Perfluoroalkyl Substances: A Review on Environmental and Commercial Exposure Risks

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Abstract

Per- and polyfluoroalkyl substances (PFAS) are a group of toxic man-made chemicals that are manufactured globally and are found in a wide range of consumer products and commercial and industrial applications. PFAS contamination has become an important issue as they do not naturally break down in the environment and accumulate in the human body. According to the Centers for Disease Control and Prevention (CDC), some level of the most widely produced types of PFAS have been found in 98% of blood samples of Americans. PFAS exposure has been linked to many diseases including cancer, thyroid disease, and developmental delays in children. The major pathways of exposure include PFAS contamination in drinking water, household products, and food products. Since PFAS are highly toxic compounds, there has been recent progress in controlling the levels to which our society is exposed. There are actions that can be taken at both the individual and institutional level to both reduce the exposure to and the harmful consequences caused by PFAS, including improving drinking water filtration, changing consumer behavior, researching alternative compounds, and making policy changes to ensure correct safety guidelines. However, there continues to be lingering questions as to what kinds of PFAS put us at the most risk and what is truly a safe level of PFAS concentrations in the different routes of exposure.

Background

PFAS is the plural acronym for Per- and polyfluoroalkyl substances (EPA, 2018). It is pronounced "p, then "fas" (like fast without the "t")" (Wisconsin DHS, 2019). They have been called "forever chemicals" in the media (Todd, 2019). They are a family of "man-made chemicals" with the ability to repel water and oil, suppress dust, and are heat resistant (Hersher, 2019; EPA, 2018). Because of these properties, PFAS are widely found in many consumer products and have been used in various industries since the 1940s (EPA, 2018). For example, in cookware like Teflon products they "keep food from sticking," make furniture, clothes, and fabrics "resistant to stains," and make firefighting foam "more effective" (NIEHS, 2019). PFAS are also found in products as diverse as food wrappers, cosmetics, tents, carpets, paints, and cleaning products (Hersher, 2019). One thing all PFAS have in common is containing a "chain of carbon atoms bonded to fluorine atoms" (ATSDR, 2017). Carbon-fluorine bonds are very strong which causes PFAS to not degrade in our bodies nor the environment (NIEHS, 2019). There are almost 5,000 PFAS and many of them have not been studied for health and environmental effects (FDA, 2019).

The two most common PFAS are perfluorooctanesulfonic acid (PFOS) and perfluorooctanoic acid (PFOA) (Wisconsin DHS, 2019). The United States Environmental Protection Agency (EPA, 2018) began the PFOA Stewardship Program in 2006 and asked eight companies to join with the goal of completely eliminating PFOA from production by 2015 (EPA, 2018). All companies met this goal. PFOS is also no longer manufactured in the US, however, both PFOS and PFOA are still produced in other countries and can be found in imported products, including "carpet, leather and apparel, textiles, paper and packaging, coatings, rubber and plastics" (EPA, 2018).

In 2010, the Minnesota attorney general filed a lawsuit against 3M alleging that the company polluted "ground and surface water" with PFAS and "knew or should have known" of the “potentially harmful effects” that these chemicals have on “human health and the environment” and that it resulted in “injury, destruction, and loss of natural resources of the State” (State of Minnesota vs. 3M Co., 2010). 3M was the company that “first developed and sold PFOS and PFOA” (Lerner, 2018). Last year this case was settled for $850 million that 3M will pay to the state that will go toward water quality programs (Shaw, 2018). 3M argued that “no health effect to humans has ever been proven, and the parts-per-trillion amounts in groundwater couldn’t hurt people or the environment” (Shaw, 2018). The Minnesota State Health Department released a report one week before the trial that found that health records from three different time periods, 2001-2005, 2006-2010, and 2011-2015, from areas affected by the PFAS pollution showed “no increase in the rates of cancer and low birth-weight babies” despite an “exposure of more than 30 years” (Shaw, 2018a; 2018b). The State Health Department’s report contradicted findings by David Sunding, a professor in the College of Natural Resources at the University of California at Berkeley, who found that from 2001-2016 in Oakdale, Minnesota, “the 3M pollution caused increased rates of cancer, low birth-weight babies, premature births and infertility” (Shaw, 2018b).

After the settlement, the Minnesota attorney general’s office released documents, some of which had been sealed under a protective order in 2005 because they were part of another lawsuit, that “detail[ed] what 3M knew about the chemicals’ harms” (Lerner, 2018). Several of these documents were also known to the EPA; in 2000, 3M gave the EPA “hundreds of documents it had withheld from the agency” that revealed previously unreported information about PFOS and PFOA (Lerner, 2018; Ryan, 2006). In 2006, the EPA fined 3M $1.5 million for these “reporting violations under the Toxics Substances Control Act” (Ryan, 2006).

Health Effects

Poly-and perfluoroalkyls (PFAS) can enter the body in several ways. The most common means of PFA exposure is through food, drinking water and air. PFAS are also capable of entering the body through the skin if someone has direct contact with dust or aerosols that contain it (“Perfluoroalkyls”, 2015). This poses a greater risk to individuals that work directly with PFAS.

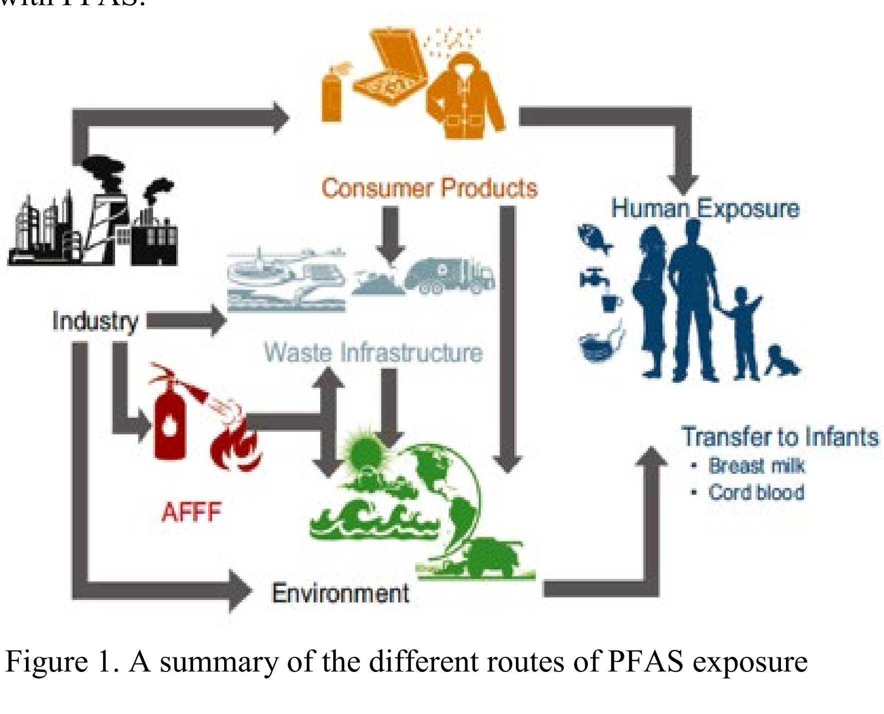

Figure 1. A summary of the different routes of PFAS exposure

The first report of PFAS inside the human body was in the late 1960s where blood samples being tested for fluorides were found to be bound to an unknown organic compound. These organic compounds were later tested and discovered to be a member of the family of PFAS (Grandjean, 2015). In the 1970s, there were documented cases of high concentrations of PFAS in workers exposed to specific PFAS (Granjean, 2015). Today, studies have shown that most people in the United States have at least one kind of PFAS in their blood sample. Due to the widespread use of PFAS it is unlikely that anyone would be completely free from exposure. Even if one doesn't drink contaminated water, there are multiple ways that PFAS can enter the body ("PFAS Contamination of Water", n.d.). With the CDC even reporting that 98% of all Americans have PFAS in their bodies (Sunderland et. al, 2018), this leads us to the question that many scientists are trying to answer: What do PFAS do inside the human body? Since they are everywhere, are they that bad for people? Unfortunately, the answers to these questions are far from straightforward. One reason is that even though PFAS have been in use for over sixty years, research on their effects have only intensified in the past couple of years. As a result, there is limited toxicological results to infer from. Yet, these studies have been instrumental in bringing to light some ways that PFAS could be harmful.

Once PFAS enter the body, they are absorbed and can be found in blood, urine, breast milk and umbilical cord blood as previously mentioned. According to the Agency for Toxic Substances and Disease Registry (ATSDR), there are multiple factors determining how one's health will be affected after exposure to PFAS. These include the duration of exposure, the level of PFAS exposure and the route of exposure. The ATSDR reports that the results of the health effects of PFAS are "difficult to interpret" because they are inconsistent. For example, whereas some studies have shown a correlation between cholesterol levels and increased PFAS concentration, some have not. A paper by Grandjean et.al explains that some of the discrepancies could be coming from the fact that many of these studies were performed on rats who eliminate PFAS from their systems much quicker than humans (Grandjean, n.d.). However, current human epidemiology studies have shown adverse effects on PFAS including elevated cholesterol, disrupted hormonal functions, increase in infertility and lower infant weight ("PFAS Contamination of Water", n.d.).

Early studies done on PFAS exposure in humans were on industry workers who were exposed to higher levels of PFAS. The company 3M was the largest manufacturer of PFAS in the 1990s. As so, many of the early studies on PFAS exposure were conducted by the company itself. The first study conducted on 3M workers found their PFAS concentration in serum to be ten times higher than the average person (Sunderland, 2018). The company then went on to conduct a 90-day study on Rhesus monkeys using high doses of PFAS but after 20 days all the Rhesus monkeys died (Sunderland, 2018). When lower doses were used, some of the results were increased liver weights and decreased total cholesterol (Sunderland, 2018). None of the studies done by 3M were released to the public which is why there are very few studies done on PFAS exposure during that time. Research on PFAS only began in 2000 after 3M voluntarily decided to discontinue the use of one PFA-PFOS and its precursor. This prompted scientists to begin investigating the effects on PFOS in humans and it was identified that PFOS is linked to diseases like thyroid disease, kidney cancer and high cholesterol (Sunderland, 2018). Currently, the studies on health effects of PFAS exposure in humans can be divided into four main areas: cancer, immune effects, metabolic effects and neurodevelopmental effects (Sunderland, 2018).

With respect to cancer, studies conducted on workers in chemical plants show that there is a 3.3-fold increase in chances of dying from prostate cancer when compared to workers who did not work at chemical plants at all (Sunderland, 2018). It is important to note that PFAS exposure studies done on non-occupational workers who do not live in the same community continuously give inconsistent results (Sunderland, 2018). The strongest associations between PFAS and their health effects are only seen in people living in the same community or occupational workers (Sunderland, 2018). This is because in these groups it is easier to infer the concentration of PFAS exposure in the individuals whereas when comparing non-occupational people who do not live in the same community it is much harder to infer the dose of PFAS in their body. For this reason, the best evidence for PFAS exposure and cancer is from the C8 Health project. This project was conducted by Barry et.al and Vierra et. al (Sunderland, 2018). The C8 health project was an epidemiologic study done on a population in West Virginia living near the Dupont Washington Works fluorotelomer plant (Sunderland, 2018). Barry et. al and Vierra et. al were able to show a positive correlation between PFOA concentrations and testicular and kidney cancer (Sunderland, 2018).

Studies conducted on PFOA and PFOS have shown that they act as immunosuppressants (Sunderland, 2018). Five studies investigated how PFAS exposure is linked to decreased antibody response after vaccination in children and adults. Out of the five studies, four found a negative correlation between increased PFAS concentration and immune response (Sunderland,2018).

Sunderland et. al reviewed 69 human epidemiologic studies from 1996 to 2018 and found that a majority of the studies concluded that increased serum PFA levels negatively impacted the lipid profiles in the subjects. Some of these changes included high cholesterol and low-density lipoprotein cholesterol (LDL-C). The PFA primarily studied in these studies were PFOA and PFOS (Sunderland,2018). Animal studies have however showed the opposite result. There have been animal studies that showed increased PFA levels leading to decreased cholesterol. One explanation for this is differential levels of nuclear receptors such as peroxisome proliferator-activated receptor (PPAR)-alpha in experimental animals and humans (Sunderland, 2018). PPAR-alpha is a transcription factor that is activated for fatty acid oxidation. The products of fatty acid oxidation are used in the cholesterol biosynthesis pathway hence differential PPAR-alpha concentration will have different effects on concentration of cholesterol. Hence the fact that animals showed a decrease in cholesterol that does not mean the increase in cholesterol in humans should be disregarded. This is because increase in cholesterol is strongly associated with cardiovascular diseases (Sunderland, 2018). Among PFAS, the health effects of PFOA and PFOS are the most understood, but more research needs to be done on emerging PFAS.

Exposure: Water

PFAS are not only found in household products and entities such as fire extinguishers, but also in water. Exposure through water contamination is one of the most common forms of exposure to PFAS and can carry numerous risks. PFAS can be found in lakes and rivers, which can have adverse effects on the environment and wildlife. Also, PFAS have been found in drinking water across the United States, along with groundwater from which many people create wells for drinking water. Reports show that more than 1,500 sources of drinking water may have PFA contamination which can affect up to 110 million Americans (Andrews, 2018). This is very alarming considering that this class of chemicals is linked to cancer, thyroid disease, weakened immunity, and other health issues (Andrews, 2018). There are methods of removing PFAS from water that can be used in the household as well as on a larger scale in water treatment plants to detoxify the drinking water that is distributed to the public.

The amount of PFAS in water across the nation has become a national dilemma and grown increasing concern from the Environmental Protection Agency (EPA). Interestingly, from 2013 to 2015 the EPA conducted national research on the public water systems in the United States without releasing the full results of the study (Andrews, 2018). Although these studies were conducted with taxpayer money, the EPA only released the areas that tested for the highest concentrations of PFA chemicals (Andrews, 2018). The results that were released had to be in between a reporting level of 10-90 parts per trillion (ppt), so any water sources with PFA concentrations below 10 ppt were not made known to the public or people residing in the area (Andrews, 2018).

The EPA has yet to establish a regulation on the concentration of PFAS in drinking water but has created a recommended health advisory level at 70 ppt (Drinking Water, 2019). Many believe this limit is too high to be considered safe, however. For example, in 2018 the federal agency for Toxic Substances Control suggested the minimal risk level of PFAS in water should be set at 6.5 ppt (Naldenko, 2019). Other studies have recommended the safe levels of PFAS in drinking water more than 200 times below the EPA health advisory (Naldenko, 2019). Some independent studies have suggested that the safe level for PFAS in water be at about 1 ppt (Andrews, 2018). The state of New Jersey has created the limits to be 13-14 ppt for PFAS in their drinking water (Andrews, 2018). Millions of Americans that may be exposed to water with levels of PFAS that are below 10 ppt were not notified by the EPA of their risk to this toxic chemical. Studies from the University of Copenhagen and Harvard have suggested that the recommended level of PFAS in water should be 0.3 ppt (Naldenko, 2019).

One of the main issues with PFAS is that they are collectively a diverse group of chemicals that have many derivatives which all can be found in different contaminated substances. PFAS have been produced for over 60 years but academic research on the risk and hazards of the group have only appeared in the past 10 years and reports of toxicity were not released to the public until after the year 2000 (Grandjean, 2019). Although there has been progress on the regulatory limit becoming lower with time, the standards remain higher than suggested by data on human adverse effects, especially on the immune system (Grandjean, 2019). There is a substantial delay on the understanding of toxicity of new PFA substitutes, as they are increasingly being introduced to industry as replacements for the known toxic derivatives (Grandjean, 2019). Environmental toxicologist Jamie DeWitt says, “We may be underestimating PFAS contamination as monitoring does not often capture data from small systems and private wells…PFAS contamination in our country’s drinking water supply is much greater than previous studies indicate” (Scialla, 2016). Long chained PFAS were banned in the early 2000s but the emergence of short chain PFAS has emerged from industries (Scialla, 2016).

PFAS are highly soluble, meaning they can easily contaminate water given their molecular structure. Research suggests that PFAS can contaminate water by sources used in firefighting foams used by the military and airports (Scialla, 2016). Executive Director of the Green Science Policy Institute, Arlene Blum, states “During fire-fighting practice drills, large volumes of these toxic chemicals wash into surface and ground waters and can end up in our drinking water” (Scialla, 2016). Dr. Mark Brusseau, Professor of Environmental Science at the University of Arizona explained that the main sources of PFAS to the environment come from manufacturing facilities, fire training facilities, and disposal sites such as landfills, wastewater treatment plants, and biosolids application sites. The output of these sites leads to contamination of the atmosphere, soil, surface water, and groundwater.

PFAS in water is a controversial topic that has been relevant recently in Tucson, Arizona as well. Tucson Water has identified numerous sites across the city that are contaminated with PFAS, however these sites were reported as not connected to the drinking water system (PFAS, 2019). Alarmingly, studies done by Tucson Water of ADEQ/EPA owned monitoring sites in the area north of Arizona Air National Guard at Tucson International Airport show preliminary results of PFAS concentrations of more than 10,000 ppt (PFAS, 2019). The PFAS compounds for which the EPA Health Advisory set limits of 70 ppt (PFOA and PFOS) are not detected in drinking water served by Tucson water and have never been present in levels above the Health Advisory (PFAS,2019). Tucson Water also stated that the water does not present an immediate threat to the drinking water provided by the city (PFAS, 2019). Fernando Molina, a Public Information Officer at Tucson Water, explained that the water which was found to be contaminated with PFAS is water intended for uses other than drinking, such as watering golf courses. Molina also assured that Tucson Water treats the health advisory of PFAS water contamination as a primary standard, which means they treat the advisory as if it were a serious issue rather than just a warning about possible hazards.

The guidelines by which Tucson Water limits the PFAS concentrations in city drinking water are well below any federal regulations. However, as the target concentration of PFOAS and PFOS is limited to 18 ppt, the target for PFHxS and PFHxA (additional unregulated PFAS compounds) is 47 ppt (PFAS, 2019). Tucson and Marana recently sued 3M, a company that manufactured firefighting foam that contained PFAS for the removal of the chemicals in water wells across the area (Ferguson, 2018). Three wells near Davis Monthan Air Force Base in Tucson and 6 wells on the northwest side have been shut down (Ferguson, 2018). In August 2018, a water treatment plant was sending out to customers containing levels reaching 30 ppt in samples at three sample points; the plant was temporarily shut down (Ferguson, 2018). Tucson Mayor Jonathan Rothschild has stated that Tucson has "taken proper precautions and the drinking water is safe, but there is a long-term cost associated with the contamination." Senator Martha McSally asked Secretary of the Air Force nominee Barbara Barret for commitment to partner with Tucson and other communities to address PFAS to which Barrett responded, "Absolutely...the relationship between our military facilities and the communities is vitally important, and this contamination is a problem that is not unique to Arizona but is something that would be, if confirmed, carefully attended" (Ferguson, 2019).

Exposure: Food and Food Packaging

Humans are exposed to polyfluoroalkyl substances (PFAS) via ingestion. Traces of PFAS are commonly found in various water and grease repelling food containers throughout the world (Schaider, 2017). Previous studies aimed to identify if PFAS, perfluorooctanesulfonic acid or perfluorooctanoic acid, was more common in food packaging. Evidence shows that when food comes into contact with PFAS molecules, a transmission occurs, and the food absorbs some of those compounds (Schaider, 2017). With limited data regarding the toxic dose levels of exposure, it is estimated that 100% of the PFAS absorbed in food enters the human body. Ingestion of PFAS is a growing concern due to elevated levels of each compound found in various food packaging and food itself.

With the increasing use of PFAS in food, firefighting, and painting industries, it is clear the levels in the environment will continue to increase. PFAS are easily transmitted from the source to the dinner table. Evidence also shows that PFAS exist in the ocean, as it is transmitted from plastic foodware to water (Wilke, 2013). Another source that gives rise to PFAS in food products includes non-stick kitchen pots and pans. A transmission also occurs when non-stick paper is used for baking purposes (Schaider, 2017). Food comes into contact with PFAS many times during the preparation process, which is why it is critical to assess human exposure and chronic dose levels.

When containers, materials, and packaging that repel water and oil are disposed in landfills they can cause harm to the environment. Studies have found increased concentrations of PFAS in soil near landfills where the items were disposed. Short chain PFAS travel easier and are found at low levels in food that grows in the soil containing the compounds. In Europe, a study identified that PFAOs were the most abundant compound of the PFA family present in vegetables (Herzke, 2013). The longer chained PFCAs were found only in the roots of the vegetables (Herzke, 2013). Leafy vegetables had the highest concentration of PFAOs compared to non-leafy vegetables. The concentration of PFAOs in lettuce was 10 μg/L (Herzke, 2013). Food is not only exposed to PFAS while growing in the fields, but it also comes into contact with the compounds again once placed in a water and oil proof food package.

In a similar research study, fourteen cardboard and six plastic food packages were analyzed for PFAS, PFAOs, and PFOs. The researchers used chromatography and PIGE methods to analyze the PFA compounds in various packaging. Of the twenty samples collected, only three cardboard and three plastic containers did not have PFAS levels above the detection limit in the PIGE analysis (Schaider, 2017). The remaining fourteen food packages passed the detection limit for PFAS, PAOs, and PFOs. The food packages analyzed included popcorn bags, candy wrappers, cardboard cake boxes, etc. The elevated concentration of PFAS in food packaging were found in the containers used to help reduce grease leakage from a package (Schaider, 2017). It is unknown if the transmission of PFAS is affected by the temperature of the food placed in packaging.

Recently, it was discovered that another source of transmission of PFAS was during the first trimester of pregnancy in Spain. Traces of PFAS were found in umbilical cord blood. The research study examined the two types of PFAS, PFOS and PFOAS, levels in a mother's body. This was a concern for the area due to high levels of PFAS being found in soil and food products throughout the region. The study identified two routes of exposure for the mother, inhalation and ingestion. The levels in the mother's plasma and cord blood exceeded the EPSAs weekly tolerable intake of PFAS (Rovira, 2019). The levels were then assessed after the delivery of the child and the levels still exceeded the EPSAs weekly tolerable intake (Rovira, 2019). The average PFOA level in the placenta was 0.45 ng/ml. The average PFO level was 2.93 ng/ml (Rovira). This study was done in Europe, where they have established toxic dose levels for PFOs and PFAS. Toxic ingestion levels of the compounds by the human body has not yet been established in the United States. One of the ways PFAS will decline in the human body will be due to its half-life over time (Rovira, 2019). Although, the half-life for PFOs is expected to be at most five years and for short chain PFAS it is approximately four to five days (Rovira, 2019). The transmission of some PFAS into certain foods is unknown. For example, a study looked at a dairy farm where the water was contaminated with PFAS. Of the cows in the dairy farm, some produced milk with PFAS and some cows did not (U.S. FDA, 2019). From other studies it was clear that in areas where concentration of PFAS in soil was high there was elevated levels in vegetation. It is uncertain if the transmission of PFAS is seen through the ingestion of the compound by a living organism then transferred to the next (U.S. FDA, 2019). This is important when analyzing human ingestion of vegetables with high PFAS because studies have shown their exposure to PFAS in the digestive system is low (U.S. FDA, 2019).

In closer proximity, the transmission of PFAS via food products is possibly occurring one hour south of Tucson. Traces of PFAS were found in a wastewater treatment plant near Nogales, Arizona (News 4 Tucson, 2019). Nogales supplies a large amount of vegetation to the State of Arizona and wheat to various parts of the country. From previous research studies, it is clear that short chain PFAS can enter the vegetation, specifically leafy greens when they are present in the soil and water. No testing has been done on the vegetation leaving the fields. In order to fully assess the transmission of PFAS from water to soil and then ingestion by humans it is critical to establish a toxic dose level for a better understanding of hazards.

Food packaging and food itself are modes of transportation for PFAS. Items that are manufactured to repel water or oil increase the amount of PFAS found in water and soil throughout the world. As food comes into contact with packaging, soil, and water that contains PFAS there is a transmission that occurs. However, human exposure is low when ingesting food that has PFA contents. PFAS is a growing concern for many researchers and the development of guidelines will help with future directions of food exposure to PFAS.

Solutions

To both prevent the rise of PFAS contamination and reduce the harmful consequences of PFAS exposure, changes need to be made at both the individual and institutional levels. As a consumer, there are several measures that can be taken, ranging from changing buyer decisions, to correct waste disposal, to at-home water filtration. At the institutional level, policy changes, large-scale water filtration, and more research could provide solutions to this global issue we are currently facing.

There are several filtration methods currently used to filter PFAS from drinking water, available for both at-home and industrial use. The EPA has identified three main filtration types: activated carbon, ion exchange, and high-pressure membranes (EPA, 2018) Activated carbon filtration is a water treatment method where water is passed through granular or powdered activated carbon, leaving the unwanted chemicals behind. This process is called "adsorption" (Envis, n.d.) Granular activated carbon (GAC) is made from raw materials with high carbon content which are then heated to increase surface area, creating large particles, while powdered activated carbon (PAC) has a smaller particle size (Envis, n.d.). The second filtration method includes ion exchange, which uses highly porous and polymeric resins. There are cationic exchange resins (CER), and anionic exchange resins (AER). Because many PFAS are negatively charged, AERs are used to filter PFAS from contaminated water (EPA, 2018). Finally, high pressure membranes include nanofiltration and reverse osmosis filtration techniques. Both use membranes with specific permeability to filter out chemicals. Reverse osmosis membranes are less permeable than nanofiltration membranes, but along with removing harmful chemicals, they also remove minerals from water (EPA, 2018), which is not ideal for drinking water.

Of the above filtration methods, GAC and AER both remove 100% of PFAS, while PAC and CER are not effective filtration methods for PFOA/PFAS removal. High pressure membranes have been found to be 90 percent effective at removing a wide range of PFAS, including shorter chain PFAS (EPA, 2018). NSF International, which created a certification standard for removal of PFOS/PFAS, has approved 71 products from seven manufacturers for effectively reducing PFAS levels to below the EPA safety guideline of 70ppt (EWG Science Team, 2018). GAC systems are more affordable than reverse osmosis systems for at-home use, and at the industrial level, are more sustainable due to their regenerative capacity. While membranes and resins must be incinerated after use, GAC can be regenerated by heating the material, thus oxidizing organic material trapped in the pores, and releasing them from the carbon surface (EPA, 2000).

Currently, the EPA has recommended a "screening level (level over which a potential contamination site should be investigated further) of 40 parts per trillion (ppt) for PFOA and PFOS," and a non-regulatory Health Advisory (HA) of 70 ppt (Reade, 2019). However, several states have set their own lower limits for PFAS levels. New Jersey set the safety limit to 13 ppt (Onge & Reade, 2019). Linda Birnbaum, former Director of the National Institute for Environmental Health Sciences, presented at a conference on PFAS at Northeastern University in June 2019, where she suggested that there is new data that shows that the safety level of PFAS should be 0.1 ppt, which is 700 times lower than the current safety threshold of 70 ppt (Lerner, 2019). In order to better prevent harmful effects, research needs to be done for a scientific consensus to be reached about what the safety threshold of PFAS should be. This issue raises questions about current policy procedures on safety thresholds for all harmful chemicals. How are these guidelines being set without sufficient research to back them? If there is research showing that 70 ppt is still a harmful exposure level, how is it still our EPA recommended threshold? Only recently has the EPA begun to take steps towards identifying PFAS as "hazardous chemicals". Currently, no PFAS chemicals are included on the list of chemicals required to report to the EPA Toxics Release Inventory (TRI), however, according to the EPA PFAS Action Plan, published in February 2019, the EPA is considering whether to add PFAS to the list. Because PFAS are a group of chemicals with such a wide range of advantageous uses, manufacturing of PFAS in the US continued until 2015, when the EPA's PFOA/PFAS Stewardship Program, which began in 2006 and functioned as a plan for 8 companies to phase out PFAS manufacturing, finally reached its goals.

Currently, there several alternative chemicals being manufactured and used to avoid PFAS use, but these are not well studied, and the effects are not well known. As the EPA's Stewardship Program phased out PFAS manufacturing in the US, companies had to look for alternatives. These include short-chain PFAS, GenX chemicals, and others. Short-chain PFAS are 6-carbon chains, as opposed to long-chain PFAS, which tend to be 8-carbon chains or longer. While manufacturers claim that short-chain PFAS are safe alternatives to long-chain PFAS, research is yet to confirm these claims. So far, research has shown that long and short chain PFAS affect the same organ systems, but that higher doses of short-chain PFAS are required to produce the same effects as long-chain PFAS. However, short-chain PFAS were still shown to affect the liver, immune system, mitochondrial function, and neural development. Currently, studies of carcinogenicity of short-chain PFAS are underway (Formuzis, 2018). GenX chemicals and PFBS are chemicals also currently being manufactured as alternatives to PFAS, and have very similar structures to PFOAs (National Toxicology Program, n.d.), but GenX chemicals have a carboxylic acid inserted into the structure, which is part of the mechanism by which it is able to break down in water, though its effect on toxicity is not well-known (Hogue, 2018). GenX chemicals have already been found to have harmful effects in animal studies, meaning they could potentially be harmful to humans. This raises the question of whether all chemicals, even alternative chemicals that theoretically should be less long-lasting, or harmful, should be tested and researched before they are manufactured and used.

Discussion/Conclusion

This issue of PFAS contamination, and how it has been handled, brings up big picture questions about the relationships between policy, business, and scientific research. The PFAS contamination crisis is not the first crisis of its kind. In the 1950s, manufacturing of trichloroethylene (TCE), a toxic, known human carcinogen, became widespread as its use in cleaning metal parts grew. This is not a complete sentence. Perhaps rephrase to “Tucson, Arizona, specifically experienced a contamination crisis due to the incorrect disposal of TCE at the Tucson International Airport by manufacturing facilities. Until the 1980s, the disposal process involved “pouring it into open pits and occasionally by pouring it directly on the ground and down drains” (PimaLib_LibrarianFiles, 2014). This led to a plume of contamination throughout Tucson which required a $35 million cleanup plan (PimaLib_LibrarianFiles, 2014). The last settlements regarding TCE contamination were settled in 2006, the same year when the PFAS/PFOA Stewardship Program began, yet the manufacturing of PFAS in the US did not end until 2015, and manufacturing continues abroad. How many more contamination crises will have to occur before the cycle is stopped?

Regulation of chemical manufacturing and use must be more preventative. This is a matter of balancing concerns. No matter the usefulness of a chemical for making a product, its health effects should be of utmost importance. How can chemicals be used in our everyday products before sufficient research about their health effects can rule out harmful effects? This is a fundamental issue in the current regulatory system, as it does not prevent future crises by allowing us all to be exposed to potentially harmful chemicals. Even alternative compounds are continuing the cycle. “Safer” alternative compounds to PFAS are currently being manufactured without sufficient research to prove that these compounds do not have harmful effects themselves, so are they safer? At the end of her presentation at the PFAS conference, Linda Birnbaum, former NIEHS Director, stated, “It is time that we ask ourselves: where are these widely used chemicals really needed? Does the value of PFAS use for modern-day convenience outweigh the risks to public health and related health care costs?” she asked, “No matter how we answer that question, one thing is clear — scientific innovation is critical for shifting to safer alternatives.” (Lenox, 2019).

As environmental health science researchers, we encourage the public to voice their concerns about PFAS contamination. The best way to get involved to help reduce PFAS contamination is to join local community groups and contact your state representatives to demand tighter regulations on PFAS used in commercial products, and support funding of environmental health science research.

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