# 2019 Per- and Polyfluoroalkyl Substances: Second National Conference Scientific Poster Sessions

June 10-12, 2019

Northeastern University, Boston, MA

## Session 1

### 1. Guardian, M.G., et al. "Application of COSMO-RS-derived Octanol0water Partition Coefficients in Characterizing Emerging Per- and Polyfluoroalkyl Substances".

M. Guardian (Department of Chemistry, University at Buffalo, the State University of New York (SUNY), Buffalo, New York 14260, United States, mguardia@buffalo.edu), P. Vexelman, S. Simpson, D. Aga

The COnductor-like Screening MOdel for Realistic Solvents (COSMO-RS) was used to calculate the octanol-water partition coefficients (Kow) of 28 Per- and Polyfluoroalkyl Substances (PFASs). The Log Kow values calculated from COSMO-RS were found to have a logarithmic relationship to the experimentally determined retention times from liquid chromatography−mass spectrometry. The calculated coefficients were used to predict retention times of 10 PFASs treated as "unknowns". Predicted retention times were found to be within 0-13% of their experimental retention times for 8 of the unknowns, while the remaining 2 compounds were found to be within 24-25% that can be explained by the presence of a different functional group in the molecules. This simple approach could be useful in the identification and prediction of sorption behavior and mobility in the environment of the new and emerging PFASs that lack reference standards.

### 2. Miller, A., et al. "In Situ Containment of PFAS using Colloidal Activated Carbon".

A.Miller (REGENSIS, amiller@regenesis.com), K. Thoreson

With the widespread contamination associated with PFAS compounds, there is a need for new and lower cost treatment options that can address the large, dilute plumes that these contaminants commonly form. At the present time, the accepted remediation method is to use pump and treat systems equipped with activated carbon. The costs associated with running these systems and replacing the carbon can be quite high. For that reason, the ability to implement an in situ barrier of activated carbon that can cut off and contain these plumes for many years with a single application affords a beneficial means to decrease or avoid the operating and maintenance costs in the existing aboveground systems. This presentation examines the use of a colloidal activated carbon that readily distributes within the subsurface, providing a method for injecting an in situ barrier of activated carbon for PFAS treatment.

Laboratory batch studies were conducted to measure the relative adsorption of PFOS, PFOA, PFHpA and PFBS with a distributable form of colloidal activated carbon. Results of these studies demonstrated that a field relevant dose of the colloidal activated carbon could reduce 100 µg/L of each PFAS compound tested by at least 99.9% and the relative adsorption followed in the order: PFOS > PFOA > PFHpA > PFBS, as has been observed with other activated carbons. In these experiments PFOS and PFOA were reduced to below the 2016 revised EPA health advisory limits of 70 ng/L. Additionally, performance data from field site applications that were injected with colloidal activated carbon demonstrate that consistent results can be achieved in the field. The field applications include a CERCLA site in Connecticut, a former fire training site in Canada, and a military training center in Michigan. Finally, advanced groundwater transport modeling was completed to demonstrate containment longevity of the PFAS compounds.

### 3. Kim, Y.S., et al. "Potential PFASs Contamination Sites in Guam"

Y. Kim (University of Guam, kimys@triton.uog.edu), M. Duenas, J, Becanova, R. Lohmann, N. Habana, M. Lander; G. Denton, J. Jenson.

Recent UCMR3 results reveal three Guam Waterworks Authority (GWA) production wells to be contaminated with perfluorooctanesulfonic acid (PFOS). One of these wells (NAS-1) is located inside of the former Naval Air Station at Tiyan, in the village of Barrigada. PFOS concentrations found in this well to date range from 67-110 ng/L. The two other wells (A-23 and A-25) are located in Hagatña, one of the oldest villages on Guam. PFOS concentrations determined in both of these wells to date are consistently above 70 ng/L with maximum levels occasionally exceeding 400 ng/L in well A-25. Both wells are currently off-line. Ongoing PFOS source studies have so far identified four potential contamination sites based on historical records and favorable hydrogeological properties of the surrounding area. These sites include: 1) a defective wastewater pump station that leaked millions of gallons of wastewater into the Chaot River over a 25-year period, 2) Agana swamp which drains the Chaot River and where chronic illegal dumping has occurred since WWII, 3) neighboring ponding basins that direct stormwater into the underlying aquifer, and 4) a nearby air flight crash site. Soil/sediment samples were retrieved for PFOS and other perfluoralkyl analyses from 22 sampling sites overall. Preliminary data are presented and discussed here.

### 4. Fulong, C.R., et al. "Metal-organic Polyhedra as Tunable Agents for Selective Capture and Degradation of Per-and Polyfluoroalkyl Substances (PFASs)".

C. Fulong (Department of Chemistry, University at Buffalo, The State University of New York, Buffalo, NY 14260, USA, cressari@buffalo.edu), M. Guardian, D. Aga, T. Cook

Metal-organic materials (MOMs) such as discrete metal-organic polyhedra (MOPs) and polymeric metal-organic frameworks are known for their interesting properties including well-defined internal cavities, rigid structures, and modular syntheses. These properties enable the use of MOMs in catalysis and energy/molecule capture and storage. Several groups have already demonstrated the ability of MOMs to not only capture organic pollutants in water but also catalyze photodegradation into benign molecules such as CO2 and H2O. An important mechanism for the capture and subsequent degradation of these pollutants is by host/guest interaction, which requires careful design of MOMs to accommodate the guest into its internal cavity. In this work, we evaluated the capacity of MOPs for sequestration and degradation of per- and polyfluoroalkyl substances (PFASs) which are ubiquitous environmental contaminants. We aim to design water-soluble MOPs that can selectively interact with specific chain-lengths of PFASs by tuning the size or introducing high fluorine-affinity functional groups. In this preliminary study, we tested two MOP motifs, a cuboctahedral Cu-based (CuMOP) and a tetrahedral Fe-based MOP (FeMOP), for host/guest interaction with a wide range of PFASs including perfluoroalkylcarboxylic acids, sulfonic acids, sulfonic telomers, and others. Quantification and degradation studies were done using liquid chromatography tandem mass spectrometry. We observed a reduction in PFASs concentration upon addition of both MOPs, with significant reduction of up to 90% for long-chain PFASs and about 10% for short-chain PFASs upon addition of FeMOP. In contrast, addition of pure copper(II) acetate resulted in lower levels of PFASs remaining in solution as compared to addition of CuMOP. In order to better understand the molecular interactions of these MOPs with PFASs, we are now interrogating the interaction of the long-chain PFASs with FeMOP using 19F nuclear magnetic resonance spectroscopy.

### 5. Frazar, E.M., et al. "Smart Polymeric Sorbents for the Selective Removal of PFAS from Contaminated Water Systems"

E. Frazar (Department of Chemical and Materials Engineering, University of Kentucky, molly.frazar@uky.edu), T. Dziubla, J. Hilt

Decades of use of per- and polyfluoroalkyl substances (PFAS) in a multitude of consumer and industry based products have led to an overwhelming amount of soil and water contamination by these compounds. The chemical and thermal stability of PFAS have proved them to be an especially daunting challenge from an environmental remediation standpoint. Presently, the only full-scale water treatment separates via sorption and uses non-selective materials such as activated carbon (AC) or mineral media. However, research focused on selective adsorption is becoming a more practical route for capture and removal from contaminated water systems. This research focuses on the incorporation of stimulus-repsonsive monomers with those that possess cationic properties in order to selectively absorb and desorb PFAS. Polymers are synthesized via free radical polymerization reactions with N-isopropylacrylamide (NIPAAm), various cationic co-monomers and a commercially available cross-linker, N,N'-methylenebisacrylamide (NMBA).
The compositions of the resulting polymeric gels are characterized through Fourier-transform infrared spectroscopy (FTIR), dynamic light scattering (DLS) and swelling studies. Binding studies are conducted by subjecting 2.5 mg/mL of sorbent to 200 ppb of aqueous PFOA for up to 20 h at either 22 ºC or 50 ºC. Systems that showed greatest PFOA removal efficiency are cationic covalently cross-linked poly(NIPAAm) gels exposed at 50 ºC whereas systems exposed at 22 ºC showed significantly less binding. This temperature dependent binding provides sorbents with controllable on/off affinity for PFAS and has the potential to be utilized as a highly regenerative remediation system.

### 6. Ruyle, B., et al. "Transport of Perfluoroalkyl acids and their Precursors in Coastal Groundwater and Surface Water Systems"

B. Ruyle (Harvard John A. Paulson School of Engineering and Applied Sciences, Harvard University, bruyle@g.harvard.edu), H Pickard, E. Sunderland

Poly- and perfluoroalkyl substances (PFASs) are a class of more than 4000 aliphatic fluorinated compounds manufactured for use in firefighting applications (aqueous film forming foam: AFFF) and other industrial and commercial applications. Human health effects associated with exposures to PFASs include cancer, immunosuppression, and metabolic disruption. Many PFASs do not appreciably degrade under environmental conditions and thus their distribution extends globally with the oceans as the terminal sink. However, little is known about the interactions with surface water and groundwater chemistry that affect PFAS transport away from contaminated environments. Here we investigate the hydrological and geochemical factors affecting the downgradient transport of PFASs in six coastal watersheds (three AFFF contaminated systems and three non-point source systems) in Cape Cod, Massachusetts. Perfluoroalkyl acids (PFAAs) are conservatively transported in the rivers and their concentrations measured over a multi-year sampling campaign in an AFFF contaminated watershed show no seasonal variation. These findings provide confirmation that the marine environment is the terminal sink for PFAAs in rivers and that natural attenuation in highly contaminated environments will likely occur over long timescales. PFAA precursors measured by the Total Oxidizable Precursor (TOP) assay do not exhibit the same transport or seasonal invariance, highlighting the impact functional group has on PFAS behavior in surface water and groundwater. Evidence of biological transformation of PFAA precursors is apparent over multi-year timescales by the appearance of 4:2 fluorotelomer sulfonate (4:2 FtS) between a kettle pond and river connected by groundwater flowlines. However, there is no evidence of complete transformation of precursors into PFAAs in faster residence time river systems. These findings suggest that a fraction of PFAA precursors are persistent in aqueous environments and that rivers may be an important and understudied pathway for PFAA precursors to the marine environment.

### 7. Robuck, A.R., et al. "Tissue-specific Distribution of Legacy and Emerging Per- and Polyfluoroalkyl Substances (PFASs) in Seabirds From Atlantic Offshore and Coastal Environments"

A.Robuck (Graduate School of Oceanography, University of Rhode Island, Narragansett, Rhode Island 02882, United States, anna_robuck@uri.edu), J.P. McCord, M.J. Strynar, R. Lohmann

Long-chain per- and polyfluoroalkyl substances (PFASs) demonstrate remarkable environmental persistence, bioaccumulative capacity, and have been found globally in surface water and biota, including birds from diverse habitats. Public health concerns and regulatory attention have caused a shift in PFAS production, causing industry to move away from longer chain perfluorinated structures towards short-chain PFAS analogues or structurally diverse compounds with variable functional groups or fluorination patterns. Seabirds are ideal sentinels to assess the occurrence of both legacy and emerging PFASs in food webs, as their upper trophic level position allows them to assimilate resources and related biological, physical, and chemical conditions across multiple ecosystems and temporal scales. Here, PFASs were measured in multiple tissues from juvenile Atlantic seabirds collected in 2017 and 2018. Species sampled included deceased juvenile or sub-adult herring gulls, great shearwaters, terns, and pelicans from Narragansett Bay in Rhode Island, Massachusetts Bay off the coast of Massachusetts, and the Cape Fear River Estuary (CFRE) in southeastern North Carolina. Samples were analyzed for legacy and emerging PFASs using liquid chromatography/high resolution mass spectrometry, employing both targeted and suspect screening methods. Tissues screened included heart, brain, kidney, lungs, uropygial gland, adipose fat, liver, muscle, blood, and feces. PFOS dominated all liver samples across all individuals and habitats. Emerging compounds previously found in the CFRE system were variably detected in tissues from CFRE chicks, with high inter-individual variability. Emerging compound Nafion byproduct-2 was detected at concentrations similar to or exceeding legacy PFOS in brain and muscular tissues, driven largely by low PFOS concentrations in these matrices in conjunction with significant Nafion byproduct-2 concentrations. Concentrations of emerging compounds decreased significantly in chicks collected from the CFRE system in 2018, suggesting a rapid food web response to cessation of upstream sources.

### 8. Becanova, J., et al. "Characterization of a Fiber Passive Sampler for PFAS Detection at AFFF Impacted Sites"

J. Becanova (STEEP URI, becanova@uri.edu), R. Lohmann

An essential step to prevent the future PFAS exposure is to establish a quick, reliable and robust monitoring tool for the detection of PFAS at potentially contaminated sites in combination with subsequent corrective action (e.g. remedial projects). The use of passive samplers, which has become a routine application for hydrophobic organic contaminants is convenient for the purpose of determining dissolved PFAS concentrations in porewater. Moreover, the passive samplers provide time-weighted average concentrations in water and porewater, which can be used to assess bioavailability of PFASs at contaminated sites.

Solid-phase microextraction (SPME) fibers have been successfully used previously to quantify freely dissolved concentrations of nonionic, anionic, and cationic surfactants. In this work, polyacrylate (PA) fibers were used to determine the equilibrium partitioning constant, KPA-W (the ratio of PFAS concentrations in solution and on the fiber at equilibrium) and factors affecting the partitioning process. SPME fibers were exposed to dissolved 21 PFASs including PFCAs, PFSAs, FOSA, FTSs and GenX for various times (0h to 48h). After exposure, the concentration of PFAS in both, water solutions and fiber extracts were analyzed using LC-MS/MS. Apparent equilibrium was reached within 24 hours and the distribution coefficients were calculated. The values of log KPA_W increase with increasing molar weight/ length of the carbon chain of all analyzed PFASs and vary with PFAS functional group. The follow-up detailed studies of i) water properties effecting the PFAS sorption (pH and salinity) and ii) PFAS concentrations were conducted to characterize robustness of the fiber sampler for their application in various environmental matrixes.

### 9. Gardiner, C., et al. "Characterizing the In-Situ Sampling Rate of a Novel Integrative Passive Sampler for PFASs"

C. Gardiner (University of Rhode Island, Graduate School of Oceanography, 215 South Ferry Rd., Narragansett, RI 02882, clgardiner@my.uri.edu), A. Robuck, J. Becanova, R. Lohmann

Poly- and perfluoroalkyl substances (PFASs) are of growing concern worldwide, due to their ubiquitous presence and adverse health effects in humans and the environment. Surface waters in the northeastern United States in particular have displayed elevated concentrations of PFASs. Passive sampling devices are excellent monitoring tools, that accumulate contaminate loadings through passive diffusion and adsorption to the sampler, and provide a long-term, time-weighted average of the contaminant over large temporal and special scales. Here we utilize a novel integrative passive sampler—a microporous polyethylene (PE) tube filled with Hydrophilic-Lipophilic-Balanced sorbent—to gain a better understanding of its function, utility, and uptake rates in field environments. Two sampling campaigns were conducted in the fall of 2017 and summer 2018, deploying a total of seventy-two PE tube passive samplers across nine sites in a well-mixed estuary and two wastewater treatment plant effluents for one month's duration. Twenty-five PFASs compounds (including carboxylic acids, sulfonates, and precursors) were measured across all sites in the passive samplers, as well as analogous water samples, using Ultra Performance Liquid Chromatography/Mass Spectrometry. In the estuary, the PE tube samplers accumulated a sum PFASs of 2 to 15 ng/sampler, and in the waste water treatment plant effluent 60 to 70 ng/sampler. In situ sampling rates, which are essential when needed to calculate the contaminant concentrations in water, were characterized using a first order kinetic model, yielding sampling rates of 10 to 50 mL/day. Additionally, these results demonstrate that the PE tube samplers up-take PFASs in a similar ratio as observed in water samples. This preliminary study suggests the successful use of these passive samplers for PFASs, and future utility as a monitoring device in aquatic environments to better asses their longevity in water and connected environmental compartments.

### 10. Pickard, H., et al. "Uptake and Effects of PFAS in Fish Exposed to Contaminated Environments"

H. Pickard (Harvard University, hpickard@g.harvard.edu), A. Vajda, C. Vecitis, E. Sunderland

Exposure to poly- and perfluoroalkyl substances (PFASs) has been associated with a suite of negative impacts on human health including immunotoxicity and metabolic disruption. Aqueous film-forming foams (AFFFs) are effective at extinguishing hydrocarbon fire but are a large source of PFAS releases to the environment. Here we use metagenomic analyses to investigate whether exposures to PFASs are associated with specific markers of health outcomes in exposed fish, including immune suppression and changes in metabolism. We experimentally measured PFAS accumulation in freshwater fish along a hydrological transect in Cape Cod, Massachusetts, where groundwater quality has been impacted by historical use of AFFF. Using a mobile laboratory to control chronic exposure scenarios, fathead minnows were exposed on-site over a 21-day period under flow-through conditions to both an area of uncontaminated groundwater and in the vicinity of a fire-training area with known high concentrations of PFAS. PFAS uptake and whole body burden were evaluated using an ion-pairing extraction and liquid chromatography tandem mass spectrometry method. We are currently assessing the contaminant profile in the fish tissues in relation to the aqueous concentrations and are assessing toxicological biomarkers for responses, including transcriptional, metabolic, and endocrine endpoints. Preliminary results thus far show that PFASs with longer carbon chain length and sulfonate head groups preferentially accumulate in fish, with increases in body burden over the 21-day period. Our hypothesis is that this will lead to increased expression of biomarkers for metabolism and immune function.

### 11. Morales-McDevitt, M.E., et al. "Determination of Volatile PFAS in Indoor Air Using PE Sheets"

M. Morales-McDevitt (University of Rhode Island, memdevitt@my.uri.edu), S. Vojta, R. Lohmann

Two types of PE passive samplers differentiated by thickness (25um and 50um) were used to determine the chemical equilibrium (K) of volatile PFAS in indoor air from carpeted environments. The compounds of interest were 6:2 FTOH, 8:2 FTOH, 10:2 FTOH. 8:2 FTAcr, 10:2 FTAcr, MeFOSA, MeFOSE, EtFOSA, and EtFOSE. The PE samplers were deployed at the sites of interest, including their respective field blanks. PE samples were collected at day 1, 2, 4, 8, 15 and 21. All samples were extracted in ethyl acetate and analyzed through GC-MS. It was expected that both types of passive samplers would have the same amount and be in equilibrium within 4 to 8 days of collection. However, only 6:2 FTOF, 8:2 FTOH, and 8:2 FTAcr were above detection limits. It is important to note that the concentration of compounds per g of PE sheet was reduced by half when the weight of the sampler was doubled. The latter suggests that compounds could be sticking to the surface rather than being absorbed. If the manufacturer treats the surface of PE sheets to increase its adhesiveness by adding small amounts of polar polymers, they could retain the tail of the FTOHs. Low flow rates at the sampler–air interface seem to have enhanced the transport resistance of the air boundary layer, causing a shift towards boundary-layer controlled uptake. Thus, taking a longer time to equilibrate. It is possible that the increasing thickness of the sorbent does not necessarily help to maintain the uptake in a linear phase. Our future work will be performed in an environment with high concentrations of volatile PFAS, such as a carpet warehouse. This will provide a better understanding of the partitioning of the volatile PFASs with PE passive samplers.

### 12. Hahn, I. "US EPA's STAR RFA on PFAS: Practical Methods to Analyze and Treat Emerging Contaminants (PFAS) in Solid Waste, Landfills, Wastewater/Leachates, Soils, and Groundwater to Protect Human Health and the Environment"

I. Hahn (Environmental Protection Agency, hahn.intaek@epa.gov)

US EPA's STAR RFA on PFAS: Practical Methods to Analyze and Treat Emerging Contaminants (PFAS) in Solid Waste, Landfills, Wastewater/Leachates, Soils, and Groundwater to Protect Human Health and the Environment. The U.S. Environmental Protection Agency (EPA), as part of its Science to Achieve Results (STAR) program, has sought applications proposing research for more effective, efficient, and practical approaches for estimating PFAS concentrations in solid waste, landfills, landfill outputs such as leachates and wastewaters, and in surrounding environmental media (e.g., air within landfills, soils, surface waters, and groundwater). Proposed approaches, tools, and data should contribute to providing a better scientific understanding of the magnitude of PFAS and, if feasible, lead to more effective, efficient, and practical methods to manage and mitigate PFAS risks. The proposed research would provide the best available science needed to manage PFAS in waste and landfills. The research will also improve the scientific foundation for environmental policy and decision-making related to PFAS and would ultimately reduce risks to human health and the environment from PFAS resulting in cleaner water resources and healthier communities.
Research Areas: • Better understanding and characterization of the types and quantities of current and historical PFAS and PFAS-containing waste associated with waste disposal (e.g., landfills), as well as media containing PFAS released from these activities (e.g., PFAS in leachate collected by landfills or PFAS leaching to subsurface soils and groundwater). • Increased knowledge of the fate, transport, potential for degradation or other changes to PFAS, and their mobility during materials management (e.g., under different landfill conditions such as pH, temperature, moisture content) that facilitate or retard such transformation or movement. • New or improved methods that are more effective and practical in controlling, treating, destroying, or removing PFAS in waste and wastewater, landfill leachates, biosolids, or environmental media.

## 13. Brown, P., et al. "Overview of SSEHRI's PFAS Project Activities"

P. Brown (Northeastern University, p.brown@neu.edu), A. Cordner, L. Richter, J. Ohayon, C. Alder, G. Poudrier, K. Brown, J. Rodriguez, E. Cousins

This poster describes the work of Northeastern University's PFAS Project Lab (www.pfasproject.com). Since the summer of 2015, a group of faculty, post-doctoral scholars, graduate students, and undergraduates affiliated with the Social Science Environmental Health Research Institute at Northeastern have worked with Dr. Phil Brown and Dr. Alissa Cordner on two grants from the National Science Foundation and one from the National Institute of Environmental Health Sciences. Our research team investigates the emergence of lay awareness, government involvement, media coverage, litigation, and advocacy. We collaborate with Toxics Action Center, Silent Spring Institute, the Green Science Policy Institute, Environmental Working Group, Testing for Pease, scientists in academia and state and federal regulatory agencies, and other organizations to track state, industry, and community responses to PFAS contamination. Additionally, we are interviewing residents of communities across the country dealing with this water contamination.

## 14. Tier, Xenia. "PFAS in Europe: Risks and options for risk governance to protect people and the environment."

X. Tier (xenia.trier@eea.europa.eu), S. Dalla Costa, V. Urdanoz, J. Lobo Vicente, M. Uhl, A. Colles, L. Gilles, T. Kold Jensen, L. Palkovičová Murínová.

PFAS consist of more than 4700 man-made chemicals, which all degrade to persistent substances. PFAS therefore accumulate internally in humans and biota (long-chain bio-accumulative PFAS), or externally in the environment (short-chain mobile, water-soluble or volatile PFAS). This is of concern for drinking water and for releases of fluorinated greenhouse gasses. Several PFASs have been linked to various diseases, such as immune-suppression, high cholesterol and cancer. Data for PFOA and PFOS concentrations in human blood available in the Information Platform for Chemical Monitoring (IPCHEM) are presented here. Data was collected within the EU project Human Biomonitoring Initiative for Europe (HBM4EU), the water framework directive and by countries and research programs. Our results confirms other studies, in finding widespread PFAS contamination in water and the blood of European citizens, with highest levels near hot-spot polluted areas, and along major rivers. Extent of exceedances was calculated for PFOS in surface water which has a legal limit value (EQS). For the rest legal limits are not yet in place. Comparisons were therefore made with the provisional European Food Safety Authority Scientific Opinion (2018) on tolerable weekly intakes and BMDL5 in blood, the proposed EU drinking water limits. Significant exceedances were found in all matrices. Exceedances may change, if the provisional EFSA limits change following current discussions on safety factors and mixture effects of PFASs, or if the sensitivities of the test methods (LODs) decrease. A challenge is how to assess newer PFASs for which there is limited toxicity data. An example is the fluorinated ethers which have substituted PFOA-precursors in food contact materials, and PFOA in fluoropolymers (e.g. GenX and Adona). GenX has recently contaminated the surroundings of Dutch and US production plants.
A substance-by-substance approach has so far not protected people, products and the environment from being exposed to toxic PFAS and regrettable substitution within the group of PFAS, e.g. from PFOA to GenX and Adona. This calls for application of the precautionary principle in the risk governance of PFASs, such as:

- Regulation of the whole class or subgroups of PFAS, e.g. for drinking water.
- Develop early warning indicators for single/ groups of PFAS in humans and the environment, that follow trends and provide a link to legislation
- Public and private procurement to avoid non-essential uses of PFASs: Front-running business have already done this for textiles, food packaging, and personal care products.
- Promoting a transition to innovation and up-take of 'Safe-and-circular-by-design' products and chemicals free from non-essential PFASs.

# Session 2

## 15. Rogers, R., et al. "Current ATSDR Activities to Address PFAS Exposure Concerns"

R. Rogers (CDC/ATSDR, idz7@cdc.gov) S. Lane, B. Gerhardstein, A. Pomales, J. Rayman

Human exposure to PFAS is an important public health concern that CDC/ATSDR is helping our local, territorial, tribal, state, and federal partners to address. Over the last decade, interest in PFAS has been growing. CDC/ATSDR and our state health partners are investigating exposure to and possible health effects associated with PFAS in more than 30 communities across the United States. The agency is also developing PFAS-focused tools and resources for states, territories, and affected communities.

ATSDR's overarching approach focuses on assessing and reducing/eliminating community PFAS exposures, by

- Addressing community health concerns related to existing or previous PFAS exposures
- Supporting action on the basis of scientific information, and
- Conducting studies on exposure and health endpoints to provide actionable information to communities and health care providers.

CDC/ATSDR is currently engaged in many PFAS projects, including:

- Multi-Site Health Study
- Pease Study & Historical Dose Reconstruction
- Exposure Assessments
- PFAS Exposure Assessment Technical Tools (PEATT)
- Toxicological Profile for Perfluoroalkyls
- PFAS Guidance for Clinicians
- Development of models to predict PFAS serum levels
- PFAS Research Agenda
- Community Stress and Resilience

Taken together, these PFAS-related activities will fill knowledge gaps, deliver practical tools, and engage communities to address this important public health challenge.

## 16. Long, R., et al. "Conducting a Community Exposure Assessment for Per- and Polyfluoroalkyl Substances (PFAS)-the North Kent County Michigan Experience

R. Long (Michigan Department of Health and Human Services, longr5@michigan.gov) L. Abington, K. Groetsch

Background: Several waste sites containing PFAS have been identified in northern Kent County in Western Michigan; these have resulted in the highest private drinking water well PFAS concentrations found in the state. Wells in this area have detectable levels of up to 24 PFAS analytes.

Methods: In response to the PFAS contamination in Kent County, the Michigan Department of Health and Human Services (MDHHS) Division of Environmental Health, in partnership with the Kent County Health Department, invited selected households from Kent County, Michigan (n=416) to participate in an exposure assessment based on the Agency for Toxic Substances and Disease Registry PFAS Exposure Assessment Technical Tools (PEATT) from the fall of 2018 to the spring of 2019. This sample of homes was stratified into high (>70 ppt) and low (≤70 ppt) exposure strata based on preliminary water PFAS levels. Recruitment efforts have included letters, phone calls, and door-knocking to reach our target sample size of 400 participants from each exposure stratum. Participants' blood serum and samples of their private drinking well water are tested for 24 PFAS analytes using an isotope dilution method and standardized lab procedures. Participants also complete a questionnaire to identify occupational, dietary, and other factors that influence blood serum PFAS levels.

Findings: The project is ongoing; to date, we have enrolled 175 sampled homes (42% of those invited) and 423 participants, 57% of whom are from the high exposure stratum. The design, implementation, challenges, and lessons learned will be presented. This assessment exemplifies commitment to public health action around emerging contaminants in Michigan and will serve as a model for future assessments conducted via state-local partnerships.

## 17. Dalsager, L., et al. "Prenatal PFAS Exposure and Childhood Hospitalization Due to Infectious Disease"

L. Dalsager (Department of Environmental Medicine; Institute of Public Health, University of Southern Denmark, Odense, Denmark, ldalsager@health.sdu.dk), N. Christensen, F. Nielsen, P. Grandjean, H.B Kyhl, H.C, Anderson, H.R. Andersen, T.K. Jensen

Background: TPerfluoralkyl substances (PFAS) are manmade chemicals widely used in consumer products. PFAS accumulates in the environment and are present in human blood samples worldwide. The immunosuppressive properties of PFAS are widely recognized, and early-life exposure have been linked to reduced immune response to vaccination and increased rates of common infections. A study from 2010 previously investigated the relationship between perfluorooctane sulfonic acid (PFOS) and perfluorooctanoic acid (PFOA), and hospitalization due to any infectious diagnosis up to age 11 years but found no associations. Aim: To investigate the association between maternal serum concentrations of five major PFAS during pregnancy and the rate of hospitalization due to common childhood infections. Methods: Participants were derived from the Odense Child Cohort (OCC), which is an ongoing mother-child cohort in Denmark. Serum samples from 1699 pregnant women (gestational week 10-16) were analyzed for concentrations of PFOS, PFOA, perfluorohexane sulfonic acid (PFHxS), perfluorodecanoic acid (PFDA) and perfluorononanoic acid (PFNA). Data on symptoms of infectious disease were first collected prospectively during a one-year period when the children were 2-4 years of age from a biweekly questionnaire to the mothers by cell phone texting. A positive association between PFOS and PFOA concentrations, and the reported number of days with fever was seen. The children are now followed until a mean age of 7.1 years on hospitalization with an ICD-10 code for infection from the Regional Health Authorities. Diagnoses of infections are grouped into four categories: upper respiratory tract infections, lower respiratory tract infections, gastrointestinal infections and other infections. Multiple regression models are used to investigate the association between the PFAS exposures and the rate of hospitalization within the four categories of infections.

## 18. Timmermann, C.A.G., et al. "Decreased Vaccine Response in Guinea-Bissau Children Exposed to Perfluoroalkyl Substances"

C. Timmermann (Department of Environmental Medicine, University of Southern Denmark, atimmermann@health.sdu.dk), K.J Jensen, F. Nielsen, E. Budtz-Jørgensen, C.S. Benn, P. Grandjean, A.B. Fisker

Background: Perfluoroalkyl Substances (PFASs) have previously been associated with immunotoxicity in experimental models, and with increased risk of common colds, gastroenteritis, and fever and with decreased antibody concentrations after routine immunizations in Nordic children. However, no previous studies have explored health effects of PFASs in an African setting. The present study aimed to examine the association between infant PFAS exposure and immune responses to measles vaccination as well as fever and diarrhoea among children in Guinea-Bissau, West Africa. Methods: A total of 237 children enrolled in a randomised trial were studied. Half the children received a measles vaccination at both inclusion (4.5 months) and 9 months of age; the other half received a measles vaccination at 9 months only (current recommendation). Quantitative measles antibody levels were assessed at inclusion, 9 months, and 2 years of age in finger prick blood samples. At inclusion and 9 months, mothers were interviewed about infant morbidity. Five PFASs, i.e. perfluorohexane sulfonic acid (PFHxS), perfluorooctane sulfonic acid (PFOS), perfluorooctanoic acid (PFOA), perfluorononanoic acid (PFNA), and perfluorodecanoic acid (PFDA), were quantified in serum at inclusion. Findings: All children had detectable serum concentrations of all five PFASs. Among the children who received measles vaccine at inclusion, a doubling in PFOS and PFDA was associated with 22% (95% CI: 2-37%) and 26% (95% CI: 2-44%), respectively, lower measles antibody concentrations at age 9 months. We also saw tendencies of reduced pre-vaccination (maternal) measles antibody concentrations at elevated serum-PFAS concentrations. Likewise, we saw consistent tendencies towards increased odds of fever and diarrhoea with higher serum-PFAS concentrations, though not statistically significant. These results from a study of low exposed West African children adds to the burden of evidence suggesting that PFASs are immunotoxic for infants even in small concentrations.

## 19. Shelly, C.E., et al. "Early Life Exposures to Perfluoroalkyl Substances in Relation to Adipokine Hormone Levels at Birth and During Childhood"

C. Shelly (Harvard T.H. Chan School of Public Health, cshelly@mgh.harvard.edu), P. Grandjean, P. Plomgaard, R. Frikke-Schmidt, D. Zmirou-Navier, P. Weihe, D. Valvi

Background: Birth cohort studies have linked exposure to perfluoroalkyl substances (PFASs) with child anthropometry. Metabolic hormone dysregulation needs to be considered as a potential adverse outcome pathway. We examined the associations between PFAS exposures and concentrations of adipokine hormones from birth to adolescence.
Methods: We studied 80 mother-child pairs from a Faroese cohort born in 1997-2000. Five PFASs were measured in maternal pregnancy serum and child serum at ages 5, 7 and 13 years. Leptin, adiponectin and resistin were analyzed in cord serum and child serum at the same ages. We fitted multivariable-adjusted generalized estimating equations to assess the associations of PFASs at each age with repeated adipokine concentrations at concurrent and subsequent ages.
Results: We observed tendencies of inverse associations between PFASs and adipokine hormones specific to particular ages and child sex. Significant associations with all adipokines were observed for maternal and child 5-year serum PFAS concentrations, whereas associations for PFASs measured at ages 7-13 years were mostly null. The inverse associations with leptin and adiponectin were mainly seen in females, whereas the inverse PFAS associations with resistin levels were mainly seen in males. Estimates for significant associations (at p-value<0.05) suggested mean decreases in hormone levels (range) by 38%-89% for leptin, 16%-70% for adiponectin, and 33%-62% for resistin for each 2-fold increase in serum-PFAS concentrations.
Conclusions: These findings suggest adipokine hormone dysregulation in early life as a potential pathway underlying PFAS-related health outcomes, and underscore the need to further account for susceptibility windows and sex-dimorphic effects in future investigations.

## 20. Pomales, A., et al. "CDC/ATSDR PFAS Exposure Assessments: Communication and Community Engagement Strategies"

A.Pomales (CDC/ATSDR, fwa9@cdc.gov), B. Goodwin, R. Rogers, M. Karwowski, P. Kowalski, K. Scruton, K. Durocher, J. Sautner, C. Gaines, M. Sones, H. Tian, C. Reh

Human exposure to PFAS is a public health concern that has generated increased attention. To provide clues about sources of exposure, CDC/ATDSR is conducting exposure assessments in communities near current or former military bases that are known to have had PFAS in their drinking water.
The primary goal of these exposure assessments is to provide information to communities about levels of PFAS in their bodies. For each of the exposure assessment communities, a random selection of households impacted by PFAS in their drinking water will be identified. Eligible participants will be asked to provide a blood and urine sample, and answer a questionnaire. The exposure assessments will also measure levels of PFAS in water and dust from some homes.
The results of these exposure assessments will help individual participants and their communities better understand their exposure to PFAS and provide information that the communities can use to reduce PFAS exposure. Furthermore, the benefits of the exposure assessments will extend beyond the communities identified, as the lessons learned can also be applied to communities facing similar PFAS drinking water exposures.
CDC/ATSDR is developing a suite of community engagement and communications tools to ensure that community members in each of the exposure assessment sites are kept regularly updated about CDC/ATSDR activities and have an opportunity to provide input and insight. Further, CDC/ATSDR is developing educational materials for a wider audience of stakeholders who may be grappling with concerns related to PFAS exposure.

## 21. Deng, P., et al. "Mixture-specific Gene Expression and Lipid Profile in Mice Exposed to Perfluorooctane Sulfonic Acid and PCB 126"

Perfluorooctane sulfonic acid (PFOS) and PCB126 are persistent organic pollutants of high concern because of their environmental persistence, bioaccumulation and toxic properties. Besides, due to the same human exposure route of PFOS and PCB126, there could be interactions in the toxicity of these two chemicals. The present study aimed at identifying the interactions and whether PFOS is capable of modifying the PCB126-related toxicity pathways. For this purpose, male and female C57BL/6 mice were exposed to vehicle, 5 μmol/kg of PCB126 (male mice), 250 mg/kg of PFOS (male mice), or a mixture of PFOS and PCB126. Plasma and liver samples were collected 48 h after dosing. Quantitative PCR was performed on liver RNA to investigate expression changes of genes involved in oxidative stress (Nrf2, Nqo1), inflammation (Tnf-alpha IL1-beta, Icam1), and atherogenic mechanisms (Pparg, Sele, PAI1). Plasma global lipidomic analysis was performed using an UHPLC-Q Exactive Orbitrap mass spectrometer. It was found that Nqo1 and PAI1 expressions were not significantly induced by PCB126 or PFOS, however, after co-exposure the expressions of these two genes were significantly higher than mice exposed to each chemical along. Similar inductions were observed in female mice. Plasma levels of phospholipids and glycerolipids decreased in co-exposed mice compared with PCB126-treated mice, on the contrary, redox-related oxidized lipids increased in co-exposed mice. Our study demonstrated that there is synergistic effect of PFOS and PCB126 on redox and atherogenic genes, and PFOS could exacerbate PCB126-induced lipid oxidation, suggesting that PFOS may change PCB126 toxicity. This study underlines the importance to integrate mixture effects of chemicals in risk assessment and biomonitoring frameworks.

## 22. Wang, C., et al. "PFOS Modifies PCB 126 Induced Inflammation in Macrophages"

C. Wang (University of Kentucky, pde233@uky.edu), C. Wang, M. Petriello, J. Hoffman, J. Barney, A. Morris, B. Hennig

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Perfluorooctane sulfonate (PFOS) is one of the most common environmental perfluoroalkyl substances (PFAS), and is a major concern to human health risks. Accumulating evidence shows that PFOS can contribute to a range of adverse health effects, such as immunotoxicity and cardiovascular toxicity. Macrophages play a key role in the immune responses related to the development of atherosclerosis. Since our previous study showed that PCB 126 can induce macrophage polarization associated with inflammation, we decided to explore the interaction between PCB 126 and PFOS on macrophage related inflammation. We
hypothesize that PFOS will alter the immune responses in macrophages associated with PCB 126 exposure. To test this hypothesis, human monocytes (THP-1, PBMCs) were differentiated to macrophages and subsequently exposed to PFOS, PCB 126, and PFOS + PCB 126, respectively. PFOS significantly suppressed the expression of inflammatory cytokines that were induced by PCB 126 in THP-1 derived macrophages, including TNFα, IL-1β, IL-8, CCL3, and CCL4. In macrophages derived from human primary monocytes (PBMCs), PFOS showed a similar but less marked immunosuppressive effect on inflammatory cytokine expression. In addition, the redox-sensitive genes nuclear factor (erythroid-derived 2)-like 2 (NFE2L2) and NAD(P)H quinone oxidoreductase 1 (NQO1) that were induced by PCB 126, were suppressed in THP-1 derived macrophages but not in PBMCs derived macrophages, when combined with PFOS exposure. Additionally, plasminogen activator inhibitor-1 (PAI-1), which is a risk marker for thrombosis and atherosclerosis, was synergistically induced by the combination of PFOS and PCB 126 exposure only in PBMCs derived macrophages. Our data demonstrate the involvement of PFOS in modulating immune responses in macrophages, indicating another important role of PFOS immunotoxicity and associated cardiovascular risk. These data may provide a new insight into cytotoxic interactions of PFOS with other POPs (e.g., PCBs). (Supported in part by NIEHS/NIH grant P42ES007380)

## 23. Lin, P.B., et al. "Association Between Diet and Plasma Concentrations of Perfluoroalkyl and Polyfluoroalkyl Substances"

P. Lin (Harvard Medical School and Harvard Pilgrim Health Care Institute, p_lin@harvardpilgrim.org), A.Cardenas, R.Hauser, D.R. Gold, K.P. Kleinman, M.F. Hivert, A.F. Fleisch; T.F. Webster, E.S. Horton, M. Sanchez-Guerra, C. Osorio, E. Oken.

Background: In December 2018, the European Food Safety Authority (EFSA) issued provisional tolerable weekly intakes (TWIs) for two widespread perfluoroalkyl and polyfluoroalkyl substances (PFASs); PFOA and PFOS. Diet is a one of the main sources of exposure to PFASs, but limited information is available on the association between diet and circulating blood levels of PFASs. This study aims to provide late-breaking evidence on dietary characteristics associated with variation in plasma PFAS concentrations. Methods: We evaluated cross-sectional associations between diet and plasma PFAS concentrations among prediabetic adults enrolled in the Diabetic Prevention Program 1996-1999. We used weighted quantile sum (WQS) regression to estimate the total effect of the dietary mixture on plasma concentrations of each PFAS, adjusted for age, sex, race, marital status, education, income, smoking, waist circumference and total caloric intake. We developed two weighted dietary indices for each PFAS, one constrained to be positively and one constrained to be negatively associated with PFAS concentrations. Results: Participants (N=941; 65% female, 58% Caucasian, 68% married, 75% with higher education, 95% nonsmoker) had similar plasma PFAS concentrations compared to the general US population measured in 1999-2000. A "positively constrained" WQS index was associated with MeFOSAA [β=0.18, (95% CI: 0.09, 0.27)], and within the mixture, intakes of sweets/dessert had the highest weight (14%), followed by meat (12%), fish/shellfish (11%), and grains (10%), and coffee/tea (9%). A "positively constrained WQS index was also associated with PFNA [β=0.19, (95% CI: 0.13, 0.32)], and the predominate dietary contributions came from other fish/shellfish, poultry, sweets/dessert, and dairy. The "negatively constrained" WQS indices were predominately composed of vegetable food groups and associations with PFAS concentrations were not statistically significant. Conclusion: WQS regression can be a useful method to identify food items and diet mixture associated with elevated PFAS exposure; however, it should be used in conjunction with other dietary pattern analyses to provide a more comprehensive dietary assessment for health outcome studies.

## 24. Jensen, R.C., et al. "Prenatal Exposure to Perfluoroalkyl Substances is Associated with Increased Markers of Adiposity and Total Cholesterol in Infancy"

R. Jensen (Department of Environmental Medicine, University of Southern Denmark, DK, rcjensen@health.sdu.dk), M. Andersen, P. Larsen, D. Glintborg, C. Dalgård, A. Timmermann, F. Nielsen, M. Sandberg, H. Andersen,; H. Christesen,; P. Grandjean, T. Jensen

Background and aim: Perfluoroalkyl substances (PFASs) are surface repellants with putative endocrine disrupting properties. PFASs cross the placental barrier enabling interference with fetal programming. In the present study, we investigated longitudinal associations between maternal PFAS concentrations in first tri-mester and repeated markers of adiposity and lipid metabolism in offspring up to 18 months of age. Design and methods: Odense Child Cohort is a prospective study including 2,874 mother-child pairs. We measured maternal serum concentrations of five PFASs: Perfluorohexane sulfonic acid (PFHxS), perfluorooctane sulfonic acid (PFOS), perfluo-rooctanoic acid (PFOA), perfluorononanoic acid (PFNA), and perfluorodecanoic acid (PFDA) in 649 women (median gestation-al week 11). Offspring clinical examinations were conducted at birth (N=613), three months (N=602), and 18 months (N=530) of age. Total cholesterol (TC), LDL, HDL, and triglyceride were evaluated at ages three months (N=260) and 18 months (N=198). Mixed-effects linear regression models estimated associations between maternal pregnancy PFASs and repeated standardized (SDS) ponderal index in offspring. Associations between maternal PFASs and body fat % (BF%) SDS and plasma lipids SDS at ages three and 18 months were investigated with linear regression models. Results: PFOA, PFNA, and PFDA were associated with higher ponderal index SDS (PFDA, β=1.04 (95 % CI: 0.41, 1.66)) at ages three and 18 months in girls. PFOA, PFNA, and PFDA were associated with increased BF% SDS (PFDA, β=0.42 (95 % CI: 0.06, 0.77)) at three months of age in boys and girls. PFDA was associated with increased TC SDS (β=1.30 (95 % CI: 0.18, 2.42)) at 18 months of age in girls. Conclusions: Maternal first trimester PFASs were associated with increased longitudinal markers of adiposity and higher total cholesterol in offspring.

## 25. Khalil, N., et al. "The Association of Perfluoroalkyl and Polyfluroralkyl Substances Exposure and Renal Function in the NHANES 2015-2016 Population"

N. Khalil (Wright State University, naila.khalil@wright.edu), Katelynn, Sabrina

Background: Perfluoroalkyl and polyfluoroalkyl substances (PFASs) are manufactured compounds widely used in consumer products. Limited evidence from human and laboratory studies suggests that PFASs can impact renal function via toxicity on glomerular endothelial cells and oxidative stress in a sexually dimorphic manner.
Methods: A cross-sectional analyses of data from 1953 participants aged 12 or older from 2015–2016 National Health and Nutrition Examination Surveys was completed. Five serum PFASs analytes were assessed including Perfluorooctanoic acid (n-PFOA), perfluorononanoic acid (PFNA), perfluorohexane sulfonic acid (PFHxS), and two analytes of perfluorooctane sulfonic acid (n-PFOS) and sum of perfluoromethylheptane sulfonate isomers (Sm-PFOS). Serum creatinine was assessed as biomarker of renal function.
Findings: In confounder adjusted analysis, as compared to the lowest tertile of serum PFASs, the medium and high tertiles had a significantly increased risk of elevated serum creatinine levels for all five analytes. Strongest association was observed for Sm-PFOS where the medium tertile had 95% higher risk: 1.95 (95% CI: 1.47 to 2.59, p<.001) and the highest tertile had 149% higher risk: 2.49 (95% CI: 1.78 to 3.48, p<.001) of elevated serum creatinine, respectively. In both men and women strongest association was also seen for Sm-PFOS with 198% and 177% higher risk of elevated serum creatinine, respectively. An increasing dose-response relationship was seen for n-PFOA, n-PFOS.
These results support existing limited findings that PFASs are associated with reduced renal function. Future longitudinal studies can examine if declining US population PFASs exposure is reflected in renal function assessments.

## 26. Khalil, N., et al. "Perfluoroalkyl Substance Exposure and Lung Function in the US Population"

N. Khalil (Wright State University, naila.khalil@wright.edu), B. Heinle, T. Crawford, S. Paton

Background/Aim: Perfluoroalkyl substances (PFASs) are chemicals compounds used in consumer products and are linked with increase in cholesterol, thyroid disease, and pregnancy-induced hypertension. However, their association with lung function is not completely understood.
Methods: Cross sectional 2011-12 U.S. population data from the National Health and Nutrition Examination Survey (NHANES) was used. Serum concentration of four PFASs, perfluorononanoic acid (PFNA), perfluorooctanoic acid (PFOA), perfluorooctane sulfonic acid (PFOS), and perfluorohexane sulfonic acid (PFHxS) were assessed using mass spectrometry and were categorized into tertiles. Lung function was measured by spirometry as forced vital capacity (FVC), forced expiratory volume in one second (FEV1), and the ratio of FVC/FEV1 (%). Sex stratified adjusted linear regression analysis was used to predict lung function with PFASs tertiles.
Findings: In men (n=1450, aged 12 to 79 years, 52% men) all four PFASs serum concentrations and lung function was higher, except FVC/FEV1 (%) which was lower than women (p<.001 for all). In men, compared with low tertiles, high exposure to PFOS, PFNA, predicted a significant decrease in FEV1 and FVC, respectively, and PFOA, PFOS, and PFHxS predicted significant low FVC/FEV1 (%) in unadjusted models. In women, compared with low tertiles, high exposure to all PFASs predicted a significant decrease in FEV1, FVC and FVC/FEV1 (%) (except PFHxS in FVC), respectively, in unadjusted models (p<.001). No association was seen in adjusted models in both men and women.
High PFASs exposure has a consistent significant negative impact on female lung function in unadjusted analysis and this association needs further exploration.

## 27. Khalil, N., et al. "Perfluoroalkyl Substances and Metabolic Syndrome in Firefighters"

N. Khalil (Wright State University, naila.khalil@wright.edu), D. B. Leary, M. Takazawa K. Kurunthachalam

Background: Perfluoroalkyl substances (PFASs) are man-made chemicals used widely in aqueous film forming foams (AFFF). Firefighters (FF) at airports are expected to have higher PFASs exposure due to regular contact with AFFF compared to civilian firefighters and the general population. PFASs are persistent, bioaccumulative, and are associated with adverse cardiometabolic profiles. Methods: The cross sectional study assessed 47 male FF ages 18-62 years at an airport and a civilian unit in Ohio and 604 males aged 19-62 years from the 2015-2016 National Health and Nutrition Examination Survey. Association between metabolic syndrome (MetS) and serum concentrations of four PFASs, perfluorooctane sulfonic acid (PFOS), perfluorooctanoic acid (PFOA), perfluorohexane sulfonic acid (PFHxS) and perfluorononanoic acid (PFNA) was evaluated using multivariable logistic regression. Findings: Except PFNA, PFASs serum concentrations were 18-74% higher in FF than the general population, and 21-62% higher in airport FF than civilian FF. Serum PFOS (ng/mL) and mean diastolic blood pressure (mmHg) were significantly correlated (rs (45) = .297, p=.047) in FF and (rs (59) = .135, p=.001) in NHANES. In FF, the adjusted odds of MetS were 46% (OR 0.54; 95% CI 0.85 to 3.43), 33% (OR 0.67; 95% CI 0.24 to 1.86), 65% (OR 0.35; 95% CI 0.05 to 2.35), and 23 % (OR 0.77; 95% CI 0.25 to 2.71) lower for unit increase in serum PFOA, PFOS, PFNA, PFHxS concentrations, respectively (all non-significant). In NHANES adult males, the adjusted odds of MetS were 33 % (OR 0.67; 95% CI 0.40 to 1.13), 32 % (OR 0.68; 95% CI 0.43 to 1.08), 28 % (OR 0.72; 95% CI 0.43 to 1.19) 19 % (OR 0.81; 95% CI 0.54 to 1.21) lower for unit increase in serum PFOA, PFOS, PFNA, PFHxS concentrations, respectively (all non-significant). Current serum PFASs in FF and US adult males are not associated with elevated risk of MetS.

## 28. Gigot, C., et al. "PFAS Exposure Variability Across Biological Media and Critical Windows of Susceptibility: Risk Assessment"

C. Gigot (Oak Ridge Associated Universities (ORAU) Environmental Health Assessment Support, U.S. Environmental Protection Agency National Center for Environmental Assessment gigot.carolyn@epa.gov), J. Michael Wright, Elizabeth Radke.

Background: Prenatal exposure to per-and polyfluoroalkyl substances (PFAS) may impact neonatal development. Examining which PFAS co-occur, to what extent, and with what level of variability across time and space is necessary to evaluate the appropriateness of limited sampling data and to assess the potential for confounding and exposure misclassification. Methods: As part of a systematic review, 21 epidemiological studies of developmental endpoints and PFAS exposure were identified that reported correlation coefficients between different PFAS. Sixteen reported PFAS correlations in maternal blood, plasma, or serum; five in umbilical cord blood or serum; one in child serum. Correlations between PFDA, PFNA, PFHxA, PFHxS, PFBA, PFOS, and PFOA were compiled. Results: Correlations varied across different PFAS and matrices, with the most consistent relationship between PFDA and PFNA: all 10 studies examining maternal samples found correlations above 0.6, as did three of four using cord samples. PFDA and PFHxS correlations were weaker: 0.07-0.44 in nine studies with maternal samples; 0.07-0.29 in three studies of cord samples. Substantial variability was evident for all other pairs: 0.01-0.75. Only one study calculated correlations between PFAS in both maternal and cord samples: for PFHxS and PFOS, 0.57 versus 0.43, respectively; for PFHxS and PFOA, 0.23 versus 0.07; between-matrix correlations for PFNA, PFHxS, PFOS, and PFOA were all >0.83. Conclusions: The strong correlations between PFDA and PFNA and variability observed between PFAS examined here necessitate careful consideration of different approaches to address potential confounding in epidemiological studies from PFAS co-exposures, especially given recent bias amplification analyses from multipollutant modeling. Limited data on within-PFAS variability across different matrixes precluded a definitive conclusion on exposure misclassification, especially for PFAS with shorter half-lives. Ongoing analyses will examine the impact of different predictors of the within- and between-matrix variability and how these relationships influence consideration of exposure misclassification and confounding in risk assessment.

## 29. Oulhote, Y., et al. "Gestational Perfluoroalkyl Concentrations and Thyroid Hormone Levels in Faroese Pregnant Women and Neonates: A Prospective Cohort Study"

Y. Oulhote (Department of Environmental Health, Harvard T. H. Chan School of Public Health, Boston, MA, youlhote@umass.edu), C. Xiao, P. Grandjean D. Valvi, F. Nielsen, P. Weihe.

Background: Exposure to perfluoroalkyl substances (PFASs) may disrupt maternal and neonatal endocrine function. Adequate thyroid hormone (TH) levels during pregnancy are essential for ensuring optimal fetal and early childhood development. Objective: To assess the relationship between gestational PFAS exposures and maternal and cord TH levels. Methods: Data was collected from a cohort of 182 mother-child pairs from 1994-1995 in the Faroe Islands. The concentrations of 17 PFASs, including perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA) were measured in maternal serum. Maternal and cord serum were measured for THs such as thyroid stimulating hormone (TSH), free thyroxine (FT4), thyroxine (T4), free triiodothyronine (FT3), free triiodothyronine resin uptake (T3RU), and free T4 index (FTI). We examined relationships between PFAS concentrations and TH levels using multivariable regression models as well as effect measure modification in sex-stratified analyses. Results: PFAS concentrations were mostly positively associated with both maternal and fetal TSH, with PFOS and PFOA having the strongest estimates. Doubling PFOS and PFOA concentrations were associated with 49% (95% CI: 18, 87%) and 33% (95% CI: 11, 59%) increase in cord TSH concentrations respectively. Perfluorooctanesulfonamide (PFOSA) was negatively associated with maternal FT4 and T3RU but positively associated with cord T4 and FTI levels. In mothers carrying female fetuses, doubling PFOS concentrations was associated with a 54% (95% CI: 14, 109%) increase in maternal TSH, but not in mothers bearing male neonates (-5%; 95% CI: -27, 24%). We did not observe consistent patterns for sex-stratified associations between gestational PFAS concentrations and cord TH levels. Conclusions: Based on our results, prenatal exposure to several PFASs during pregnancy, such as PFOS and PFOA, is associated with increases in infant TSH levels. PFOS may also affect maternal TSH levels depending on the fetus's sex. The implications of the latter result are still to be understood.

## 30. Pfohl, M., et al. "An 'Omics Approach to Unraveling the Paradoxical Effect of Diet on PFOS and PFNA Induced Non-alcoholic Fatty Liver Disease (NAFLD)"

M, Pfohl (University of Rhode Island, marisa_pfohl@uri.edu),H. Ma, URI; M. Aubustan, URI; E. Marques, URI; N. Seeram, URI; and A. Slitt, URI.

It is estimated that over 30% of the population present with non-alcoholic fatty liver disease (NAFLD) in the United States. The role of environmental exposures as risk factors for fatty liver disease is not well known. Perfluorooctanesulfonic acid (PFOS) and perfluorononanoic acid (PFNA) are widespread environmental toxicants that persist in over 98% of the general population. The aim of this study was to evaluate whether PFOS or PFNA exposure in combination with a moderately high-fat diet, augmented hepatic lipid content and biomarkers associated with NAFLD. Six-week-old C57BL/6 mice were fed either a 10% kCal low fat diet (LFD) or 45% kCal high fat diet (HFD), with or without 0.0003% PFOS or PFNA for twelve weeks. An untargeted genomic array was used to assess global PFOS/PFNA induced alterations in hepatic transcriptomic profiles. IPA software was used to explore and visualize the impacted lipid associated pathways. A targeted array was used to further explore and confirm the mechanism of PFOS/PFNA induced steatosis within a LFD or HFD diet. Protein level changes were explored using SWATH proteomics. The mechanisms of PFOS and PFNA were compared and the additional impact of diet on these mechanisms was assessed. Both PFOS and PFNA treatment resulted in significantly increased expression of fatty acid uptake genes cluster of differentiation 36 (CD36) and solute carrier family 27 member 1 (Slc27a1), while they exerted opposing effects on fatty acid synthesis (FAS) expression. PFNA exposure resulted in more profound effects on gene and protein expression overall when compared to PFOS. Diet exerted an additional impact on the mechanisms and potency of PFOS and PFNA in the liver. The data suggests that PFOS and PFNA at an exposure relevant dose (0.0003%) may have an adverse effect on hepatic lipid accumulation when combined with a LFD. The paradoxical impact of diet on the mechanism and potency of PFOS and PFNA is described herein.

31. **Messmer, M.F., et al. "Systematic Review and Meta-Analysis: Exposure to Perfluorinated Alkyl Substances - Health Outcomes in Children and Impacts on Human Fertility"**

M.F. Messmer (Georgetown University, mm3875@georgetown.edu) JS Salloway, N.M. Shara

Background: Debate persists about whether there is sufficient science to support policy changes between industry, regulators, policy makers, and public health officials. New Jersey, Massachusetts, Vermont, and Minnesota have proactively adopted or proposed more stringent drinking water criteria for perfluorinated alkyl substances (PFAS). Currently, New Hampshire regulators are debating lowering the appropriate drinking water standards and whether additional PFAS compounds should be regulated to protect public health.

Methods: The study protocol includes a systematic review in accordance with the general principles recommended in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (Moher et al., 2010). Participants: Pregnant women, men, and children up to 19 years old. Studies on general or occupational populations were also eligible if results were stratified by sex (specifying the pregnant status of women) or age of the children, and only those results were included in this review. Exposures: Studies on direct measurement of PFAS in a biological matrix or indirect exposure estimations. Comparators: Continuous PFAS levels or groups categorized according to individual PFAS levels if at least one or more of the four chemicals (PFHxS, PFOA, PFOS, PFNA) or the generic PFC, PFAA, and PFAS were included. Outcomes: The review captures current available human studies examining associations between PFAS and immunity/infection/asthma, cardiometabolic, neurodevelopment/attention, thyroid, renal, puberty, adiposity, male sperm quality/quantity, testosterone, infertility, TH levels (thyroid-stimulating hormone [TSH], total triiodothyronine [TT3], free T3 [FT3], thyroxin [T4], and free T4 [FT4]) or thyroid dysfunctions. Study design: Cross-sectional, case-control, longitudinal, and cohort studies.

Findings: The poster presents a summary of a robust, systematic review performed to assess exposure to PFAS and health outcomes in children and measures of human fertility to inform scientists and regulators about the current state of the science on the public health threats. to provide information crucial for developing science-based policy.