Summary of Expert Discussion Forum on Possible Human Health Risks from Microplastics in the Marine Environment

EPA Forum Convened on April 23, 2014

Marine Pollution Control Branch

Office of Wetlands, Oceans and Watersheds

U.S. Environmental Protection Agency

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Contents

Appendices

Participating Experts

Anthony Andrady, Adjunct Professor, North Carolina State University

Mark Browne, Postdoctoral Fellow, University of California, Santa Barbara

Jim Bus, Senior Managing Scientist in Toxicology and Mechanistic Biology, Exponent, Inc.

Richard Engler, Program Manager of Green Chemistry Program, Environmental Protection Agency, Headquarters

Mark Hahn, Senior Scientist and Chair of the Biology Department, Woods Hole Oceanographic Institution

Rolf Halden, Director of Center for Environmental Security, Biodesign Institute at Arizona State University

Rob Hale, Professor of Marine Science, Virginia Institute of Marine Science; College of William and Mary

Kara Lavender Law, Professor of Oceanography, Sea Education Association

Christopher Reddy, Senior Scientist of Marine Chemistry and Geochemistry, Woods Hole Oceanographic Institution

Chelsea Rochman, Postdoctoral Scholar at the School of Veterinary Medicine, University of California, Davis

Irv Shultz, Scientist, Marine Science Laboratory, Pacific Northwest National Laboratory

Introduction

The ever-increasing volume of trash, litter, and debris entering inland waterways, coastal waters, and oceans presents a challenge to water quality and habitat protection that warrants attention. Trash has become a pervasive problem in these environments, causing aesthetic blight, ecological effects, economic impacts, and possible human health risks.

Land-based sources account for a majority of trash in the ocean and coastal environments. Land-based trash that is disposed of improperly can enter freshwater and coastal ecosystems and eventually make its way to the ocean. EPA has established the national Trash Free Waters (TFW) program to encourage collaborative actions by public and private stakeholders to prevent trash from entering water (http://water.epa.gov/type/oceb/marinedebris/). Through EPA analysis, communication, policy and program development, and support for strategic planning, the Agency can be a catalyst for proactive prevention and reduction actions by government, businesses, and citizens to keep trash out of water.

Aquatic trash consists of many different types of products and materials, including commonly found plastic items such as bags, bottles, food containers and wrappers, and service ware. In the marine environment, plastic trash is associated with direct impacts on marine life via strangulation, ingestion, or other physical harm. In addition to these impacts, there is a growing concern about the potential for microplastic particles (plastic trash broken into smaller pieces) and their associated toxic chemicals to contribute to human health risks as the microplastics and toxics move through the marine food web.

Plastic particles are widely distributed in the surface waters and sediments of oceans. Microplastics have the potential to both sorb and desorb chemicals in the marine environment; these chemicals may be persistent, bioaccumulative, and toxic (PBT). Toxic impacts on marine species due to ingestion of plastic particles are not well understood, but are being explored. There also is scientific uncertainty about the potential for bioaccumulation of PBTs from microplastics in the marine food web and for risks to human health due to contaminated seafood consumption.

To gain further insights on these issues, EPA's Office of Water contracted with the National Research Council (NRC) to convene subject-matter experts in a discussion forum to consider possible human health risks from microplastics in the marine environment. NRC identified and invited national experts who have conducted research and published papers on this issue. Participation in the forum was by invitation only and the meeting was not open to the general public. A limited number of individuals from a range of constituencies were invited to attend and observe as well.

Purpose of the Discussion Forum

The purpose of the forum was to discuss available data and studies on the issue of possible human health risks from microplastics in the marine environment. The participating subject-matter experts were asked to provide insights on the current scientific basis for determining human health risks, based on a review of scientific research done to date. The experts also were asked to identify data gaps and make suggestions for further study. They were given background documents and a set of discussion questions to prepare for the meeting.

Although the topic of possible statutory or regulatory requirements to address the issue of plastic trash entering water was raised by panel members during the forum, EPA did not intend for this meeting to result in recommendations for specific regulatory or non-regulatory actions to be taken.

This document presents a summary of the discussion held on April 23, 2014. It was prepared for informational purposes only. The summary has been reviewed and edited by meeting participants, but has not undergone a formal peer review process. The information presented herein should not be cited or quoted as the endorsed views or policies of EPA, NRC, or the organizations represented by the meeting participants.

This document does not confer any EPA determination and is solely intended to reflect the discussion at the April 23, 2014, forum.

Acknowledgements

Bob Benson, Matt Colombo, and Laura S. Johnson of EPA's Office of Wetlands, Oceans, and Watersheds and Richard Engler of the Office of Pollution Prevention and Toxics contributed to the coordination and organization of the discussion forum, as well as the preparation and compilation of this document.

Claudia Mengelt, Dorothy Zolandz, and Nawina Matshona of the National Academy of Sciences coordinated, organized, and convened the Discussion Forum under EPA Contract Number EPC09003. The initial agenda, meeting recap, and discussant biographies were prepared and compiled by the National Academy of Sciences.

Cover Photos

Top left: Man fishing in Toa Baja, Puerto Rico. April, 2012.
Photo courtesy of Jose E. Maldonado as part of EPA State of the Environment Photography Project.

Top right: Microplastics along Kamilo Point on the Big Island of Hawaii. August, 2013.
Photo courtesy of Anna-Marie Cook, EPA, Region 9.

Bottom left: Fish in Gooseneck Cove, Newport, RI. October, 2012.
Photo courtesy of Josh Cummings as part of EPA State of the Environment Photography Project.

Bottom right: Marine debris from an underwater view in Hawaii.
Photo courtesy of NOAA Marine Debris Program.

Discussion Themes

Although the purpose of the forum was simply to elicit perspectives on the topic under discussion and not to reach consensus on any single issue, several broad themes did emerge from the discussion. The following statements have been reviewed and endorsed by the forum participants.

The forum participants agreed that the current state of the science does not allow an assessment of possible human health risks from the ingestion of seafood contaminated with microplastic-derived persistent, bioaccumulative, and toxic chemicals (PBTs).

There was split opinion among participants on whether there is sufficient evidence to construct the pathway of microplastic-derived PBTs to aquatic life tissue and ultimately to human tissue via seafood consumption. Some participants indicated that this pathway is likely, whereas others stated that further research would allow assessment of this pathway.

The forum participants identified further research priorities to more clearly demonstrate the potential pathway of PBTs from PBT-laden microplastics to seafood tissue to human tissue. Those priorities are identified in the forum summary, below.

The forum participants identified a specific priority – to determine the relative contribution of PBTs sorbed to or inherent in microplastics versus PBTs from other sources to seafood and, ultimately, to human body burden – to support scientifically rigorous conclusions about the potential for human health risks resulting from marine microplastics.

Forum participants expressed concern that other PBT sources (non-microplastic contributions to seafood, dust, etc.) might result in a higher magnitude of human PBT exposure than that from the indirect route of microplastics through seafood.

Forum Summary

The following summary includes information presented and statements made by the participating experts and other attendees during the forum session. The summary was circulated to participants to review for accuracy. Several participants offered supplemental statements which also are presented below (and are specifically identified as such). These statements also were reviewed by forum participants for accuracy.

Appendices to these notes are available online at https://www.dropbox.com/sh/pjd271m9bmmb6lw/AAAbUp5kJx6bSdHw3vJDA9Uia/Meeting%20recap:

- Appendix D – Presentations
- Appendix E – Background Documents

Welcome, Meeting Objectives, and Introductions

Staff from the NRC and Bob Benson, EPA, opened the meeting by providing the context and background for the meeting and laying out the goals (see agenda, Appendix A). Richard Engler, EPA, provided a brief summary of his review paper to frame the discussion (see Appendix D and E for his presentation and review paper).

Christopher Reddy questioned the quality of data in the 250 studies Rich Engler reviewed; Dr. Engler replied that the data were of variable quality, but that the conclusions were well established. The importance of good controls and avoiding lab contamination was stressed by Tim Begley. Mark Browne stated that he found flaws in about 20% of the microplastics-related studies that he has reviewed.

Anna- Marie Cook and Harry Allen, EPA Region 9, discussed the Region's immediate needs for information on marine microplastics, as well as their most recent research findings (for additional details, see Appendix D). The Region will be treating microplastics as a new medium of concern, essentially a 'floating sediment,' capable of harboring, accumulating and transporting contaminants in a manner similar to that of other media.

Session I: Plastics in the Marine Environment: Distribution, Chemical Characteristics, Fate, and Sorption

Christopher Reddy's presentation (for details regarding this and subsequent presentations, see Appendix D) raised questions about the complexity of the microplastics and potential human health problem and the paucity of information. Many information gaps remain to be filled in order to establish a scientifically rigorous end-to-end mass balance for marine plastics analogous to the one developed for environmental mercury. Examples of unanswered questions include: How do we establish mass balances? What are the loss terms? What is the residence time? How much remobilization of plastics occurs along the coastline during a large tsunami or hurricane? What is the relative sorption of PBTs to different types of organics, including plastics?

Anthony Andrady described the societal benefits of plastic and the growing trend in its use. He also discussed various degradation processes of plastics and pointed out that the degradation rates of plastics on the beach are moderate to high compared to those of plastics in the water. Dr. Andrady discussed pathways of microplastic ingestion by marine organisms and potential for human exposure to the adsorbed toxins. He noted that we should not ignore sub-300-micron plastic particles given the prevalent use of 300 micron net tows to sample from ships. His presentation identified the following scientific unknowns:

- The solar-ultraviolet-induced fragmentation of plastics into meso/microplastics has not been studied at all.
- Bioavailability of Persistent Organic Pollutants (POPs) and additives in plastics are not known.
- A technique for assessing the 'age' or duration of exposure of meso/microplastics has not been developed.
- A rapid method for quantifying microplastics in sediment or water is not available.
- Selective grazing and avoidance of POPs-loaded microplastics in the marine environment has not been studied.
- Potential 'cocktail effects' in bioavailability and toxicity of POPs in microplastics is unknown.

Kara Lavender Law's presentation introduced a project of the National Center for Ecological Analysis and Synthesis (NCEAS, a research center of the University of California, Santa Barbara) which aims to synthesize information on the topic at hand. This effort makes it apparent that it is a scientific field in its infancy. Understanding the potential health risks to humans via the seafood pathway is predicated on understanding the distribution of microplastics in the marine environment. However, data is currently limited to a subset of the marine and coastal environment: sandy beaches, sea surface, and a small part of the biota. The majority of the sea surface surveys are done using a net tow with mesh size of 0.33 mm. Thus, little information is currently available on microplastics smaller than 0.33 mm. The maximum abundance is measured in the central gyres and is as high as 26 million pieces per km^2. The presentation ended with the following summary bullets:

- Plastic accumulation is found in large-scale subtropical gyres and at least some marginal seas.
- Within subtropical gyres, small-scale variability in plastic concentration is very large due to:
    - Wind-driven vertical mixing
    - Submesoscale frontogenesis (local convergences)
    - Wave breaking, Langmuir circulations
- Highest measured concentrations in a single net tow are ~1 piece per square meter.

The following outstanding unknowns were also mentioned:

- Abundance and distribution data
    - In all habitats of interest (e.g., sea surface, water column, shallow and deep seafloor)
- Particle size distribution
    - Including particles smaller than 0.33 mm
- Degradation processes and time scales

Mark Browne's presentation discussed the link between population density and microplastics in sediments, particularly the high concentrations of fibers near sewer outfalls. He also discussed the long-overlooked impact of microplastics on marine life.

Several case studies were mentioned, including one that indicates transfer of particles from gut into tissue. Dr. Browne ended with his opinion that evidence is quite strong that there is a potential health risk.

> Post-meeting comment: Dr. Browne noted that he showed, with peer-reviewed scientific literature, that (i) clothing was a major source of microplastic; (ii) microplastic is found on shores on every continent; (iii) the amount of microplastic outnumbers macroplastic; (iv) ingested microplastic can transfer from the gut to the circulatory system of invertebrates, rodents and humans; (v) that ingested microplastic acts as a vector for additives and pollutants to the ecosystem and that this damages functions that sustain health and biodiversity; and (vi) microplastic damages the health of humans and mammals.

The discussion after the presentation focused on the lack of an established, uniform method for measuring and reporting microplastics. To address this issue, the participants discussed the following options to fill this gap: reporting the number of particles, the total surface area of particles, or total mass of particles. Furthermore, participants mentioned that more routine measurements should be taken to reliably establish trends and an understanding of the global scale of the problem.

Session II: Pollutants in the Marine Food Web

Mark Hahn's presentation began with a brief introduction of his own research followed by a list of research questions:

- What fraction of Persistent Bioaccumulative Toxic (PBT) chemical burden measured in marine animals (including seafood) originates from microplastics?
- What is the relative role of microplastics versus other sources of PBTs (diet, water, sediment) to animals?

  > Post-meeting comment: Dr. Browne noted that a controlled experiment has been done to partially answer this question for worms in Browne *et al*., 2013, "Microplastic Moves Pollutants and Additives to Worms, Reducing Functions Linked to Health and Biodiversity."

- Microplastics: Source or Sink?

- Are there certain species, locations, or seafood resources that are especially vulnerable to or impacted by microplastic-borne PBTs?
- Source of monomers, additives, some PBTs?
- To what extent might microplastics sequester PBTs and make them less bioavailable?
- What is the bioavailability of PBTs on microplastics versus in other matrices (e.g. detritus, animal food sources)?
- How do microbes (e.g., Zettler *et al*.) and microbial biofilms affect adsorption/desorption (capacity/bioavailability) of PBTs on microplastics?
- Determining a mass-balance for PBTs consumed on microplastics: uptake versus pass-through?
- What is the value of focusing on microplastics as a vector of PBTs versus all other vectors of PBTs to marine animals and humans? Do microplastic-associated chemicals pose a unique risk?
- Is there a fundamental difference in effects of PBTs delivered by microplastics versus those delivered by other matrices/routes of exposure?
    - If so, what are the mechanisms (e.g., desorption kinetics, timing and location of uptake)?

The presentation included the possibility that toxic Halogenated Marine Natural Products (HMNPs) and harmful algal bloom toxins might adsorb to microplastics. The presentation ended with the point that consideration of human health effects of microplastic-borne PBTs must take into account the evolving understanding of chemical impacts, including the emerging recognition that low-level exposure during embryonic development can lead to delayed effects resulting in adult disease or to transgenerational effects.

Chelsea Rochman's presentation mentioned various pathways by which plastic and chemical pollutants enter the marine environment and subsequently the marine food web. Dr. Rochman suggested that that there is growing evidence that a large number of species are ingesting marine debris. Her laboratory experiments with adult medaka indicate that this ingestion of microdebris results in the transfer of toxins to the food web. Dr. Rochman cited studies that demonstrated this transfer to occur in the marine environment. Dr. Rochman noted that higher brominated polybrominated diphenyl ethers (PBDEs) in particular appear to enter the food chain from microplastics, and that

the question is not whether these constituents make their way to humans, but in what quantity. The presentation ended with the following statements:

- All plastics sorb priority pollutants;
- Not all plastics are created equal;
- Concentration and cocktail varies by location;
- Plastics may become more hazardous over time.

Robert Hale's presentation discussed the range of plastic materials and the diversity of forms and chemical composition of plastics in the marine environment. He also mentioned that this is not just a marine issue, but that there is exposure near population centers. In fact, he noted, the situation might be worse in non-marine waters near areas of high population density.

Furthermore, Dr. Hale discussed the different feeding modes. Given the aim to assess the potential risk to humans, he stressed the importance of focusing the early work in some of the most exposed environments (e.g., 'worst-case scenarios'). For example, he mentioned, oysters are filter feeders and consumed as whole-organisms, including the gut. Therefore, Dr. Hale suggested that the risk to humans might be greatest in the case of oyster consumption. The presentation included the following suggestions:

- Consider insights from 'non-marine' fields of inquiry.
    - e.g., indoor exposure to Brominated Flame Retardants (BFRs); passive sampling work, nanomaterials.
- What about contaminants in paper, wood, and textile products?
- Consider BOTH environmentally-sorbed PBTs and additives.
    - Relative bioavailability of debris-associated chemicals?
        - Will decreasing particle size 'normalize' these?
- Are toxicological impacts occurring?
    - Look to worst-case environments and most exposed organisms?
- Do plastics change ecosystems – unexpected effects?

The discussion after the presentation focused on the problem of attribution and experimental design. Carol Henry asked if studies exist to prove health effects from

microplastics in marine life. Mark Hahn indicated that reproductive effects have been noted in seals due to PBTs from non-microplastic sources. Given the environmental variability and the many unknowns regarding the distribution and fate of plastics, as well as distribution of chemical pollutants, participants mentioned that the problem of large background noise (other sources and pathways of chemical pollutants into the organisms) will be an important and difficult problem to address. Suggestions to overcome this problem include starting in a low-carbon environment or with a worst case (high plastic concentration and filter feeder) scenario.

Anna-Marie Cook noted that the proposed study on Tern Island in Hawaii might be one such case. Dr. Law noted that we should start our body burden studies with human food sources such as tuna and mussels, since these are organisms commonly consumed by humans. In addition, questions were raised whether the food-safety angle was the appropriate approach to mitigating marine debris in the environment given the potential difficulty in establishing attribution and threshold values. Dr. Andrady noted that endocrine disruption studies could be a good angle since these disruptions often occur at less than established 'safe' levels. He also suggested looking at impacts on organisms at the base of the food chain, like zooplankton. Keith Christman noted that not all plastics are the same, and that they should not be lumped together.

Session III: Potential Human Health Risks

Rolf Halden began his opening remarks by indicating that his work focuses on a range of contaminants of concern such as PBTs, POPs, and other organics. Dr. Halden mentioned that these chemicals are ubiquitous and humans are chronically exposed to a range of sources. Thus, he pointed out that the questions raised in the context of this meeting were not new with the exception of whether micro- and nanoplastics are found in human tissues.

Dr. Halden indicated that a lot is known about the chronic toxicity of these chemicals, and a lot of scientific methods have been developed to attribute the PBT body burden to different dietary sources. Due to the visibility of this problem, he suggested that this topic presents an opportunity to raise the issue related to improving product design (e.g., a more bio-degradable drinking straw) and the ubiquitous nature of chemical contamination and associated health risks. His presentation ended with the following challenges:

- Measurement;
- Terminology;
- Improved definition of the problem;
- Currently only considering light/floating plastics;
- Human exposure to toxins;
- Determination of the relative role of plastics and naturally occurring sorbents in the oceans;
- Little information on microplastics in freshwater and drinking water;
- There likely are many more direct ways that humans are exposed to microplastics.

Irv Schultz's presentation began with a discussion of the human dietary sources of PBTs. Dr. Schultz's review of the literature found that marine fish were the major source of PBTs from aquatic products. However, results from that same paper are "…indicating that the amount of PBT's stored in aquatic products appears to be an extremely small fraction of the total amount in the environment." PCBs in human blood were found at higher concentration than PBDEs. There are naturally occurring PBDEs and the Methoxylated-PBDEs track with those that eat a higher percent of seafood. The presentation lists some of the techniques that could be used to attribute PBT body burden to the dietary source including:

- Environmental forensics - Identify chemical fingerprint of contaminants associated with specific dietary sources;
- Within chemical class- comparison of congeners, structural isomers (perfluorinated compounds as example);
- Structural analogues of natural origin or associated with specific food sources (PBDE / hydroxy / methoxy as examples);
- Compound Specific Isotope Analysis (see Zeng *et al*., in Environmental Science and Technology).

Jim Bus provided some opening remarks without slides. Like the previous speaker, he pointed to the analytical tools that could be applied to this problem. Dr. Bus suggests an assessment of this issue within a risk priority framework (tier based assessment) considering the other human health risks from chemical contaminants. Thus, he

suggested addressing the questions of dose levels to humans. Considering that he has observed dose levels to be on the decline, he expressed doubts that the dose level from microplastics would result in dose levels to plateau or even increase.

He also suggested developing a worst case scenario risk assessment to evaluate whether this presents a significant risk and thus is a priority compared to other environmental health issues. Using such a tier-based assessment, Dr. Bus suggested that microplastics would likely be found to be a negligible contributor to chemical contaminants in the human diet and to the body burden.

> Post-meeting comment: Dr. Browne noted that existing methods underestimate the amount of microplastic in aquatic environments, and so a 'worst-case scenario' with current knowledge still might be an underestimate.

The discussion after the presentation began with conflicting statements related to how likely seafood contributes to an increase in human body burden of PBTs. While Dr. Schultz observed an increase from seafood consumption in his samples, Dr. Halden and Dr. Bus assumed that terrestrial sources would be the major contributor to body burden. Panel participants clarified these statements and suggested the relative contribution would depend on the population and the type of chemicals under consideration.

The range of data and knowledge gaps were discussed. Participants suggested that too many knowledge gaps might make it difficult to begin to construct the worst case scenario.

Tim Begley from the Food and Drug Administration (FDA) explained current efforts to ensure seafood safety and test for PCBs: When unsafe concentrations based on dietary consumption considerations are detected, fish are taken off the market. However, the FDA testing only applies to products in interstate commerce; and states control a large part of the fisheries and commercial fish market.

Participants discussed PBDEs and their potential as emergent chemicals of concern and the timeliness of efforts to start examining seafood for PBDEs. In response to Bob Benson's question to the group about potential 'silver bullet' studies, Dr. Rochman suggested comparing the human body burden of PBTs in subsistence fishing communities bounded by high plastic waters (low contribution of PBTs from other sources) against body burden in subsistence fishing communities bounded by low/no plastic waters and low contribution of PBTs from other sources.

Meeting Re-cap: What are the main themes of the day?

Rolf Halden opened the discussion with his compilation of suggestions made by individual speakers throughout the day. He identified a number of possible knowledge gaps with the following questions:

- Are plastic particles taken up by humans? If so, how much?
- Is there an increased microbial risk from biofilms on plastics?
- Are there important exposures from plastics in drinking water?
- Are there important exposures from inhalation of airborne plastics?
- Could this be a good sustainability case study that leads to improvements in the products we produce and use?
- What fraction of PBT compounds in seafood comes from microplastics?
- What is the size range of plastics that is being taken up by humans from food?
- What is the effect of polymer fragments in the human body?

  Post-meeting comment: Dr. Browne noted that the effect of polymer fragments on humans has been shown in the literature (e.g. Wagoner *et al*., 2013; "Toxicity of Vinyl Chloride and Poly (vinyl Chloride): A Critical Review").

- Could there be a benefit in having contaminants on plastics at the surface where they can undergo photodegradation?
- What about freshwater and drinking water? Does micro/nanoplastic make it into drinking water treatment plants; what happens during chlorination; and what is the dose to humans?
- What seafood species in the oceans and in freshwater are most exposed to microplastics?
- What is the role of plastics relative to naturally occurring sorbents in the ocean? Is this a uniquely manmade problem or are there natural 'floats' performing a similar function?
- Is there an accumulation of natural products adsorbed onto plastics that also could pose risks?
- Should we rush in and perform CPR on the 'Canary in the Coal Mine' or deal with the problem at a higher level?

Dr. Halden suggested the following steps to address these issues:

- Define the problem;
- Standardize terminology and methodology;
- Prioritize the potential risks and focus on the ones presumed to be of greatest magnitude using risk and exposure mapping;
- Identify funding mechanisms for future work;
- Leverage knowledge from allied disciplines such as nanometrology and toxicology; and
- Adopt a systematic and coordinated effort to get the most information in the shortest possible time.

Individual participants identified additional data gaps and sources of information during the subsequent discussion:

- Size distribution and chemical composition of the microplastics;
- The role of organic matter (in general) in adsorbing PBTs in the marine environment and the transfer to seafood;
- Aggregation of particles;
- How much plastic is in the ocean? Mass balances are incomplete; where is the missing material?
- Are the products that pollute needed (noted as a behavioral problem)?
- Improving life-cycle analysis of plastics that form micro-particles and ways we use/re-use resources.

In continued discussion, Keith Christman stated that the American Chemistry Council supported the International Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) report on microplastics as a vector for PBT transfer in the ocean. Mr. Christman highlighted efforts undertaken by the global plastics industry, distributing a progress report containing 185 projects launched since 2011. Dr. Henry asked if there are research recommendations to link PBTs from microplastics to aquatic life tissue to human tissue in the report, to which Mr. Christman and others replied “no.”

Post-meeting comment: Mr. Christman noted that GESAMP has not concluded at this point that microplastics act as a significant vector for PBTs to aquatic organisms. Courtney Arthur indicated that another GESAMP report is slated for release in late 2014.

Dr. Halden urged academic/industry collaboration. Dr. Henry and Dr. Rochman noted that, at some point, research can take the back burner and mitigation and prevention should take the forefront. Dr. Schultz and Dr. Hale noted that the area around municipal outfalls should be studied for fibers since the concentration of plastic is likely higher than in the ocean.

Post-meeting comment: Dr. Browne noted that research is available on fibers at the area around outfalls in Browne *et al.*, 2011, "Accumulation of Microplastic on Shorelines Worldwide: Sources and Sinks."

Post-meeting comment: Dr. Hale expressed his opinion that expanding the scope of the discussion from solely microplastics in the ocean to plastics at all stages (production, use, post-disposal) and in all media (on land, in air, in water) would lend strong support to the statement that microplastics are a source of PBTs to humans.

Mr. Benson asked the group if the PBTs from marine microplastics are likely to cause human health effects. Dr. Bus replied that the PBT dose from microplastics must be addressed before answering this question. Dr. Engler clarified Mr. Benson's question to focus on microplastics as a source for PBT exposure as opposed to a cause of human health effects. Dr. Rochman agreed that microplastics are likely a source of PBTs to humans. Dr. Law noted that microplastics are a source of PBTs to marine organisms, but that there is insufficient data to draw conclusions about human body burden.

Suggested Future Research

One objective of this discussion forum was to identify research priorities relevant to assessing the likelihood of human health risks from the consumption of seafood that has been contaminated with microplastic-derived PBTs. The panel participants identified the research proposals listed below as important for future consideration by researchers. This list is meant to provide general guidance for all researchers and does not constitute a research agenda for EPA or any other organization. The projects are not listed in a particular order.

1. Establish metrics, terminology, and procedures for aquatic microplastics research and conduct more routine microplastic measurements in the marine environment.

    a. The ultimate goal of these measurements would be to gain an understanding of the potential encounter rate of aquatic life with microplastics.

2. Determine the relative contribution of PBTs from plastic and non-plastic sources to aquatic life using, for example, mass balance and/or chemical fingerprinting (isotopic, congener, etc.) studies.

3. Run a 'tier based assessment' to assess the potential for human health risks from the consumption of seafood that has been contaminated with microplatic-derived PBTs.

    a. Start with a back-of-the-envelope calculation. Assume the highest amount of plastic estimated or measured in a given area and the highest amount of PBTs possible sorbed on that plastic. Assume all available PBTs go to biota, and then determine if the PBT burden is of concern.

    b. If the PBT burden is a cause of concern, move to higher levels of complexity and rigor.

4. Perform field studies in areas where there is high plastic loaded with PBTs (worst-case scenario) and low conflicting sources of contaminants (i.e., water column, non-plastic particles, dissolved organic matter) to determine aquatic life and human exposure.

    a. Other elements of a worst-case scenario could be incorporated:

        i. Fish or other aquatic life population that stays localized in high plastic area (e.g., filter feeders).

        ii. Subsistence fishing population in a high plastic area with low contribution of PBTs from other sources.

5. Perform combined lab and field studies on the relative adsorption of PBTs to plastic versus non-plastic organic materials commonly found in the water column.

    a. Take into account the changing properties of plastic due to weathering.

6. Compare human body burden of PBTs in subsistence fishing communities bounded by high plastic waters (low contribution of PBTs from non-plastic sources) against body burden in subsistence fishing communities bounded by low/no plastic waters and low contribution of PBTs from non-plastic sources.

7. Determine the occurrence and distribution of plastics below 300 microns (size of current net tows) and those in the water column/sediment.

Appendix A: Agenda

National Academy of Sciences
Keck Building
500 Fifth Street NW
Washington, DC 20418
ROOM 208

Meeting Objectives:

- Discuss available data and studies on the interaction of toxic chemicals and marine plastic debris
- Discuss available information on the potential health risks to humans from ingesting contaminated seafood
- Identify important research questions and ways to advance the understanding of potential health risks

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9:00 a.m. **Welcome, Meeting Objectives, and Introductions**
Claudia Mengelt, National Research Council staff
Chris Reddy, Woods Hole Oceanographic Institution

9:15 a.m. **Problem Statement**
Rich Engler and Bob Benson, Environmental Protection Agency, Headquarters

9:40 a.m. **Recent Results from EPA Region 9**
Anna-Marie Cook and Harry Allen, Environmental Protection Agency, Region 9

10:00 a.m. **Session I: Plastics in the Marine Environment: Distribution, Chemical Characteristics, Fate, and Sorption**

Discussants

Anthony L. Andrady, North Carolina State University
Kara Lavender Law, Sea Education Association (SEA) Semester
Christopher Reddy, Woods Hole Oceanographic Institution
Mark Browne, University of California, Santa Barbara (by phone)

11:00 p.m. *Break*

11:15 p.m. **Session II: Pollutants in the Marine Food Web**

Discussants

Mark Hahn, Woods Hole Oceanographic Institution
Chelsea Rochman, University of California, Davis
Robert Hale, Virginia Institute of Marine Science; College of William and Mary

12:45 p.m. *Lunch Break*

1:30 p.m. **Session III: Potential Human Health Risks**

Discussants

Rolf Halden, Center for Environmental Security, Arizona State University
Irv Schultz, Pacific Northwest National Laboratory
Jim Bus, Exponent

3:00 p.m. **Meeting Re-cap: What are the main themes of the day?**
Rolf Halden and Discussants

4:00 p.m. **Meeting Adjourns**

Appendix B: Attendees List

Harry Allen, Chief of Emergency Response, Environmental Protection Agency, Region 9

Anthony Andrady, Adjunct Professor, North Carolina State University

Courtney Arthur, Research Specialist, I.M. Systems Group and Marine Debris Program, National Oceanic and Atmospheric Administration

Tina Bahadori, National Program Director, Chemical Safety for Sustainability, Environmental Protection Agency Headquarters

Timothy Begley, Director of Division for Analytical Chemistry, Food and Drug Administration

Bob Benson, Acting Chief of Marine Pollution Control Branch, Environmental Protection Agency, Headquarters

Mark Browne (via WebEx), Postdoctoral Fellow, University of California, Santa Barbara

Jim Bus, Senior Managing Scientist in Toxicology and Mechanistic Biology, Exponent, Inc.

Keith Christman, Managing Director of Plastic Markets, American Chemistry Council

Matt Colombo, ORISE Fellow, Environmental Protection Agency, Headquarters

Anna-Marie Cook, Coordinator of Marine Debris Program, Environmental Protection Agency, Region 9

Susan Kane Driscoll, Aquatic Toxicologist, Exponent, Inc.

Rich Engler, Program Manager of Green Chemistry Program, Environmental Protection Agency, Headquarters

Mark Hahn, Senior Scientist and Chair of the Biology Department, Woods Hole Oceanographic Institution

Rolf Halden, Director of Center for Environmental Security, Biodesign Institute at Arizona State University

Rob Hale, Professor of Marine Science, Virginia Institute of Marine Science; College of William and Mary

Carol Henry, Member, Board on Chemical Sciences and Technology, National Academy of Sciences

Laura S. Johnson, Trash Free Waters Team Lead, Environmental Protection Agency, Headquarters

Jason Landrum, American Association for the Advancement of Science, Fellow and Senior Scientist, Marine Debris Program, National Oceanic and Atmospheric Administration

Kara Lavender Law, Professor of Oceanography, Sea Education Association

Christopher Reddy, Senior Scientist of Marine Chemistry and Geochemistry, Woods Hole Oceanographic Institution

Nick Mallos, Director of Trash Free Seas Program, Ocean Conservancy

Chelsea Rochman, Postdoctoral Scholar at the School of Veterinary Medicine, University of California, Davis

Kevin Sellner, Director, Chesapeake Research Consortium

Irv Shultz, Scientist, Marine Science Laboratory, Pacific Northwest National Laboratory

Nancy Wallace, Director of Marine Debris Program, National Ocean and Atmospheric Administration

Appendix C: Expert Biographies

Introductory Remarks

Rich Engler – Program Manager, Green Chemistry Program, Office of Pollution Prevention & Toxins, Environmental Protection Agency, Headquarters

Rich Engler manages the Green Chemistry Program within the Office of Pollution Prevention and Toxics at EPA. He has worked on green chemistry since his arrival at EPA in 1997. He also works with EPA's New Chemicals Program reviewing new chemical substances under the Toxic Substances Control Act as well as the Risk-Screening Environmental Indicators Program which puts Toxic Release Inventory (TRI) release information into a risk context. He has won numerous awards for his work at EPA including the James W. Craig Pollution Prevention Leadership Award and 3 bronze medals. Prior to joining EPA, he taught Organic Chemistry at the University of San Diego and thinking and learning strategies at the University of California, San Diego (UCSD). He earned his doctorate in physical organic chemistry from UCSD.

Bob Benson – Acting Chief of Marine Pollution Control Branch, Environmental Protection Agency, Headquarters

Bob Benson is the Acting Chief of the Marine Pollution Control Branch at EPA. He works on aquatic trash programs in EPA's Office of Water. For much of Bob's career, he managed Agency partnership programs that worked to improve the environmental performance of major U.S. industrial and business sectors. Bob recently completed a two-year assignment with The Nature Conservancy, where he developed a healthy watersheds' partnership with EPA to protect and restore large aquatic ecosystems.

Anna-Marie Cook – Coordinator of Marine Debris Program, Environmental Protection Agency, Region 9

Anna-Marie Cook is an environmental engineer. She currently works for EPA’s Region 9 Superfund Division, where she serves as the Coordinator for the Marine Debris Program. She has been with the Agency for over 20 years, working in a variety of positions related to water protection and restoration. Prior to her Marine Debris assignment, Anna-Marie served as a Remediation Project Manager on the cleanup of military bases and worked for the Water Division’s Groundwater Office, where she conducted inspections and performed enforcement and permitting work.

Harry Allen, Chief of Emergency Response, Environmental Protection Agency, Region 9

Harry Allen is a Federal On-Scene Coordinator (OSC) and Chief of EPA Region 9's Emergency Response Section. Harry is responsible for managing 16 other OSCs in 3 offices in the region. EPA OSCs are responsible for directing responses to releases of oil and hazardous substances and the development of strategies for assessment and cleanup of toxic sites throughout the Region (California, Arizona, Nevada, Hawaii and the Pacific Trust Territories). Most notably Harry led efforts to carry out large scale radium contamination assessment and cleanup efforts on the Navajo Nation (for which he earned EPA's National Honor Award "Gold Medal" for exemplary service and the Navajo Nation EPA's Award for Outstanding Service to the Environment).

In addition to carrying out numerous emergency responses each year, Harry's program conducts cleanups at numerous abandoned mine sites, pesticide sites, metal plating shops and oil facilities. He also manages the Emergency Response Section extramural budget of approximately $13M per annum. His main focus is on environmental assessment of contaminated sites with an emphasis on data collection and analysis during environmental emergency responses as well as large-scale disasters. He earned a B.S. in Environmental Science from Rutgers University and a M.S. in Environmental Management from the University of San Francisco where he serves as an adjunct faculty member presenting classes in environmental data analysis, contaminated site management, and environmental emergency response.

Session I: Plastics in the Marine Environment: Distribution, Chemical Characteristics, Fate, and Sorption

Anthony Andrady - Adjunct Professor, North Carolina State University

Dr. Andrady is an experienced Senior Research Scientist from the Research Triangle Park in North Carolina. He is an Adjunct Professor of Chemical and Biomolecular Engineering at the North Carolina State University, an Adjunct Research Professor at the Medical School at the University of North Carolina at Chapel Hill. He also serves as the Principal of Helix Science LLC (Apex, NC), a technical consultancy organization. His research interests include the environmental impacts of plastics, sustainability in the plastics industry and micro plastics in the marine environment. He is the editor of the volume "Plastics and the Environment" (John Wiley) and the same publisher will release his authored book "Sustainability and Plastics" at the end of this year. Dr. Andrady is a member of the Group of Experts on Scientific Aspects of Marine Pollution convened by the United Nations Educational, Scientific, and Cultural Organization and also a member of the Environmental Effects Assessment Panel covered by the United Nations Environment Program to support the implementation of the Montreal Protocol. He has over a hundred peer-reviewed publications and has over 25 years of experience in directing research and development on behalf of government agencies and private industry.

Christopher Reddy - Senior Scientist of Marine Chemistry and Geochemistry, Woods Hole Oceanographic Institution

Dr. Reddy studies both the short and long-term fate of petroleum in the environment. His lab's approach is often to use novel and advanced techniques like molecular level radiocarbon analysis and comprehensive two-dimensional gas chromatography. This work includes the study of natural oil seeps off the coast of Santa Barbara, CA and the Gulf of Mexico, as well as numerous oil spills (Florida, 1969; Bouchard 65, 1974; North Cape, 1996; Bouchard 120, 2003; Cosco Busan, 2007; and Deepwater Horizon disaster, 2010). Work on the Santa Barbara seeps, Deepwater Horizon disaster, and microbial degradation of hydrocarbons is supported by the National Science Foundation.

Kara Lavender Law - Professor of Oceanography, Sea Education Association

Dr. Law is a research professor at Sea Education Association (SEA). There, she studies plastic marine debris using SEA's 25+ year data set consisting of plastic counts from more than 7,500 plankton net tows that were carried out by over 7,000 SEA students and scientists. Her interests include understanding how ocean physics determines the distribution of plastic and other marine debris, and the behavior and ultimate fate of different plastics exposed to the harsh ocean environment.

Mark Browne - Postdoctoral Fellow, University of California, Santa Barbara

Dr. Browne works on understanding how natural and anthropogenic processes (e.g., plastic debris, priority pollutants, engineering) affect marine habitats and biodiversity. He collaborates closely with colleagues at a wide range of national and international institutions, enabling a strong interdisciplinary approach. He is particularly interested in policy and the scientific basis for managing environmental problems, and advises the United Nations, European Union, and governments (U.S., U.K., Australia) on this. Dr. Browne co-leads a working group at the National Center for Ecological Analysis and Synthesis on marine debris and was chairman of the North Sea Plastic Marine Litter Scientific Advisory Board.

Session II: Pollutants in the Marine Food Web

Mark Hahn - Senior Scientist and Chair of the Biology Department, Woods Hole Oceanographic Institution

Dr. Hahn serves as a Senior Scientist and the Chair of the Biology Department at Woods Hole Oceanographic Institution (WHOI). The Hahn Lab at WHOI is focused on understanding the biochemical and molecular mechanisms underlying interactions

between animals and their environment. Dr. Hahn's additional research interests include receptor-mediated mechanisms of gene regulation and toxicity; molecular evolution of transcription factors involved in environmental sensing; mechanisms of response to oxidative stress; biological effects of marine natural products; comparative genomics; and the role of microRNAs in developmental toxicity.

Robert Hale Professor of Marine Science, Virginia Institute of Marine Science; College of William and Mary

Dr. Hale is a Professor of Marine Science at the Virginia Institute of Marine Science. His focus has been on the identification of anthropogenic organic pollutants and the elucidation of their sources, fate, bioavailability, and effects on ecosystems. His additional research interests include: organic contaminants in organisms, including fishes of Virginia waters; identification of pollutants released following sewage sludge (biosolids) applications and the associated effects; bioavailability of sludge associated chemicals; brominated flame retardants and non-ionic detergents in the environment; and consequences of plastic debris in terrestrial and aquatic environments.

Chelsea Rochman - Postdoctoral Scholar at the School of Veterinary Medicine, University of California, Davis

Dr. Rochman is an ecologist who has focused her research in Marine Ecology, Ecotoxicology, and Environmental Chemistry. She is currently working as a postdoctoral scholar in the Aquatic Health Program, funded by the National Oceanic and Atmospheric Administration's Marine Debris Program under Dr. Swee Teh at the University of California, Davis School of Veterinary Medicine. She is especially interested in how human progress affects the well-being of other species. Her research interests include the ecological effects of anthropogenic contaminants on wildlife and resources (e.g., water, seafood). More specifically, her focus is the implications of the infiltration of plastic debris into aquatic habitats.

Session III: Potential Human Health Risks

Rolf Halden, Director, Center for Environmental Security, Biodesign Institute at Arizona State University

Dr. Rolf Halden, P.E., is Founding Director of the Center for Environmental Security (CES) at the Biodesign Institute; Director of the Biodesign Institute CES Mass Spectrometry Facility; Professor in the School of Sustainable Engineering and the Built Environment at Arizona State University (ASU); and Senior Sustainability Scientist at ASU's Global Institute of Sustainability, as well as Adjunct Faculty of the Department of

Environmental Health Sciences at the Johns Hopkins University Bloomberg School of Public Health. Rolf received a Master's in Biology (Diploma, 1992) from the Technical University of Braunschweig, Germany, and a Master's (1994) and Ph.D. (1997) in Civil Engineering with a concentration in Environmental Engineering from the University of Minnesota. Prior to joining academia, Rolf was project engineer at the Lawrence Livermore National Laboratory, where he directed the construction and operation of physical and biological groundwater treatment systems. He has served on the Maryland State Water Quality Advisory Committee, the Food and Drug Administration's Nonprescription Drugs Advisory Committee, and the National Research Council committee of the National Academies.

Irv Shultz – Scientist, Marine Science Laboratory, Pacific Northwest National Laboratory

Dr. Schultz has been involved in toxicological research since 1986 with interests associated with both ecological and human health problems. His areas of expertise are in bioaccumulation, toxicokinetics and computational biological modeling; biotransformation; analytical chemistry; and environmental and human toxicological issues such as endocrine disruption and carcinogenesis. Dr. Schultz has worked for the Battelle Pacific Northwest National Laboratory since 1996. His research interests include bioaccumulation of environmental contaminants in fish; the disposition and bioavailability of inorganic and organo-metallic compounds, nanomaterials, persistent organic pollutants (POPs) and radionuclides such as Cs-137 in aquatic animals; and the disposition of chlorinated and brominated acetic acids. Current research in Dr. Schultz's laboratory is focusing on three primary areas: (1) The effects of various types of endocrine disruptors on reproduction in fishes; (2) Better understanding human exposure to POPs resulting from consumption of marine seafood; and (3) The impact of artificial electromagnetic field exposure on the development and behavior of marine fishes.

Jim Bus – Senior Managing Scientist, Toxicology and Mechanistic Biology, Exponent, Inc.

James Bus, Ph.D., DABT, Fellow ATS, is a Senior Managing Scientist for Toxicology and Mechanistic Biology, at Exponent Consulting. Dr. Bus has over 35 years of toxicology experience focused on research and evidence-based literature analyses informing potential health risks associated with chemical and pesticide exposures. He offers chemical specific and strategic toxicology expertise addressing development, stewardship, and regulatory actions to individual industry clients and business consortia and government and non-governmental agencies. Dr. Bus provides expertise in design, implementation, and interpretation of toxicity tests and mode of action and dose response/exposure evaluations furthering translation of toxicology findings to risk assessment. His expertise includes target-organ and endpoint-specific modes of action,

and specific toxicity of chemicals including chlorinated organics, ethylene glycol and glycol ethers, aromatic derivatives benzene, styrene, aniline and others, and pesticides such as 2,4-D. His research interests include toxicokinetic mechanisms mediating dose-dependent expression of chemical toxicity.

Dr. Bus's experience includes over 23 years as a consulting toxicologist in the Toxicology and Environmental Research and Consulting unit of The Dow Chemical Company. He previously held positions at the Upjohn Company, the Chemical Industry Institute of Toxicology, and as Assistant Professor of Toxicology at the University of Cincinnati. Across all of these positions he focused on providing consulting and research expertise in support of health risk evaluations of environmental and industrial chemicals and pesticide and pharmaceutical products.