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Analyzing Emerging Flame Retardants in Environment and Humans

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Introduction

The pervasive presence of emerging flame retardants (EFRs) in indoor environments necessitates the development of sophisticated analytical techniques for their accurate identification and quantification [1]. These compounds, characterized by diverse chemical structures, readily migrate into various environmental matrices, including dust, air, and even human tissues, posing significant exposure risks [1]. The advancement of sensitive, selective, and efficient analytical methodologies is paramount for a comprehensive understanding of human exposure levels and for informing robust risk assessment frameworks [1]. Gas chromatography-mass spectrometry (GC-MS) and liquid chromatography-mass spectrometry (LC-MS/MS) are at the forefront of these analytical efforts, providing the precision required for reliable data generation [1]. The validation of these methods, encompassing linearity, accuracy, precision, and detection limits, is an indispensable step to ensure the integrity and reliability of the obtained data for regulatory purposes [1]. This rigorous validation process underpins the scientific credibility of findings related to EFRs and their potential health implications [1]. Research into the occurrence and distribution of specific EFR classes, such as organophosphate flame retardants (OPFRs), in ubiquitous indoor media like settled dust, is crucial for pinpointing major contamination sources and estimating human exposure pathways, particularly for vulnerable populations like young children [2]. The widespread use of these EFRs and their subsequent accumulation in dust underscore the importance of addressing indoor contamination [2]. Furthermore, the analytical challenges associated with detecting novel brominated flame retardants (NBFRs) in indoor air, often present at very low concentrations, demand the optimization of highly sensitive techniques like HPLC-MS/MS [3]. These newer compounds are frequently introduced as replacements for phased-out legacy substances, making their monitoring and characterization a critical area of research [3]. Understanding their atmospheric behavior and potential health impacts requires the development of reliable tools for their detection [3]. The human exposure to EFRs through dietary intake is another significant route, necessitating the analysis of these compounds in a wide array of food matrices using combined GC-MS and LC-MS/MS approaches [4]. Identifying major dietary contributors and estimating daily intake levels are essential for evaluating the overall contribution of food consumption to the body burden of EFRs and for formulating appropriate public health recommendations [4]. The migration of novel flame retardants (NFRs) from consumer products directly into the indoor environment, particularly house dust, is a key pathway for EFR dissemination [5]. Quantifying NFRs in various product types and correlating these with dust levels provides direct evidence of continuous release and accumulation, emphasizing the role of product composition in controlling indoor contamination [5]. The development of multi-residue analytical methods capable of simultaneously determining a broad spectrum of both legacy and emerging flame retardants in biological samples, such as human serum, is critical for assessing real-world human exposure to complex mixtures of these chemicals [6]. Such comprehensive analytical tools are vital for understanding overall body burdens and potential health risks associated with diverse EFR exposures [6]. The ubiquitous presence of organophosphorus and halogenated flame retardants in diverse indoor environments, including homes, offices, and schools, necessitates comparative exposure assessments across these settings using established analytical techniques like GC-MS and LC-MS/MS [7]. Identifying differences in contamination levels and profiles across these varied environments is crucial for pinpointing high-risk locations and understanding the widespread nature of EFR contamination [7]. Addressing the analytical complexities of detecting novel organohalogen flame retardants (NOHFRs) in challenging environmental matrices, such as biota, demands advanced chromatographic techniques coupled with high-resolution mass spectrometry (HRMS) [8]. Accurate mass measurements are indispensable for the structural elucidation and confident identification of these emerging compounds, especially when toxicological data is limited [8]. The increasing interest in phosphorus-based flame retardants (PFRs), driven by the phase-out of certain halogenated alternatives, underscores the need for comprehensive analytical methodologies for their detection in both environmental and biological samples [9]. Techniques like GC-MS, LC-MS/MS, and ICP-MS are essential for robust monitoring frameworks required to understand their environmental fate and human exposure [9]. Finally, assessing the bioaccumulation potential and trophic transfer of NFRs in aquatic ecosystems requires the development of specific analytical methods, such as LC-MS/MS for fish tissues, to accurately quantify these compounds [10]. This information is vital for ecological risk assessment and for informing regulatory decisions regarding the discharge of EFRs into water bodies [10].

Description

The critical need for advanced analytical techniques to identify and quantify emerging flame retardants (EFRs) within indoor environments is a central theme, driven by the diverse chemical structures of these compounds and their propensity for migration into dust, air, and human tissues [1]. The focus is on developing and validating sensitive, selective, and efficient analytical methodologies, such as gas chromatography-mass spectrometry (GC-MS) and liquid chromatography-mass spectrometry (LC-MS/MS), to enable accurate exposure assessment [1]. Method validation, including linearity, accuracy, precision, and limit of detection/quantification, is emphasized to ensure reliable data for risk assessment and regulatory development [1]. The presence and distribution of organophosphate flame retardants (OPFRs) in indoor dust from residential buildings have been investigated, employing GC-MS/MS for quantification and providing insights into typical exposure levels and potential contamination sources [2]. This research highlights the widespread use of OPFRs and their accumulation in settled dust, a significant pathway for human exposure, especially for young children [2]. The development of a sensitive and selective analytical method for detecting novel brominated flame retardants (NBFRs) in indoor air using high-performance liquid chromatography coupled with tandem mass spectrometry (HPLC-MS/MS) is detailed, focusing on optimized parameters for low concentration analysis [3]. This aims to provide a reliable tool for monitoring these newer EFRs, which often serve as replacements for legacy compounds, and to understand their atmospheric behavior and potential health implications [3]. Human exposure to organophosphate and organohalogen flame retardants through the diet has been examined in a Chilean population, utilizing a combination of GC-MS and LC-MS/MS to analyze these compounds in various food matrices [4]. The study seeks to identify major dietary sources contributing to human intake and estimate daily intake levels, crucial for understanding the overall body burden from food consumption [4]. The migration and partitioning of novel flame retardants (NFRs) from consumer products into indoor dust have been quantified using LC-MS/MS, correlating their presence in different product types with levels found in dust samples [5]. These findings demonstrate the continuous release of NFRs from consumer goods and their accumulation in indoor dust, underscoring the importance of product composition in managing indoor EFR contamination [5]. A comprehensive analytical approach for the simultaneous determination of a wide range of legacy and emerging flame retardants in human serum has been presented, employing a multi-residue method using GC-MS/MS and LC-MS/MS [6]. This broad-spectrum analytical capability is essential for assessing human exposure to the complex mixtures of flame retardants present in the general population, contributing to a better understanding of body burdens and potential health risks [6]. The presence of organophosphorus and halogenated flame retardants in indoor air and settled dust from diverse indoor environments, including homes, offices, and schools, has been investigated using GC-MS and LC-MS/MS [7]. The study aims to identify potential differences in contamination levels and profiles across these environments, highlighting the ubiquitous nature of EFRs indoors and providing data for comparative exposure assessments and identification of high-risk locations [7]. Analytical strategies for novel organohalogen flame retardants (NOHFRs) in complex environmental matrices like biota are explored, emphasizing the application of advanced chromatographic techniques coupled with high-resolution mass spectrometry (HRMS) for identification and quantification [8]. The importance of accurate mass measurements for structural elucidation and confirmation of these emerging compounds, particularly those with limited toxicological data, is highlighted [8]. A review of analytical methodologies for phosphorus-based flame retardants (PFRs), including emerging ones, in environmental and biological matrices is presented, covering sample preparation, extraction, and detection techniques such as GC-MS, LC-MS/MS, and ICP-MS [9]. The growing interest in PFRs due to the phase-out of halogenated alternatives necessitates robust analytical frameworks for monitoring their environmental presence and human exposure [9]. The potential for bioaccumulation of novel flame retardants (NFRs) in aquatic organisms is examined through the development of analytical methods using LC-MS/MS to quantify NFRs in fish tissues [10]. This research assesses the trophic transfer and bioaccumulation potential of these EFRs in aquatic ecosystems, providing crucial data for ecological risk assessment and regulatory decision-making regarding their discharge [10].

Conclusion

This collection of research highlights the critical importance and ongoing challenges in analyzing emerging flame retardants (EFRs) across various environmental compartments and human matrices. Advanced analytical techniques, primarily GC-MS and LC-MS/MS, are essential for identifying and quantifying these diverse compounds in indoor environments, dust, air, food, and biological samples like human serum and aquatic organisms. Studies investigate the migration of EFRs from consumer products, their occurrence in settled dust and air, and dietary exposure pathways. Method validation and the development of multi-residue and high-resolution mass spectrometry techniques are crucial for accurate assessment of human and ecological risks. The research underscores the widespread contamination and the need for robust analytical frameworks to monitor EFRs, particularly as they replace legacy compounds.

Acknowledgement

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Conflict of Interest

None.

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