOS (40-130)	PFOSA (40-130)	d3NMFOS (40-170)	d5NEFOS (25-135)	M242FTS (40-200)
620-32232-1	FDR-Labelled-1&-2	98.7	109	111	89.1	104	111	118	226 *5+
620-32232-2	PCRAS-Labelled-1&-2	89.7	97.3	96.1	84.1	98.0	107	113	183
LB 410-750430/1-C	Method Blank	91.2	104	109	89.5	103	87.8	95.6	101
		Percent Isotope Dilution Recovery (Acceptance Limits)							
Lab Sample ID	Client Sample ID	M262FTS (40-200)	M282FTS (40-300)	HFPODA (40-130)	NMFM (10-130)	NEFM (10-130)	d5NPFSA (10-130)	d3NMFSA (10-130)	PFDaA (10-130)
620-32232-1	FDR-Labelled-1&-2	206 *5+	199	89.4	89.6	80.8	68.9	81.6	95.2
620-32232-2	PCRAS-Labelled-1&-2	185	177	85.4	65.9	59.6	67.4	79.2	91.0
LB 410-750430/1-C	Method Blank	110	96.2	102	92.6	86.6	74.6	81.9	97.7
Surrogate Legend									
PFBA = 13C4-PFBA									
PFPeA = 13C5-PFPeA									
13C5PHA = 13C5-PFHxA									
C4PFHA = 13C4-PFHpA									
C8PFOA = 13C8-PFOA									
C9PFNA = 13C9-PFNA									
C6PFDA = 13C6-PFDA									
13C7PUA = 13C7-PFUnA									
PFTDA = 13C2-PFTeDA									
C3PFBS = 13C3-PFBS									
C3PFHS = 13C3-PFHxS									
C8PFOS = 13C8-PFOS									
PFOSA = 13C8-PFOSA									
d3NMFOS = d3-NMeFOSAA									
d5NEFOS = d5-NEtFOSAA									
M242FTS = 13C2 4:2 FTS									
M262FTS = 13C2 6:2 FTS									
M282FTS = 13C2 8:2 FTS									
HFPODA = 13C3-HFPO-DA									
NMFM = D7-NMeFOSE									
NEFM = D9-NEtFOSE									
d5NPFSA = d5-NEtPFOSA									
d3NMFSA = d3-NMePFOSA									
PFDaA = 13C2 PFDaA									

QC Sample Results

Client: University of New Hampshire
Project/Site: YT 01 OT FDR

Job ID: 620-32232-1

Method: 8082A - Polychlorinated Biphenyls (PCBs) by Gas Chromatography

Lab Sample ID: LCS 620-57586/2-A

Matrix: Solid

Analysis Batch: 57605

Client Sample ID: Lab Control Sample

Prep Type: Total/NA

Prep Batch: 57586

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec Limits
PCB-1016	4.00	3.683		ug/L		92	33 - 114
PCB-1260	4.00	4.046		ug/L		101	42 - 112

Surrogate	LCS %Recovery	LCS Qualifier	Limits
Tetrachloro-m-xylene	78		30 - 150
DCB Decachlorobiphenyl (Surr)	83		30 - 150

Lab Sample ID: LCSD 620-57586/3-A

Matrix: Solid

Analysis Batch: 57605

Client Sample ID: Lab Control Sample Dup

Prep Type: Total/NA

Prep Batch: 57586

Analyte	Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec Limits	RPD	RPD Limit
PCB-1016	4.00	3.923		ug/L		98	33 - 114	6	20
PCB-1260	4.00	4.343		ug/L		109	42 - 112	7	20

Surrogate	LCSD %Recovery	LCSD Qualifier	Limits
Tetrachloro-m-xylene	73		30 - 150
DCB Decachlorobiphenyl (Surr)	85		30 - 150

Lab Sample ID: MB 620-56880/1-C

Matrix: Solid

Analysis Batch: 57605

Client Sample ID: Method Blank

Prep Type: SPLP East

Prep Batch: 57586

Analyte	MB Result	MB Qualifier	RL	Unit	D	Prepared	Analyzed	Dil Fac
PCB-1016	ND		0.200	ug/L		12/31/25 10:23	12/31/25 14:12	1
PCB-1221	ND		0.200	ug/L		12/31/25 10:23	12/31/25 14:12	1
PCB-1232	ND		0.200	ug/L		12/31/25 10:23	12/31/25 14:12	1
PCB-1242	ND		0.200	ug/L		12/31/25 10:23	12/31/25 14:12	1
PCB-1248	ND		0.200	ug/L		12/31/25 10:23	12/31/25 14:12	1
PCB-1254	ND		0.200	ug/L		12/31/25 10:23	12/31/25 14:12	1
PCB-1260	ND		0.200	ug/L		12/31/25 10:23	12/31/25 14:12	1
PCB-1262	ND		0.200	ug/L		12/31/25 10:23	12/31/25 14:12	1
PCB-1268	ND		0.200	ug/L		12/31/25 10:23	12/31/25 14:12	1

Surrogate	MB %Recovery	MB Qualifier	Limits	Prepared	Analyzed	Dil Fac
Tetrachloro-m-xylene	67		30 - 150	12/31/25 10:23	12/31/25 14:12	1
DCB Decachlorobiphenyl (Surr)	70		30 - 150	12/31/25 10:23	12/31/25 14:12	1

Lab Sample ID: MB 620-57457/1-B

Matrix: Solid

Analysis Batch: 57605

Client Sample ID: Method Blank

Prep Type: SPLP East

Prep Batch: 57586

Analyte	MB Result	MB Qualifier	RL	Unit	D	Prepared	Analyzed	Dil Fac
PCB-1016	ND		0.400	ug/L		12/31/25 10:40	12/31/25 16:31	1
PCB-1221	ND		0.400	ug/L		12/31/25 10:40	12/31/25 16:31	1
PCB-1232	ND		0.400	ug/L		12/31/25 10:40	12/31/25 16:31	1
PCB-1242	ND		0.400	ug/L		12/31/25 10:40	12/31/25 16:31	1
PCB-1248	ND		0.400	ug/L		12/31/25 10:40	12/31/25 16:31	1

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QC Sample Results

Client: University of New Hampshire
Project/Site: YT 01 OT FDR

Job ID: 620-32232-1

Method: 8082A - Polychlorinated Biphenyls (PCBs) by Gas Chromatography (Continued)

Lab Sample ID: MB 620-57457/1-B

Matrix: Solid

Analysis Batch: 57605

Client Sample ID: Method Blank

Prep Type: SPLP East

Prep Batch: 57586

Analyte	MB Result	MB Qualifier	RL	Unit	D	Prepared	Analyzed	Dil Fac
PCB-1254	ND		0.400	ug/L		12/31/25 10:40	12/31/25 16:31	1
PCB-1260	ND		0.400	ug/L		12/31/25 10:40	12/31/25 16:31	1
PCB-1262	ND		0.400	ug/L		12/31/25 10:40	12/31/25 16:31	1
PCB-1268	ND		0.400	ug/L		12/31/25 10:40	12/31/25 16:31	1

Surrogate	MB %Recovery	MB Qualifier	Limits	Prepared	Analyzed	Dil Fac
Tetrachloro-m-xylene	91		30 - 150	12/31/25 10:40	12/31/25 16:31	1
DCB Decachlorobiphenyl (Surr)	84		30 - 150	12/31/25 10:40	12/31/25 16:31	1

Lab Sample ID: 620-32232-2 MS

Matrix: Solid

Analysis Batch: 57605

Client Sample ID: PCRAS-Labelled-1&-2

Prep Type: SPLP East

Prep Batch: 57586

Analyte	Sample Result	Sample Qualifier	Spike Added	MS Result	MS Qualifier	Unit	D	%Rec	%Rec Limits
PCB-1016	ND		4.00	3.930		ug/L		98	40 - 140
PCB-1260	ND		4.00	4.103		ug/L		103	40 - 140

Surrogate	MS %Recovery	MS Qualifier	Limits
Tetrachloro-m-xylene	92		30 - 150
DCB Decachlorobiphenyl (Surr)	82		30 - 150

Method: 1633 - Per- and Polyfluoroalkyl Substances by LC/MS/MS

Lab Sample ID: MB 410-751084/20-A

Matrix: Solid

Analysis Batch: 751115

Client Sample ID: Method Blank

Prep Type: Total/NA

Prep Batch: 751084

Analyte	MB Result	MB Qualifier	RL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		4.00	ng/L		12/31/25 12:30	12/31/25 21:44	1
Perfluoropentanoic acid (PFPeA)	ND		2.00	ng/L		12/31/25 12:30	12/31/25 21:44	1
Perfluorohexanoic acid (PFHxA)	ND		2.00	ng/L		12/31/25 12:30	12/31/25 21:44	1
Perfluoroheptanoic acid (PFHpA)	ND		2.00	ng/L		12/31/25 12:30	12/31/25 21:44	1
Perfluorooctanoic acid (PFOA)	ND		2.00	ng/L		12/31/25 12:30	12/31/25 21:44	1
Perfluorononanoic acid (PFNA)	ND		2.00	ng/L		12/31/25 12:30	12/31/25 21:44	1
Perfluorodecanoic acid (PFDA)	ND		2.00	ng/L		12/31/25 12:30	12/31/25 21:44	1
Perfluoroundecanoic acid (PFUnA)	ND		2.00	ng/L		12/31/25 12:30	12/31/25 21:44	1
Perfluorododecanoic acid (PFDoA)	ND		2.00	ng/L		12/31/25 12:30	12/31/25 21:44	1
Perfluorotridecanoic acid (PFTrDA)	ND		2.00	ng/L		12/31/25 12:30	12/31/25 21:44	1
Perfluorotetradecanoic acid (PFTeDA)	ND		2.00	ng/L		12/31/25 12:30	12/31/25 21:44	1
Perfluorobutanesulfonic acid (PFBS)	ND		2.00	ng/L		12/31/25 12:30	12/31/25 21:44	1
Perfluoropentanesulfonic acid (PFPeS)	ND		2.00	ng/L		12/31/25 12:30	12/31/25 21:44	1
Perfluorohexanesulfonic acid (PFHxS)	ND		2.00	ng/L		12/31/25 12:30	12/31/25 21:44	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		2.00	ng/L		12/31/25 12:30	12/31/25 21:44	1
Perfluorooctanesulfonic acid (PFOS)	ND		2.00	ng/L		12/31/25 12:30	12/31/25 21:44	1
Perfluorononanesulfonic acid (PFNS)	ND		2.00	ng/L		12/31/25 12:30	12/31/25 21:44	1
Perfluorodecanesulfonic acid (PFDS)	ND		2.00	ng/L		12/31/25 12:30	12/31/25 21:44	1

Eurofins Rhode Island

QC Sample Results

Client: University of New Hampshire
Project/Site: YT 01 OT FDR

Job ID: 620-32232-1

Method: 1633 - Per- and Polyfluoroalkyl Substances by LC/MS/MS (Continued)

Lab Sample ID: MB 410-751084/20-A

Matrix: Solid

Analysis Batch: 751115

Client Sample ID: Method Blank

Prep Type: Total/NA

Prep Batch: 751084

Analyte	MB Result	MB Qualifier	RL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorodecanesulfonic acid (PFDoS)	ND		2.00	ng/L		12/31/25 12:30	12/31/25 21:44	1
1H,1H,2H,2H-Perfluorohexane sulfonic acid (4:2 FTS)	ND		4.00	ng/L		12/31/25 12:30	12/31/25 21:44	1
1H,1H,2H,2H-Perfluorooctane sulfonic acid (6:2 FTS)	ND		4.00	ng/L		12/31/25 12:30	12/31/25 21:44	1
1H,1H,2H,2H-Perfluorodecane sulfonic acid (8:2 FTS)	ND		4.00	ng/L		12/31/25 12:30	12/31/25 21:44	1
Perfluorooctanesulfonamide (PFOSA)	ND		2.00	ng/L		12/31/25 12:30	12/31/25 21:44	1
N-methylperfluorooctane sulfonamide (NMeFOSA)	ND		2.00	ng/L		12/31/25 12:30	12/31/25 21:44	1
N-ethylperfluorooctane sulfonamide (NEtFOSA)	ND		2.00	ng/L		12/31/25 12:30	12/31/25 21:44	1
N-methylperfluorooctanesulfonamidoacetic acid (NMeFOSAA)	ND		2.00	ng/L		12/31/25 12:30	12/31/25 21:44	1
N-ethylperfluorooctanesulfonamidoacetic acid (NEtFOSAA)	ND		2.00	ng/L		12/31/25 12:30	12/31/25 21:44	1
N-methylperfluorooctane sulfonamidoethanol (NMeFOSE)	ND		10.0	ng/L		12/31/25 12:30	12/31/25 21:44	1
N-ethylperfluorooctane sulfonamidoethanol (NEtFOSE)	ND		10.0	ng/L		12/31/25 12:30	12/31/25 21:44	1
Hexafluoropropylene Oxide Dimer Acid (HFPO-DA)	ND		2.00	ng/L		12/31/25 12:30	12/31/25 21:44	1
4,8-Dioxa-3H-perfluorononanoic acid (ADONA)	ND		2.00	ng/L		12/31/25 12:30	12/31/25 21:44	1
Perfluoro-3-methoxypropanoic acid (PFMPA)	ND		2.00	ng/L		12/31/25 12:30	12/31/25 21:44	1
Perfluoro-4-methoxybutanoic acid (PFMBA)	ND		2.00	ng/L		12/31/25 12:30	12/31/25 21:44	1
Nonafluoro-3,6-dioxaheptanoic acid (NFDHA)	ND		2.00	ng/L		12/31/25 12:30	12/31/25 21:44	1
9-Chlorohexadecafluoro-3-oxanonane-1-sulfonic acid (9Cl-PF3ONS)	ND		2.00	ng/L		12/31/25 12:30	12/31/25 21:44	1
11-Chloroeicosafluoro-3-oxaundecane-1-sulfonic acid (11Cl-PF3OUdS)	ND		2.00	ng/L		12/31/25 12:30	12/31/25 21:44	1
Perfluoro (2-ethoxyethane) sulfonic acid (PFEESA)	ND		2.00	ng/L		12/31/25 12:30	12/31/25 21:44	1
3-Perfluoropropylpropanoic acid (3:3 FTCA)	ND		4.00	ng/L		12/31/25 12:30	12/31/25 21:44	1
3-Perfluoropentylpropanoic acid (5:3 FTCA)	ND		10.0	ng/L		12/31/25 12:30	12/31/25 21:44	1
3-Perfluoroheptylpropanoic acid (7:3 FTCA)	ND		10.0	ng/L		12/31/25 12:30	12/31/25 21:44	1

Isotope Dilution	MB %Recovery	MB Qualifier	Limits	Prepared	Analyzed	Dil Fac
13C4-PFBA	105		5 - 130	12/31/25 12:30	12/31/25 21:44	1
13C5-PFPeA	114		40 - 130	12/31/25 12:30	12/31/25 21:44	1
13C5-PFHxA	108		40 - 130	12/31/25 12:30	12/31/25 21:44	1
13C4-PFHpA	107		40 - 130	12/31/25 12:30	12/31/25 21:44	1
13C8-PFOA	105		40 - 130	12/31/25 12:30	12/31/25 21:44	1
13C9-PFNA	109		40 - 130	12/31/25 12:30	12/31/25 21:44	1
13C6-PFDA	101		40 - 130	12/31/25 12:30	12/31/25 21:44	1
13C7-PFUnA	106		30 - 130	12/31/25 12:30	12/31/25 21:44	1
13C2-PFTeDA	89.0		10 - 130	12/31/25 12:30	12/31/25 21:44	1

Eurofins Rhode Island

QC Sample Results

Client: University of New Hampshire
Project/Site: YT 01 OT FDR

Job ID: 620-32232-1

Method: 1633 - Per- and Polyfluoroalkyl Substances by LC/MS/MS (Continued)

Lab Sample ID: MB 410-751084/20-A

Matrix: Solid

Analysis Batch: 751115

Client Sample ID: Method Blank

Prep Type: Total/NA

Prep Batch: 751084

Isotope Dilution	MB MB		Limits	Prepared	Analyzed	Dil Fac
	%Recovery	Qualifier				
13C3-PFBS	108		40 - 135	12/31/25 12:30	12/31/25 21:44	1
13C3-PFHxS	107		40 - 130	12/31/25 12:30	12/31/25 21:44	1
13C8-PFOS	92.2		40 - 130	12/31/25 12:30	12/31/25 21:44	1
13C8-PFOSA	111		40 - 130	12/31/25 12:30	12/31/25 21:44	1
d3-NMeFOSAA	96.9		40 - 170	12/31/25 12:30	12/31/25 21:44	1
d5-NEtFOSAA	103		25 - 135	12/31/25 12:30	12/31/25 21:44	1
13C2 4:2 FTS	97.9		40 - 200	12/31/25 12:30	12/31/25 21:44	1
13C2 6:2 FTS	107		40 - 200	12/31/25 12:30	12/31/25 21:44	1
13C2 8:2 FTS	87.4		40 - 300	12/31/25 12:30	12/31/25 21:44	1
13C3-HFPO-DA	102		40 - 130	12/31/25 12:30	12/31/25 21:44	1
D7-NMeFOSE	92.9		10 - 130	12/31/25 12:30	12/31/25 21:44	1
D9-NEtFOSE	85.8		10 - 130	12/31/25 12:30	12/31/25 21:44	1
d5-NEtPFOSA	78.7		10 - 130	12/31/25 12:30	12/31/25 21:44	1
d3-NMePFOSA	81.3		10 - 130	12/31/25 12:30	12/31/25 21:44	1
13C2 PFDaA	95.2		10 - 130	12/31/25 12:30	12/31/25 21:44	1

Lab Sample ID: LCS 410-751084/21-A

Matrix: Solid

Analysis Batch: 751115

Client Sample ID: Lab Control Sample

Prep Type: Total/NA

Prep Batch: 751084

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec Limits
Perfluorobutanoic acid (PFBA)	80.0	75.54		ng/L		94	70 - 140
Perfluoropentanoic acid (PFPeA)	40.0	36.94		ng/L		92	65 - 135
Perfluorohexanoic acid (PFHxA)	40.0	33.53		ng/L		84	70 - 145
Perfluoroheptanoic acid (PFHpA)	40.0	33.60		ng/L		84	70 - 150
Perfluorooctanoic acid (PFOA)	40.0	34.29		ng/L		86	70 - 150
Perfluorononanoic acid (PFNA)	40.0	31.28		ng/L		78	70 - 150
Perfluorodecanoic acid (PFDA)	40.0	34.62		ng/L		87	70 - 140
Perfluoroundecanoic acid (PFUnA)	40.0	31.85		ng/L		80	70 - 145
Perfluorododecanoic acid (PFDoA)	40.0	33.92		ng/L		85	70 - 140
Perfluorotridecanoic acid (PFTriDA)	40.0	38.79		ng/L		97	65 - 140
Perfluorotetradecanoic acid (PFTeDA)	40.0	31.15		ng/L		78	60 - 140
Perfluorobutanesulfonic acid (PFBS)	35.5	29.85		ng/L		84	60 - 145
Perfluoropentanesulfonic acid (PFPeS)	37.6	31.55		ng/L		84	65 - 140
Perfluorohexanesulfonic acid (PFHxS)	36.5	31.73		ng/L		87	65 - 145
Perfluoroheptanesulfonic acid (PFHpS)	38.2	37.83		ng/L		99	70 - 150
Perfluorooctanesulfonic acid (PFOS)	37.2	36.70		ng/L		99	55 - 150
Perfluorononanesulfonic acid (PFNS)	38.5	40.48		ng/L		105	65 - 145
Perfluorodecanesulfonic acid (PFDS)	38.6	39.00		ng/L		101	60 - 145
Perfluorododecanesulfonic acid (PFDoS)	38.8	29.37		ng/L		76	50 - 145

Eurofins Rhode Island

QC Sample Results

Client: University of New Hampshire
Project/Site: YT 01 OT FDR

Job ID: 620-32232-1

Method: 1633 - Per- and Polyfluoroalkyl Substances by LC/MS/MS (Continued)

Lab Sample ID: LCS 410-751084/21-A

Matrix: Solid

Analysis Batch: 751115

Client Sample ID: Lab Control Sample

Prep Type: Total/NA

Prep Batch: 751084

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec Limits
1H,1H,2H,2H-Perfluorohexane sulfonic acid (4:2 FTS)	75.0	61.60		ng/L		82	70 - 145
1H,1H,2H,2H-Perfluorooctane sulfonic acid (6:2 FTS)	76.2	60.84		ng/L		80	65 - 155
1H,1H,2H,2H-Perfluorodecane sulfonic acid (8:2 FTS)	76.8	73.24		ng/L		95	60 - 150
Perfluorooctanesulfonamide (PFOSA)	40.0	34.77		ng/L		87	70 - 145
N-methylperfluorooctane sulfonamide (NMeFOSA)	40.0	35.03		ng/L		88	60 - 150
N-ethylperfluorooctane sulfonamide (NEtFOSA)	40.0	36.70		ng/L		92	65 - 145
N-methylperfluorooctanesulfonamidoacetic acid (NMeFOSAA)	40.0	33.76		ng/L		84	50 - 140
N-ethylperfluorooctanesulfonamidoacetic acid (NEtFOSAA)	40.0	33.34		ng/L		83	70 - 145
N-methylperfluorooctane sulfonamidoethanol (NMeFOSE)	200	176.4		ng/L		88	70 - 145
N-ethylperfluorooctane sulfonamidoethanol (NEtFOSE)	200	182.4		ng/L		91	70 - 135
Hexafluoropropylene Oxide Dimer Acid (HFPO-DA)	30.0	28.51		ng/L		95	70 - 140
4,8-Dioxa-3H-perfluorononanoic acid (ADONA)	37.8	34.58		ng/L		91	65 - 145
Perfluoro-3-methoxypropanoic acid (PFMPA)	40.0	34.93		ng/L		87	55 - 140
Perfluoro-4-methoxybutanoic acid (PFMBA)	40.0	33.04		ng/L		83	60 - 150
Nonafluoro-3,6-dioxaheptanoic acid (NFDHA)	40.0	35.59		ng/L		89	50 - 150
9-Chlorohexadecafluoro-3-oxanonane-1-sulfonic acid (9Cl-PF3ONS)	37.4	36.92		ng/L		99	70 - 155
11-Chloroeicosafluoro-3-oxaundecane-1-sulfonic acid (11Cl-PF3OUdS)	37.8	36.53		ng/L		97	55 - 160
Perfluoro (2-ethoxyethane) sulfonic acid (PFEEESA)	35.7	35.54		ng/L		100	70 - 140
3-Perfluoropropylpropanoic acid (3:3 FTCA)	80.0	72.95		ng/L		91	65 - 130
3-Perfluoropentylpropanoic acid (5:3 FTCA)	200	148.7		ng/L		74	70 - 135
3-Perfluoroheptylpropanoic acid (7:3 FTCA)	200	151.8		ng/L		76	50 - 145

Isotope Dilution	LCS		Limits
	%Recovery	Qualifier	
13C4-PFBA	80.5		5 - 130
13C5-PFPeA	81.5		40 - 130
13C5-PFHxA	78.8		40 - 130
13C4-PFHpA	81.9		40 - 130
13C8-PFOA	81.0		40 - 130
13C9-PFNA	89.1		40 - 130
13C6-PFDA	86.1		40 - 130
13C7-PFUnA	93.8		30 - 130

Eurofins Rhode Island

QC Sample Results

Client: University of New Hampshire
Project/Site: YT 01 OT FDR

Job ID: 620-32232-1

Method: 1633 - Per- and Polyfluoroalkyl Substances by LC/MS/MS (Continued)

Lab Sample ID: LCS 410-751084/21-A

Matrix: Solid

Analysis Batch: 751115

Client Sample ID: Lab Control Sample

Prep Type: Total/NA

Prep Batch: 751084

Isotope Dilution	LCS LCS		Limits
	%Recovery	Qualifier	
13C2-PFTeDA	78.3		10 - 130
13C3-PFBS	89.3		40 - 135
13C3-PFHxS	89.0		40 - 130
13C8-PFOS	81.4		40 - 130
13C8-PFOSA	86.1		40 - 130
d3-NMeFOSAA	83.4		40 - 170
d5-NEtFOSAA	89.2		25 - 135
13C2 4:2 FTS	75.5		40 - 200
13C2 6:2 FTS	86.2		40 - 200
13C2 8:2 FTS	77.2		40 - 300
13C3-HFPO-DA	77.8		40 - 130
D7-NMeFOSE	82.8		10 - 130
D9-NEtFOSE	76.7		10 - 130
d5-NEtPFOSA	71.0		10 - 130
d3-NMePFOSA	70.9		10 - 130
13C2 PFDoA	89.5		10 - 130

Lab Sample ID: LCSD 410-751084/1-A

Matrix: Solid

Analysis Batch: 751115

Client Sample ID: Lab Control Sample Dup

Prep Type: Total/NA

Prep Batch: 751084

Analyte	Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec		RPD	Limit
							Limits	RPD		
Perfluorobutanoic acid (PFBA)	80.0	83.33		ng/L		104	70 - 140	10	30	
Perfluoropentanoic acid (PFPeA)	40.0	40.55		ng/L		101	65 - 135	9	30	
Perfluorohexanoic acid (PFHxA)	40.0	37.35		ng/L		93	70 - 145	11	30	
Perfluoroheptanoic acid (PFHpA)	40.0	35.61		ng/L		89	70 - 150	6	30	
Perfluorooctanoic acid (PFOA)	40.0	38.31		ng/L		96	70 - 150	11	30	
Perfluorononanoic acid (PFNA)	40.0	33.59		ng/L		84	70 - 150	7	30	
Perfluorodecanoic acid (PFDA)	40.0	38.22		ng/L		96	70 - 140	10	30	
Perfluoroundecanoic acid (PFUnA)	40.0	35.73		ng/L		89	70 - 145	11	30	
Perfluorododecanoic acid (PFDoA)	40.0	37.37		ng/L		93	70 - 140	10	30	
Perfluorotridecanoic acid (PFTriDA)	40.0	37.40		ng/L		94	65 - 140	4	30	
Perfluorotetradecanoic acid (PFTeDA)	40.0	31.09		ng/L		78	60 - 140	0	30	
Perfluorobutanesulfonic acid (PFBS)	35.5	32.19		ng/L		91	60 - 145	8	30	
Perfluoropentanesulfonic acid (PFPeS)	37.6	34.15		ng/L		91	65 - 140	8	30	
Perfluorohexanesulfonic acid (PFHxS)	36.5	32.50		ng/L		89	65 - 145	2	30	
Perfluoroheptanesulfonic acid (PFHpS)	38.2	41.04		ng/L		108	70 - 150	8	30	
Perfluorooctanesulfonic acid (PFOS)	37.2	40.74		ng/L		110	55 - 150	10	30	
Perfluorononanesulfonic acid (PFNS)	38.5	43.37		ng/L		113	65 - 145	7	30	
Perfluorodecanesulfonic acid (PFDS)	38.6	40.31		ng/L		105	60 - 145	3	30	

Eurofins Rhode Island

QC Sample Results

Client: University of New Hampshire
Project/Site: YT 01 OT FDR

Job ID: 620-32232-1

Method: 1633 - Per- and Polyfluoroalkyl Substances by LC/MS/MS (Continued)

Lab Sample ID: LCSD 410-751084/1-A

Matrix: Solid

Analysis Batch: 751115

Client Sample ID: Lab Control Sample Dup

Prep Type: Total/NA

Prep Batch: 751084

Analyte	Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec Limits	RPD	RPD Limit
Perfluorodecanesulfonic acid (PFDoS)	38.8	32.20		ng/L		83	50 - 145	9	30
1H,1H,2H,2H-Perfluorohexane sulfonic acid (4:2 FTS)	75.0	68.55		ng/L		91	70 - 145	11	30
1H,1H,2H,2H-Perfluorooctane sulfonic acid (6:2 FTS)	76.2	69.66		ng/L		91	65 - 155	14	30
1H,1H,2H,2H-Perfluorodecane sulfonic acid (8:2 FTS)	76.8	68.95		ng/L		90	60 - 150	6	30
Perfluorooctanesulfonamide (PFOSA)	40.0	38.94		ng/L		97	70 - 145	11	30
N-methylperfluorooctane sulfonamide (NMeFOSA)	40.0	41.45		ng/L		104	60 - 150	17	30
N-ethylperfluorooctane sulfonamide (NEtFOSA)	40.0	42.75		ng/L		107	65 - 145	15	30
N-methylperfluorooctanesulfonamidoacetic acid (NMeFOSAA)	40.0	39.47		ng/L		99	50 - 140	16	30
N-ethylperfluorooctanesulfonamidoacetic acid (NEtFOSAA)	40.0	37.23		ng/L		93	70 - 145	11	30
N-methylperfluorooctane sulfonamidoethanol (NMeFOSE)	200	197.7		ng/L		99	70 - 145	11	30
N-ethylperfluorooctane sulfonamidoethanol (NEtFOSE)	200	200.5		ng/L		100	70 - 135	9	30
Hexafluoropropylene Oxide Dimer Acid (HFPO-DA)	30.0	28.90		ng/L		96	70 - 140	1	30
4,8-Dioxa-3H-perfluorononanoic acid (ADONA)	37.8	35.97		ng/L		95	65 - 145	4	30
Perfluoro-3-methoxypropanoic acid (PFMPA)	40.0	38.19		ng/L		95	55 - 140	9	30
Perfluoro-4-methoxybutanoic acid (PFMBA)	40.0	37.31		ng/L		93	60 - 150	12	30
Nonafluoro-3,6-dioxaheptanoic acid (NFDHA)	40.0	37.00		ng/L		93	50 - 150	4	30
9-Chlorohexadecafluoro-3-oxanonane-1-sulfonic acid (9Cl-PF3ONS)	37.4	39.69		ng/L		106	70 - 155	7	30
11-Chloroeicosafluoro-3-oxaundecane-1-sulfonic acid (11Cl-PF3OUdS)	37.8	37.11		ng/L		98	55 - 160	2	30
Perfluoro (2-ethoxyethane) sulfonic acid (PFEEESA)	35.7	33.81		ng/L		95	70 - 140	5	30
3-Perfluoropropylpropanoic acid (3:3 FTCA)	80.0	73.86		ng/L		92	65 - 130	1	30
3-Perfluoropentylpropanoic acid (5:3 FTCA)	200	177.7		ng/L		89	70 - 135	18	30
3-Perfluoroheptylpropanoic acid (7:3 FTCA)	200	161.6		ng/L		81	50 - 145	6	30

Isotope Dilution	LCSD %Recovery	LCSD Qualifier	Limits
13C4-PFBA	109		5 - 130
13C5-PFPeA	110		40 - 130
13C5-PFHxA	108		40 - 130
13C4-PFHpA	106		40 - 130
13C8-PFOA	110		40 - 130
13C9-PFNA	114		40 - 130

Eurofins Rhode Island

QC Sample Results

Client: University of New Hampshire
Project/Site: YT 01 OT FDR

Job ID: 620-32232-1

Method: 1633 - Per- and Polyfluoroalkyl Substances by LC/MS/MS (Continued)

Lab Sample ID: LCSD 410-751084/1-A

Matrix: Solid

Analysis Batch: 751115

Client Sample ID: Lab Control Sample Dup

Prep Type: Total/NA

Prep Batch: 751084

Isotope Dilution	LCSD		Limits
	%Recovery	Qualifier	
13C6-PFDA	103		40 - 130
13C7-PFUnA	106		30 - 130
13C2-PFTeDA	94.2		10 - 130
13C3-PFBS	109		40 - 135
13C3-PFHxS	111		40 - 130
13C8-PFOS	92.5		40 - 130
13C8-PFOSA	101		40 - 130
d3-NMeFOSAA	85.2		40 - 170
d5-NEtFOSAA	95.4		25 - 135
13C2 4:2 FTS	100		40 - 200
13C2 6:2 FTS	106		40 - 200
13C2 8:2 FTS	99.2		40 - 300
13C3-HFPO-DA	106		40 - 130
D7-NMeFOSE	90.7		10 - 130
D9-NEtFOSE	83.2		10 - 130
d5-NEtPFOSA	74.0		10 - 130
d3-NMePFOSA	78.8		10 - 130
13C2 PFDoA	95.5		10 - 130

Lab Sample ID: LLCS 410-751084/2-A

Matrix: Solid

Analysis Batch: 751115

Client Sample ID: Lab Control Sample

Prep Type: Total/NA

Prep Batch: 751084

Analyte	Spike Added	LLCS		Unit	D	%Rec	%Rec	
		Result	Qualifier				Limits	
Perfluorobutanoic acid (PFBA)	6.40	7.992		ng/L		125	70 - 140	
Perfluoropentanoic acid (PFPeA)	3.20	3.794		ng/L		119	65 - 135	
Perfluorohexanoic acid (PFHxA)	3.20	3.630		ng/L		113	70 - 145	
Perfluoroheptanoic acid (PFHpA)	3.20	3.207		ng/L		100	70 - 150	
Perfluorooctanoic acid (PFOA)	3.20	3.289		ng/L		103	70 - 150	
Perfluorononanoic acid (PFNA)	3.20	3.365		ng/L		105	70 - 150	
Perfluorodecanoic acid (PFDA)	3.20	3.613		ng/L		113	70 - 140	
Perfluoroundecanoic acid (PFUnA)	3.20	3.323		ng/L		104	70 - 145	
Perfluorododecanoic acid (PFDoA)	3.20	3.486		ng/L		109	70 - 140	
Perfluorotridecanoic acid (PFTTrDA)	3.20	3.718		ng/L		116	65 - 140	
Perfluorotetradecanoic acid (PFTeDA)	3.20	3.052		ng/L		95	60 - 140	
Perfluorobutanesulfonic acid (PFBS)	2.84	2.886		ng/L		102	60 - 145	
Perfluoropentanesulfonic acid (PFPeS)	3.01	3.235		ng/L		108	65 - 140	
Perfluorohexanesulfonic acid (PFHxS)	2.92	3.244		ng/L		111	65 - 145	
Perfluoroheptanesulfonic acid (PFHpS)	3.05	3.924		ng/L		129	70 - 150	
Perfluorooctanesulfonic acid (PFOS)	2.98	3.860		ng/L		130	55 - 150	
Perfluorononanesulfonic acid (PFNS)	3.08	3.879		ng/L		126	65 - 145	

Eurofins Rhode Island

QC Sample Results

Client: University of New Hampshire
Project/Site: YT 01 OT FDR

Job ID: 620-32232-1

Method: 1633 - Per- and Polyfluoroalkyl Substances by LC/MS/MS (Continued)

Lab Sample ID: LLCS 410-751084/2-A

Matrix: Solid

Analysis Batch: 751115

Client Sample ID: Lab Control Sample

Prep Type: Total/NA

Prep Batch: 751084

Analyte	Spike Added	LLCS Result	LLCS Qualifier	Unit	D	%Rec	%Rec Limits
Perfluorodecanesulfonic acid (PFDS)	3.08	3.802		ng/L		123	60 - 145
Perfluorododecanesulfonic acid (PFDoS)	3.10	3.061		ng/L		99	50 - 145
1H,1H,2H,2H-Perfluorohexane sulfonic acid (4:2 FTS)	6.00	6.166		ng/L		103	70 - 145
1H,1H,2H,2H-Perfluorooctane sulfonic acid (6:2 FTS)	6.09	6.662		ng/L		109	65 - 155
1H,1H,2H,2H-Perfluorodecane sulfonic acid (8:2 FTS)	6.14	7.474		ng/L		122	60 - 150
Perfluorooctanesulfonamide (PFOSA)	3.20	3.732		ng/L		117	70 - 145
N-methylperfluorooctane sulfonamide (NMeFOSA)	3.20	4.154		ng/L		130	60 - 150
N-ethylperfluorooctane sulfonamide (NEtFOSA)	3.20	4.283		ng/L		134	65 - 145
N-methylperfluorooctanesulfonamidoacetic acid (NMeFOSAA)	3.20	4.592	*+	ng/L		144	50 - 140
N-ethylperfluorooctanesulfonamidoacetic acid (NEtFOSAA)	3.20	3.676		ng/L		115	70 - 145
N-methylperfluorooctane sulfonamidoethanol (NMeFOSE)	16.0	20.28		ng/L		127	70 - 145
N-ethylperfluorooctane sulfonamidoethanol (NEtFOSE)	16.0	20.51		ng/L		128	70 - 135
Hexafluoropropylene Oxide Dimer Acid (HFPO-DA)	2.40	2.679		ng/L		112	70 - 140
4,8-Dioxa-3H-perfluorononanoic acid (ADONA)	3.03	3.511		ng/L		116	65 - 145
Perfluoro-3-methoxypropanoic acid (PFMPA)	3.20	3.423		ng/L		107	55 - 140
Perfluoro-4-methoxybutanoic acid (PFMBA)	3.20	3.271		ng/L		102	60 - 150
Nonafluoro-3,6-dioxaheptanoic acid (NFDHA)	3.20	3.510		ng/L		110	50 - 150
9-Chlorohexadecafluoro-3-oxanonane-1-sulfonic acid (9Cl-PF3ONS)	2.99	3.634		ng/L		122	70 - 155
11-Chloroeicosafluoro-3-oxaundecane-1-sulfonic acid (11Cl-PF3OUdS)	3.02	3.616		ng/L		120	55 - 160
Perfluoro (2-ethoxyethane) sulfonic acid (PFEESA)	2.85	3.264		ng/L		114	70 - 140
3-Perfluoropropylpropanoic acid (3:3 FTCA)	6.40	8.039		ng/L		126	65 - 130
3-Perfluoropentylpropanoic acid (5:3 FTCA)	16.0	17.80		ng/L		111	70 - 135
3-Perfluoroheptylpropanoic acid (7:3 FTCA)	16.0	17.74		ng/L		111	50 - 145

Isotope Dilution	LLCS		Limits
	%Recovery	Qualifier	
13C4-PFBA	98.1		5 - 130
13C5-PFPeA	103		40 - 130
13C5-PFHxA	100		40 - 130
13C4-PFHpA	100		40 - 130
13C8-PFOA	95.3		40 - 130

Eurofins Rhode Island

QC Sample Results

Client: University of New Hampshire
Project/Site: YT 01 OT FDR

Job ID: 620-32232-1

Method: 1633 - Per- and Polyfluoroalkyl Substances by LC/MS/MS (Continued)

Lab Sample ID: LLCS 410-751084/2-A

Matrix: Solid

Analysis Batch: 751115

Client Sample ID: Lab Control Sample

Prep Type: Total/NA

Prep Batch: 751084

Isotope Dilution	LLCS LLCS		Limits
	%Recovery	Qualifier	
13C9-PFNA	105		40 - 130
13C6-PFDA	96.3		40 - 130
13C7-PFUnA	104		30 - 130
13C2-PFTeDA	90.7		10 - 130
13C3-PFBS	101		40 - 135
13C3-PFHxS	103		40 - 130
13C8-PFOS	90.2		40 - 130
13C8-PFOSA	99.0		40 - 130
d3-NMeFOSAA	82.2		40 - 170
d5-NEtFOSAA	91.3		25 - 135
13C2 4:2 FTS	91.4		40 - 200
13C2 6:2 FTS	98.9		40 - 200
13C2 8:2 FTS	90.6		40 - 300
13C3-HFPO-DA	92.9		40 - 130
D7-NMeFOSE	88.4		10 - 130
D9-NEtFOSE	82.9		10 - 130
d5-NEtPFOSA	79.2		10 - 130
d3-NMePFOSA	84.5		10 - 130
13C2 PFDoA	95.3		10 - 130

Lab Sample ID: LB 410-750430/1-C

Matrix: Solid

Analysis Batch: 751115

Client Sample ID: Method Blank

Prep Type: SPLP East

Prep Batch: 751084

Analyte	LB LB		RL	Unit	D	Prepared	Analyzed	Dil Fac
	Result	Qualifier						
Perfluorobutanoic acid (PFBA)	ND		3.74	ng/L		12/31/25 12:30	12/31/25 22:38	1
Perfluoropentanoic acid (PFPeA)	ND		1.87	ng/L		12/31/25 12:30	12/31/25 22:38	1
Perfluorohexanoic acid (PFHxA)	ND		1.87	ng/L		12/31/25 12:30	12/31/25 22:38	1
Perfluoroheptanoic acid (PFHpA)	ND		1.87	ng/L		12/31/25 12:30	12/31/25 22:38	1
Perfluorooctanoic acid (PFOA)	ND		1.87	ng/L		12/31/25 12:30	12/31/25 22:38	1
Perfluorononanoic acid (PFNA)	ND		1.87	ng/L		12/31/25 12:30	12/31/25 22:38	1
Perfluorodecanoic acid (PFDA)	ND		1.87	ng/L		12/31/25 12:30	12/31/25 22:38	1
Perfluoroundecanoic acid (PFUnA)	ND		1.87	ng/L		12/31/25 12:30	12/31/25 22:38	1
Perfluorododecanoic acid (PFDoA)	ND		1.87	ng/L		12/31/25 12:30	12/31/25 22:38	1
Perfluorotridecanoic acid (PFTrDA)	ND		1.87	ng/L		12/31/25 12:30	12/31/25 22:38	1
Perfluorotetradecanoic acid (PFTeDA)	ND		1.87	ng/L		12/31/25 12:30	12/31/25 22:38	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.87	ng/L		12/31/25 12:30	12/31/25 22:38	1
Perfluoropentanesulfonic acid (PFPeS)	ND		1.87	ng/L		12/31/25 12:30	12/31/25 22:38	1
Perfluorohexanesulfonic acid (PFHxS)	ND		1.87	ng/L		12/31/25 12:30	12/31/25 22:38	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		1.87	ng/L		12/31/25 12:30	12/31/25 22:38	1
Perfluorooctanesulfonic acid (PFOS)	ND		1.87	ng/L		12/31/25 12:30	12/31/25 22:38	1
Perfluorononanesulfonic acid (PFNS)	ND		1.87	ng/L		12/31/25 12:30	12/31/25 22:38	1
Perfluorodecanesulfonic acid (PFDS)	ND		1.87	ng/L		12/31/25 12:30	12/31/25 22:38	1
Perfluorododecanesulfonic acid (PFDoS)	ND		1.87	ng/L		12/31/25 12:30	12/31/25 22:38	1
1H,1H,2H,2H-Perfluorohexane sulfonic acid (4:2 FTS)	ND		3.74	ng/L		12/31/25 12:30	12/31/25 22:38	1

Eurofins Rhode Island

QC Sample Results

Client: University of New Hampshire
Project/Site: YT 01 OT FDR

Job ID: 620-32232-1

Method: 1633 - Per- and Polyfluoroalkyl Substances by LC/MS/MS (Continued)

Lab Sample ID: LB 410-750430/1-C

Matrix: Solid

Analysis Batch: 751115

Client Sample ID: Method Blank

Prep Type: SPLP East

Prep Batch: 751084

Analyte	LB Result	LB Qualifier	RL	Unit	D	Prepared	Analyzed	Dil Fac
1H,1H,2H,2H-Perfluorooctane sulfonic acid (6:2 FTS)	ND		3.74	ng/L		12/31/25 12:30	12/31/25 22:38	1
1H,1H,2H,2H-Perfluorodecane sulfonic acid (8:2 FTS)	ND		3.74	ng/L		12/31/25 12:30	12/31/25 22:38	1
Perfluorooctanesulfonamide (PFOSA)	ND		1.87	ng/L		12/31/25 12:30	12/31/25 22:38	1
N-methylperfluorooctane sulfonamide (NMeFOSA)	ND		1.87	ng/L		12/31/25 12:30	12/31/25 22:38	1
N-ethylperfluorooctane sulfonamide (NEtFOSA)	ND		1.87	ng/L		12/31/25 12:30	12/31/25 22:38	1
N-methylperfluorooctanesulfonamidoacetic acid (NMeFOSAA)	ND		1.87	ng/L		12/31/25 12:30	12/31/25 22:38	1
N-ethylperfluorooctanesulfonamidoacetic acid (NEtFOSAA)	ND		1.87	ng/L		12/31/25 12:30	12/31/25 22:38	1
N-methylperfluorooctane sulfonamidoethanol (NMeFOSE)	ND		9.36	ng/L		12/31/25 12:30	12/31/25 22:38	1
N-ethylperfluorooctane sulfonamidoethanol (NEtFOSE)	ND		9.36	ng/L		12/31/25 12:30	12/31/25 22:38	1
Hexafluoropropylene Oxide Dimer Acid (HFPO-DA)	ND		1.87	ng/L		12/31/25 12:30	12/31/25 22:38	1
4,8-Dioxo-3H-perfluorononanoic acid (ADONA)	ND		1.87	ng/L		12/31/25 12:30	12/31/25 22:38	1
Perfluoro-3-methoxypropanoic acid (PFMPA)	ND		1.87	ng/L		12/31/25 12:30	12/31/25 22:38	1
Perfluoro-4-methoxybutanoic acid (PFMBA)	ND		1.87	ng/L		12/31/25 12:30	12/31/25 22:38	1
Nonafluoro-3,6-dioxaheptanoic acid (NFDHA)	ND		1.87	ng/L		12/31/25 12:30	12/31/25 22:38	1
9-Chlorohexadecafluoro-3-oxanonane-1-sulfonic acid (9Cl-PF3ONS)	ND		1.87	ng/L		12/31/25 12:30	12/31/25 22:38	1
11-Chloroeicosafluoro-3-oxaundecane-1-sulfonic acid (11Cl-PF3OUdS)	ND		1.87	ng/L		12/31/25 12:30	12/31/25 22:38	1
Perfluoro (2-ethoxyethane) sulfonic acid (PFEESA)	ND		1.87	ng/L		12/31/25 12:30	12/31/25 22:38	1
3-Perfluoropropylpropanoic acid (3:3 FTCA)	ND		3.74	ng/L		12/31/25 12:30	12/31/25 22:38	1
3-Perfluoropentylpropanoic acid (5:3 FTCA)	ND		9.36	ng/L		12/31/25 12:30	12/31/25 22:38	1
3-Perfluoroheptylpropanoic acid (7:3 FTCA)	ND		9.36	ng/L		12/31/25 12:30	12/31/25 22:38	1

Isotope Dilution	LB %Recovery	LB Qualifier	Limits	Prepared	Analyzed	Dil Fac
13C4-PFBA	100		5 - 130	12/31/25 12:30	12/31/25 22:38	1
13C5-PFPeA	107		40 - 130	12/31/25 12:30	12/31/25 22:38	1
13C5-PFHxA	106		40 - 130	12/31/25 12:30	12/31/25 22:38	1
13C4-PFHpA	103		40 - 130	12/31/25 12:30	12/31/25 22:38	1
13C8-PFOA	99.2		40 - 130	12/31/25 12:30	12/31/25 22:38	1
13C9-PFNA	108		40 - 130	12/31/25 12:30	12/31/25 22:38	1
13C6-PFDA	104		40 - 130	12/31/25 12:30	12/31/25 22:38	1
13C7-PFUnA	107		30 - 130	12/31/25 12:30	12/31/25 22:38	1
13C2-PFTeDA	91.2		10 - 130	12/31/25 12:30	12/31/25 22:38	1
13C3-PFBS	104		40 - 135	12/31/25 12:30	12/31/25 22:38	1
13C3-PFHxS	109		40 - 130	12/31/25 12:30	12/31/25 22:38	1
13C8-PFOS	89.5		40 - 130	12/31/25 12:30	12/31/25 22:38	1

Eurofins Rhode Island

QC Sample Results

Client: University of New Hampshire
Project/Site: YT 01 OT FDR

Job ID: 620-32232-1

Method: 1633 - Per- and Polyfluoroalkyl Substances by LC/MS/MS (Continued)

Lab Sample ID: LB 410-750430/1-C

Matrix: Solid

Analysis Batch: 751115

Client Sample ID: Method Blank

Prep Type: SPLP East

Prep Batch: 751084

Isotope Dilution	LB LB		Limits	Prepared	Analyzed	Dil Fac
	%Recovery	Qualifier				
13C8-PFOSA	103		40 - 130	12/31/25 12:30	12/31/25 22:38	1
d3-NMeFOSAA	87.8		40 - 170	12/31/25 12:30	12/31/25 22:38	1
d5-NEtFOSAA	95.6		25 - 135	12/31/25 12:30	12/31/25 22:38	1
13C2 4:2 FTS	101		40 - 200	12/31/25 12:30	12/31/25 22:38	1
13C2 6:2 FTS	110		40 - 200	12/31/25 12:30	12/31/25 22:38	1
13C2 8:2 FTS	96.2		40 - 300	12/31/25 12:30	12/31/25 22:38	1
13C3-HFPO-DA	102		40 - 130	12/31/25 12:30	12/31/25 22:38	1
D7-NMeFOSE	92.6		10 - 130	12/31/25 12:30	12/31/25 22:38	1
D9-NEtFOSE	86.6		10 - 130	12/31/25 12:30	12/31/25 22:38	1
d5-NEtPFOSA	74.6		10 - 130	12/31/25 12:30	12/31/25 22:38	1
d3-NMePFOSA	81.9		10 - 130	12/31/25 12:30	12/31/25 22:38	1
13C2 PFDoA	97.7		10 - 130	12/31/25 12:30	12/31/25 22:38	1

QC Association Summary

Client: University of New Hampshire
Project/Site: YT 01 OT FDR

Job ID: 620-32232-1

GC Semi VOA

Leach Batch: 56880

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
MB 620-56880/1-C	Method Blank	SPLP East	Solid	1312	

Leach Batch: 57457

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
620-32232-1	FDR-Labelled-1&-2	SPLP East	Solid	1312	
620-32232-2	PCRAS-Labelled-1&-2	SPLP East	Solid	1312	
MB 620-57457/1-B	Method Blank	SPLP East	Solid	1312	
620-32232-2 MS	PCRAS-Labelled-1&-2	SPLP East	Solid	1312	

Prep Batch: 57586

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
620-32232-1	FDR-Labelled-1&-2	SPLP East	Solid	3510C	57457
620-32232-2	PCRAS-Labelled-1&-2	SPLP East	Solid	3510C	57457
MB 620-56880/1-C	Method Blank	SPLP East	Solid	3510C	56880
MB 620-57457/1-B	Method Blank	SPLP East	Solid	3510C	57457
LCS 620-57586/2-A	Lab Control Sample	Total/NA	Solid	3510C	
LCSD 620-57586/3-A	Lab Control Sample Dup	Total/NA	Solid	3510C	
620-32232-2 MS	PCRAS-Labelled-1&-2	SPLP East	Solid	3510C	57457

Analysis Batch: 57605

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
620-32232-1	FDR-Labelled-1&-2	SPLP East	Solid	8082A	57586
620-32232-2	PCRAS-Labelled-1&-2	SPLP East	Solid	8082A	57586
MB 620-56880/1-C	Method Blank	SPLP East	Solid	8082A	57586
MB 620-57457/1-B	Method Blank	SPLP East	Solid	8082A	57586
LCS 620-57586/2-A	Lab Control Sample	Total/NA	Solid	8082A	57586
LCSD 620-57586/3-A	Lab Control Sample Dup	Total/NA	Solid	8082A	57586
620-32232-2 MS	PCRAS-Labelled-1&-2	SPLP East	Solid	8082A	57586

LCMS

Leach Batch: 750430

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
620-32232-1	FDR-Labelled-1&-2	SPLP East	Solid	1312	
620-32232-2	PCRAS-Labelled-1&-2	SPLP East	Solid	1312	
LB 410-750430/1-C	Method Blank	SPLP East	Solid	1312	

Prep Batch: 751084

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
620-32232-1	FDR-Labelled-1&-2	SPLP East	Solid	1633	750430
620-32232-2	PCRAS-Labelled-1&-2	SPLP East	Solid	1633	750430
LB 410-750430/1-C	Method Blank	SPLP East	Solid	1633	750430
MB 410-751084/20-A	Method Blank	Total/NA	Solid	1633	
LCS 410-751084/21-A	Lab Control Sample	Total/NA	Solid	1633	
LCSD 410-751084/1-A	Lab Control Sample Dup	Total/NA	Solid	1633	
LLCS 410-751084/2-A	Lab Control Sample	Total/NA	Solid	1633	

Analysis Batch: 751115

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
620-32232-1	FDR-Labelled-1&-2	SPLP East	Solid	1633	751084
620-32232-2	PCRAS-Labelled-1&-2	SPLP East	Solid	1633	751084

Eurofins Rhode Island

QC Association Summary

Client: University of New Hampshire
Project/Site: YT 01 OT FDR

Job ID: 620-32232-1

LCMS (Continued)

Analysis Batch: 751115 (Continued)

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
LB 410-750430/1-C	Method Blank	SPLP East	Solid	1633	751084
MB 410-751084/20-A	Method Blank	Total/NA	Solid	1633	751084
LCS 410-751084/21-A	Lab Control Sample	Total/NA	Solid	1633	751084
LCSD 410-751084/1-A	Lab Control Sample Dup	Total/NA	Solid	1633	751084
LLCS 410-751084/2-A	Lab Control Sample	Total/NA	Solid	1633	751084

Lab Chronicle

Client: University of New Hampshire
Project/Site: YT 01 OT FDR

Job ID: 620-32232-1

Client Sample ID: FDR-Labelled-1&-2

Lab Sample ID: 620-32232-1

Date Collected: 12/18/25 16:00

Matrix: Solid

Date Received: 12/26/25 11:30

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Analyst	Lab	Prepared or Analyzed
SPLP East	Leach	1312			57457	DJW	EET RI	12/26/25 18:58
SPLP East	Prep	3510C			57586	D1G	EET RI	12/31/25 10:40
SPLP East	Analysis	8082A		1	57605	JS	EET RI	12/31/25 16:48
SPLP East	Leach	1312			750430	M6MC	ELLE	12/30/25 12:40 - 12/31/25 08:20 ¹
SPLP East	Prep	1633			751084	Y4GV	ELLE	12/31/25 12:30
SPLP East	Analysis	1633		1	751115	UUV6	ELLE	01/01/26 01:47

Client Sample ID: PCRAS-Labelled-1&-2

Lab Sample ID: 620-32232-2

Date Collected: 12/18/25 16:00

Matrix: Solid

Date Received: 12/26/25 11:30

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Analyst	Lab	Prepared or Analyzed
SPLP East	Leach	1312			57457	DJW	EET RI	12/26/25 18:58
SPLP East	Prep	3510C			57586	D1G	EET RI	12/31/25 10:40
SPLP East	Analysis	8082A		1	57605	JS	EET RI	12/31/25 17:05
SPLP East	Leach	1312			750430	M6MC	ELLE	12/30/25 12:40 - 12/31/25 08:20 ¹
SPLP East	Prep	1633			751084	Y4GV	ELLE	12/31/25 12:30
SPLP East	Analysis	1633		1	751115	UUV6	ELLE	01/01/26 02:01

¹ This procedure uses a method stipulated length of time for the process. Both start and end times are displayed.

Laboratory References:

EET RI = Eurofins Rhode Island, 646 Camp Ave, North Kingstown, RI 02852, TEL (413)789-9018

ELLE = Eurofins Lancaster Laboratories Environment Testing, LLC, 2425 New Holland Pike, Lancaster, PA 17601, TEL (717)656-2300

Accreditation/Certification Summary

Client: University of New Hampshire
Project/Site: YT 01 OT FDR

Job ID: 620-32232-1

Laboratory: Eurofins Rhode Island

The accreditations/certifications listed below are applicable to this report.

Authority	Program	Identification Number	Expiration Date
New Hampshire	NELAP	2245	09-17-26

Laboratory: Eurofins Lancaster Laboratories Environment Testing, LLC

All accreditations/certifications held by this laboratory are listed. Not all accreditations/certifications are applicable to this report.

Authority	Program	Identification Number	Expiration Date
A2LA	Dept. of Defense ELAP	0001.01	11-30-26
A2LA	Dept. of Energy	0001.01	11-30-26
A2LA	ISO/IEC 17025	0001.01	11-30-26
Alabama	State	43200	01-31-26
Alaska	State	PA00009	06-30-26
Alaska (UST)	State	17-027	12-30-26
Arizona	State	AZ0780	03-12-26
Arkansas DEQ	State	88-00660	08-09-26
California	State	2792	01-31-26
Colorado	State	PA00009	06-30-26
Connecticut	State	PH-0746	06-30-27
DE Haz. Subst. Cleanup Act (HSCA)	State	019-006 (PA cert)	01-31-26
Delaware (DW)	State	N/A	01-31-26
Florida	NELAP	E87997	06-30-26
Georgia (DW)	State	C048	01-31-26
Illinois	NELAP	200027	01-31-26
Iowa	State	361	03-01-26
Kansas	NELAP	E-10151	10-31-26
Kentucky (UST)	State	0001.01	11-30-26
Kentucky (WW)	State	KY90088	12-31-26
Louisiana (All)	NELAP	02055	06-30-26
Maine	State	2019012	03-12-27
Maryland	State	100	06-30-26
Massachusetts	State	M-PA009	06-30-26
Michigan	State	9930	01-31-26
Minnesota	NELAP	042-999-487	12-31-26
Mississippi	State	023	01-31-26
Missouri	State	450	01-31-28
Montana (DW)	State	0098	01-01-27
Nebraska	State	NE-OS-32-17	01-31-26
New Hampshire	NELAP	2730	01-10-26
New Jersey	NELAP	PA011	06-30-26
New York	NELAP	10670	04-01-26
North Carolina (DW)	State	42705	07-31-26
North Dakota	State	R-205	01-31-24 *
Ohio	State	87787	01-31-26
Oregon	NELAP	PA200001	09-11-26
Pennsylvania	NELAP	36-00037	01-31-26
Quebec Ministry of Environment and Fight against Climate Change	PALA	507	09-16-29
South Carolina	State	89002	01-31-26
Tennessee	State	02838	01-31-26
Texas	NELAP	T104704194-23-46	08-31-26
USDA	US Federal Programs	525-22-298-19481	01-23-26
Vermont	State	VT - 36037	10-28-26

* Accreditation/Certification renewal pending - accreditation/certification considered valid.

Eurofins Rhode Island

Accreditation/Certification Summary

Client: University of New Hampshire
Project/Site: YT 01 OT FDR

Job ID: 620-32232-1

Laboratory: Eurofins Lancaster Laboratories Environment Testing, LLC (Continued)

All accreditations/certifications held by this laboratory are listed. Not all accreditations/certifications are applicable to this report.

Authority	Program	Identification Number	Expiration Date
Virginia	NELAP	460182	06-14-26
Washington	State	C457	04-11-26
West Virginia (DW)	State	9906 C	03-31-26
West Virginia DEP	State	055	07-31-26
Wyoming	State	8TMS-L	01-31-26
Wyoming (UST)	A2LA	0001.01	11-30-26

Method Summary

Client: University of New Hampshire
Project/Site: YT 01 OT FDR

Job ID: 620-32232-1

Method	Method Description	Protocol	Laboratory
8082A	Polychlorinated Biphenyls (PCBs) by Gas Chromatography	SW846	EET RI
1633	Per- and Polyfluoroalkyl Substances by LC/MS/MS	EPA	ELLE
1312	SPLP Extraction	SW846	EET RI
1312	SPLP Extraction	SW846	ELLE
1633	Solid-Phase Extraction (SPE)	EPA	ELLE
3510C	Liquid-Liquid Extraction (Separatory Funnel)	SW846	EET RI

Protocol References:

EPA = US Environmental Protection Agency

SW846 = "Test Methods For Evaluating Solid Waste, Physical/Chemical Methods", Third Edition, November 1986 And Its Updates.

Laboratory References:

EET RI = Eurofins Rhode Island, 646 Camp Ave, North Kingstown, RI 02852, TEL (413)789-9018

ELLE = Eurofins Lancaster Laboratories Environment Testing, LLC, 2425 New Holland Pike, Lancaster, PA 17601, TEL (717)656-2300

Sample Summary

Client: University of New Hampshire
Project/Site: YT 01 OT FDR

Job ID: 620-32232-1

Lab Sample ID	Client Sample ID	Matrix	Collected	Received	Sample Origin
620-32232-1	FDR-Labelled-1&-2	Solid	12/18/25 16:00	12/26/25 11:30	New Hampshire
620-32232-2	PCRAS-Labelled-1&-2	Solid	12/18/25 16:00	12/26/25 11:30	New Hampshire

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Chain of Custody Record

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Login Sample Receipt Checklist

Client: Cash in Advance (Rhode Island)

Job Number: 620-32232-1

Login Number: 32232

List Source: Eurofins Rhode Island

List Number: 1

Creator: Scott, Krishnan F

Question	Answer	Comment
Radioactivity wasn't checked or is $\leq$ background as measured by a survey meter.	N/A	
The cooler's custody seal, if present, is intact.	N/A	
Sample custody seals, if present, are intact.	N/A	
The cooler or samples do not appear to have been compromised or tampered with.	True	
Samples were received on ice.	True	
Cooler Temperature is acceptable.	True	
Cooler Temperature is recorded.	True	
COC is present.	True	
COC is filled out in ink and legible.	True	
COC is filled out with all pertinent information.	True	
Is the Field Sampler's name present on COC?	True	
There are no discrepancies between the containers received and the COC.	True	
Samples are received within Holding Time (excluding tests with immediate HTs)	True	
Sample containers have legible labels.	True	
Containers are not broken or leaking.	True	
Sample collection date/times are provided.	True	
Appropriate sample containers are used.	True	
Sample bottles are completely filled.	True	
Sample Preservation Verified.	True	
There is sufficient vol. for all requested analyses, incl. any requested MS/MSDs	True	
Containers requiring zero headspace have no headspace or bubble is $<6\text{mm}$ (1/4").	True	
Multiphasic samples are not present.	True	
Samples do not require splitting or compositing.	True	
Residual Chlorine Checked.	N/A	

Login Sample Receipt Checklist

Client: Cash in Advance (Rhode Island)

Job Number: 620-32232-1

Login Number: 32232

List Number: 2

Creator: Cyms, Carolyn M

List Source: Eurofins Lancaster Laboratories Environment Testing, LLC

List Creation: 12/30/25 05:38 AM

Question	Answer	Comment
The cooler's custody seal is intact.	N/A	Not present
The cooler or samples do not appear to have been compromised or tampered with.	True	
Samples were received on ice.	True	
Cooler Temperature acceptable,where thermal pres is required(</=6C, not frozen).	True	
Cooler Temperature is recorded.	True	
WV:Container Temp acceptable,where thermal pres is required (</=6C, not frozen).	N/A	
WV: Container Temperature is recorded.	N/A	
COC is present.	True	
COC is filled out in ink and legible.	True	
COC is filled out with all pertinent information.	True	
There are no discrepancies between the containers received and the COC.	True	
Sample containers have legible labels.	True	
Containers are not broken or leaking.	True	
Sample collection date/times are provided.	True	
Appropriate sample containers are used.	True	
Sample bottles are completely filled.	True	
There is sufficient vol. for all requested analyses.	True	
Is the Field Sampler's name present on COC?	False	Received project as a subcontract.
Sample custody seals are intact.	N/A	Not present.
VOA sample vials do not have headspace >6mm in diameter (none, if from WV)?	N/A	