Human and Ecological Health Effects and Risk Assessment of Per- and Polyfluoroalkyl Substances (PFAS)

1 Introduction

Since their identification as contaminants of emerging concern in the early 2000s, per- and polyfluoroalkyl substances (PFAS) have been the focus of numerous studies that have evaluated their potential to cause adverse effects in humans, laboratory animals, and ecological species. The results of those studies, briefly summarized here, indicate that certain PFAS have been asssociated with health effects in both human and nonhuman species.

Of the PFAS studied to date, certain perfluoroalkyl acids (PFAAs) and other PFAS are known to accumulate in humans, non-human mammals, fish, and plants. Perfluoroalkyl sulfonates (PFSAs) with more than eight fluorinated carbons (that is, PFOS and longer chain for PFSAs) and PFNA and longer chain for perfluoroalkyl carboxylates (PFCAs) are substantially more bioaccumulative than shorter chain PFAAs, with PFSAs generally more bioaccumulative than PFCAs with the same number of fluorinated carbons (Conder et al. 2008; Martin et al. 2003). In plants, short-chain PFAAs tend to be more bioaccumulative than long-chain PFAAs. In species that inhabit or depend on aquatic ecosystems, PFAAs may also bioconcentrate and/or biomagnify. (see Section 5.5 and 5.6 of the Guidance Document). Information about detected PFAS concentrations in biota is included in Section 6.5 of the Guidance Document.

ITRC has developed a series of fact sheets that summarize recent science and emerging technologies regarding PFAS. The information in this and other PFAS fact sheets is more fully described in the ***ITRC PFAS Technical and Regulatory Guidance Document (Guidance Document)*** (*https://pfas-1.itrcweb.org/*).

The purpose of this fact sheet is to summarize:

- Human health effects
- Ecological effects
- Site risk assessment challenges

This fact sheet also summarizes some of the specific challenges that PFAS pose in conducting human and ecological site risk assessments. Some of these include the limitations of the studies of adverse effects as well as possible complicating factors of exposure routes.

Additional information and references on all of these topics are available in the Guidance Document.

2 Human Health Effects

Human health effects of PFAS are discussed in Sections 7.1 and 17.2 of the Guidance Document. Table 1 summarizes current animal toxicology and human epidemiology information for PFOA and PFOS, the two PFAS with the most health effects data.

Some PFAS have been linked to multiple health endpoints in studies of the general population and communities with contaminated drinking water. Laboratory animal toxicology studies and human epidemiological studies suggest health effects that may occur as a result of long-term exposure to PFOA and PFOS at environmentally relevant concentrations.

Table 1. Some health effects of PFOA and/or PFOS identified from published studies (not exhaustive).

Animal	Human (possible links)
Liver effects	Liver effects (serum enzymes/bilirubin, cholesterol)
Immunological effects	Immunological effects (decreased vaccination response, asthma)
Developmental effects	Developmental effects (birth weight)
Endocrine effects (thyroid)	Endocrine effects (thyroid disease)
Reproductive effects	Reproductive effects (decreased fertility)
Hematological (blood) effects	Cardiovascular effects (pregnancy induced hypertension)
Neurobehavioral effects	
Tumors (liver, testicular*, pancreatic*)	Cancer* (testicular, kidney)

**PFOA Only*

The toxicological effects of other PFAS that have been studied are generally similar to those of PFOA and PFOS. However, long-chain PFAS are generally toxic at lower doses than short-chain PFAS. This is because, as discussed above, long-chain PFAS are more bioaccumulative than short-chain PFAS and therefore build up to higher levels in the body from the same dose than short-chain PFAS. Human bioaccumulation of PFAS can occur regardless of the route of exposure. Of the four PFAS that have been tested for carcinogenicity in rodents, PFOA, PFOS, and the GenX chemical HFPO-DA caused tumors while PFHxA did not. The majority of the thousands of PFAS known to exist, including many that are in commercial use and/or are found in drinking water or other environmental media, have very limited or no toxicity data. This is a critical data gap in health effects information for PFAS.

Certain long-chain PFAS have human half-lives of several years, and they have been detected in the blood serum of almost all U.S. residents (CDC 2018, 2019; Olsen et al. 2017). These serum levels result from exposures to both the long-chain PFAS and to other PFAS that are their precursors from sources that appear to include food and food packaging, consumer products, and house dust. Decreasing serum levels of PFOS and PFOA in the U.S. general population likely results from the phaseout of their production and use in many products. Higher serum levels are found in communities where drinking water or recreationally caught fish are contaminated and in workers with occupational exposure.

Because developmental effects are considered to be sensitive endpoints for long-chain PFAAs, exposures during developmental lifestages (for example, fetus, infant) are important. PFAAs are known to cross the placenta to reach the fetus and are transferred from the mother to breast milk. Peak exposures to breastfed infants are several times higher than in older individuals, and infants who consume formula prepared with contaminated water also receive higher exposures. See section 17.2.3.1 of the Guidance Document for more information and references.

Although studies have associated human health effects with long-chain PFAS exposure, animal toxicity data are used as the basis for all current U.S. state and federal PFAS toxicity factors (Reference Doses, cancer slope factors) and guidelines, while some European values are based on human data. One reason for this is that there is concurrent exposure to multiple PFAAs in the study populations, making it difficult to determine the impact of individual PFAS. Blood serum levels of PFAS are higher in humans than in animals given the same dose, due to much slower human excretion, and this must be considered in developing of toxicity factors from animal data.

3 Ecological Effects

Ecological health effects of PFAS are discussed in Section 7.2 of the Guidance Document. Biomonitoring studies across a variety of organisms, habitats, and geographies show that certain PFAS compounds can accumulate in wildlife and that exposures are occurring on a global scale (Reiner and Place 2015; Giesy and Kannan 2001). However, unknown resulting adverse effects make use of these data uncertain. Tables 7-1, 7-2 and 7-3, provided as a separate Excel file and linked in Section 7.2 of the Guidance Document, summarize ecotoxicity data for PFAS exposure to various aquatic and terrestrial wildlife species. Wildlife species may accumulate PFAAs by the consumption of contaminated plants or prey items; or through the ingestion or uptake of PFAS present in soil, sediments, or water. Whether a given PFAS also bioconcentrates and/or biomagnifies depends on the chemical properties of the individual PFAS, the trophic level of the species, and other factors such as gender, and whether exposure occurs in fresh or marine waters (see Sections 5.5 and 5.6 of the Guidance Document). Because of their propensity for bioaccumulation, even extremely low or undetectable concentrations of PFAS in the environment may present potential health risks to organisms through direct exposure to impacted abiotic media, and/or indirectly through the food chain.

There are a greater number of controlled laboratory experiments on aquatic taxa compared to terrestrial. These data represent a snapshot of currently available PFAS toxicity for apical endpoints and should not be considered exhaustive as this remains an active area of research. Overall, there are comparatively more ecological effects data available for PFOS than for other PFAS across test organism taxa. Furthermore, acute exposure scenarios of laboratory tests are more commonly found than chronic exposures to PFAS.

Table 7-1 summarizes ecotoxicity data for PFAS exposure to aquatic life. In general, most aquatic toxicity data are available for PFOS, also data from freshwater exposures are more abundant than those for saltwater. Direct toxicity data are relatively limited for benthic invertebrates and sediment-dwelling species for sensitivity to PFAS from bulk sediment exposures. For PFOS, effects on both invertebrates and fish occur at lower concentrations following chronic exposures compared to acute exposures. Although data are limited, those available suggest effects of PFAS to amphibians fall within the range of those reported for fish following acute and chronic exposures.

In the terrestrial environment, there are more published studies with apical endpoints for mammalian species than other classes of organisms. Toxicity tests on laboratory mammals (for example, mice) have shown that exposure to PFAS may

result in adverse effects on the hepatic, endocrine and immune systems; development; and certain types of cancers Toxicity testing with terrestrial plants, invertebrates and avian species has been performed but data are sparse for any PFAS other than PFOS or PFOA. Table 7-2 summarizes some of the available ecotoxicity data for PFAS in terrestrial species.

Despite the growing body of literature on ecotoxicity of PFAS, there still remain significant data gaps. While there are many known PFAS, standard laboratory testing has been limited to mainly PFOS and PFOA. Furthermore, effects of PFAS mixtures remains largely unexplored. Finally, there is a need to expand PFAS testing especially for terrestrial taxa, for example, there are few data available for herpetofauna species.

4 Site Risk Assessment

Site risk assessment challenges specific to PFAS are discussed in Sections 9 and 17.3 of the Guidance Document.

Human Health Risk Assessment

In the general population, the predominant PFAS human exposure pathways are illustrated in Figure 1.

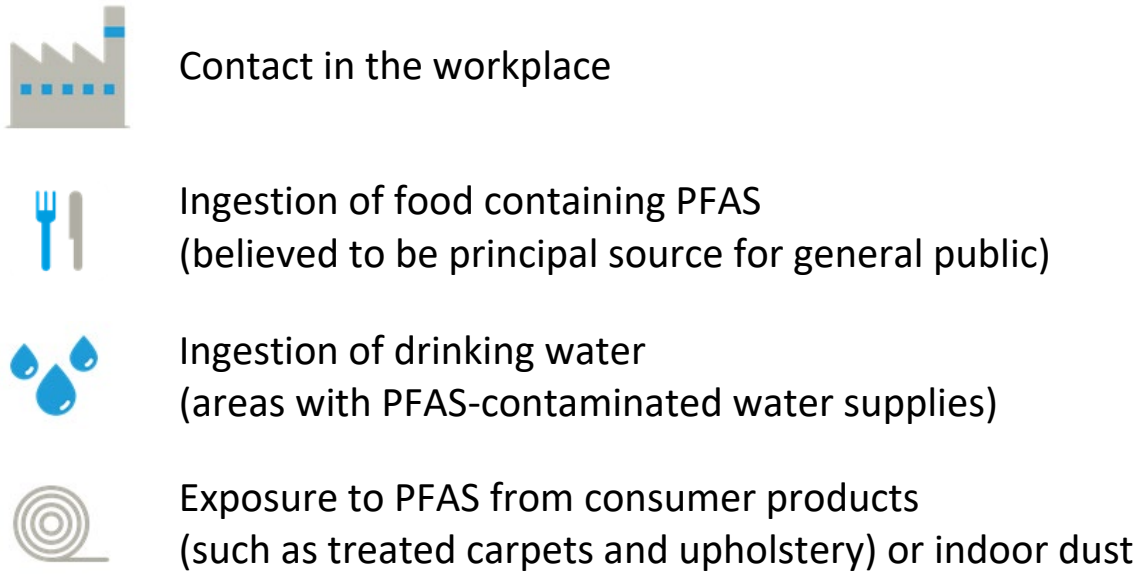

Figure 1. Predominant human exposure pathways.

The highest exposures to PFAS can occur during early life stages (ages 0–18) (Winkens et al. 2017). Exposures to infants from breast milk of exposed mothers or formula prepared with contaminated water are higher compared to older age groups. At PFAS-contaminated sites, the relevant exposure routes and scenarios will depend on the PFAS source (for example, AFFF release, industrial site release) and on the uses of the site and adjoining properties, particularly whether PFAS have migrated to groundwater on- and off-site.

Several state, national, and international regulatory and advisory agencies have developed human toxicity values for various PFAS that could be potentially used in conducting risk assessments or in support of establishing policies for PFAS risk management at a site. The mobility, persistence, and bioaccumulative properties of PFAS are discussed in the Guidance Document, and can all lead to complications in calculating toxicity values as well as challenges in evaluating the possible cumulative effects.

Ecological Risk Assessment

Ecological risk assessment (ERA) for PFAS is challenging because of limited data and technical complexity. Identification of ecological risk-based toxicity thresholds is one challenge for many PFAS. Currently, there are no federal PFAS guidelines or media screening thresholds available for ecological receptors. However, several states have established some criteria that are intended to protect aquatic organisms in their respective surface waters. Screening thresholds and guidelines have been adopted in some jurisdictions using published effects data for species pertinent to the geography and habitats within these jurisdictions. Most available guidelines are protective of freshwater aquatic life exposed to PFOS or PFOA. A second major challenge with toxicity assessment for ERA is accounting for the large number of receptor types

and the associated unknown variable sensitivity to PFAS. Although it is commonly understood that sensitivity to contaminants can vary widely across kingdoms or across classes of animals, the challenge for PFAS may be greater due to the lack of knowledge about this family of compounds. A third major challenge in effects assessment for PFAS is considering the toxicity of mixtures. At this time there are only limited data available to sufficiently understand the toxicity of more than just a few chemicals with respect to direct toxicity to lower trophic level organisms or exposure to upper trophic level wildlife. Detections of PFAS in tissues of top predators within both aquatic and terrestrial ecosystems point to ongoing exposure from bioaccumulative and possibly biomagnifying PFAS.

Thresholds for other PFAS are limited by the lack of a robust set of published ecotoxicological data from multiple species with varying sensitivity. Ecological receptors are always exposed to mixtures of PFAS, as opposed to single chemicals, but there is no consensus on how to assess the toxicity of PFAS mixtures.

Detections of PFAS in tissues of top predators within both aquatic and terrestrial ecosystems (See Section 6.5 of the Guidance Document) point to ongoing exposure from bioaccumulative and possibly biomagnifying PFAS (See Section 5.5.3 of the Guidance Document). There are some published studies of the uptake and elimination of PFAS within aquatic organisms including fish and frogs. Bioconcentration factors and bioaccumulation factors are available to aid in conducting quantitative food chain modeling to upper trophic level wildlife.

6 References and Acronyms

The references cited in this fact sheet and further references can be found at https://pfas-1.itrcweb.org/references/.
The acronyms used in this fact sheet and in the Guidance Document can be found at https://pfas-1.itrcweb.org/acronyms/.

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