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The Persistence and Toxicity of Perfluorinated Compounds in Australia

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Contents

1 Summary 3
2 PFOA and PFOS: the dangerous sister chemicals 4
3 How toxic are perfluorinated compounds? 4
4 Perfluorinated compounds in the Australian population 5
5 Is there a 'safe' level for perfluorinated compounds? 6
6 Perfluorinated compounds in the environment 7
7 International regulatory responses 8
8 Conclusions 8
9 Endnotes 9

1 Summary

"Given the inherent properties of PFOS, together with demonstrated or potential environmental concentrations that may exceed the effect levels for certain higher trophic level biota such as piscivorous birds and mammals; and given the widespread occurrence of PFOS in biota, including in remote areas; and given that PFOS precursors may contribute to the overall presence of PFOS in the environment, it is concluded that PFOS is likely, as a result of its long-range environmental transport, to lead to significant adverse human health and environmental effects, such that global action is warranted."

PERFLUOROOCTANE SULFONATE RISK PROFILE
Adopted by the Persistent Organic Pollutants Review Committee at its second meeting November 2006

Manufactured fluorinated chemicals are widely used in a variety of consumer goods from non-stick kitchenware to waterproof clothing and even cosmetics, as well as many industrial applications. Produced commercially since the 1950s, two groups of perfluorinated compounds (PFCs), the perfluoroalkyl sulfonates (PFSAs) and the perfluorocarboxylic acids (PFCAs) have raised alarm bells on a global scale. In particular, perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA) have been shown to be toxic and very persistent, posing a global contamination problem.

Australian citizens have both PFOS and PFOA in their blood, urine and breast milk. These chemicals are not manufactured in Australia but are found in many imported products and in current stockpiles of old, but still used, fire-fighting foams. Currently there are investigations into environmental contamination with PFOS and PFOA in Victoria at the Fiskville Country Fire Authority's (CFA) training college in Victoria, at the Williamstown Air Base, NSW and the Army Aviation Centre near the rural town of Oakey, in Queensland.[1] There are likely to be further contamination sites around Australia.

Due to their long half-life in human beings (PFOS 5.4 years and PFOA 3.8 years approx.), there is an increasing risk over time that the exposure will cause adverse effects. A US EPA review concluded that PFOA poses a risk for childbearing women; the estimated exposure range for humans, based on rat studies, having already overlapped with what the US EPA deem as unacceptable for toxic substances.[2] In Europe, PFOA is classified as reproductive toxin and is required to be labelled, "May damage the unborn child". PFOA and PFOS are linked to an increased risk of cancer, endocrine disruption and reproductive harm[3].

Recent research suggests that PFOS concentrations at current population levels may already be causing adverse health impacts,[4,5] which indicates that even these values may be too high. As PFOS and PFOA do not break down, are passed from one generation to the next via breast milk and *in utero*, and have in some cases demonstrated changes in gene expression at very low levels, it is possible that like lead and mercury, there may be no safe level of exposure to PFOS and /or PFOA.

Urgent regulatory action is needed to ensure Australian citizens are protected from ongoing exposures to perfluorinated compounds in consumer products. Special consideration must also be given to ensuring contaminated sites are cleaned up and firefighter's and other relevant worker's health is monitored. The Australian government must immediately ratify and act on the POPs listings on the Stockholm Convention, including the listing of PFOS in 2010.

2 PFOA and PFOS: the dangerous sister chemicals

The most well-known use of PFOA is in the manufacture of Teflon, the polymer used in non-stick coatings. PFOA is a very toxic chemical, which has been nominated for listing on the United Nation's *Stockholm Convention on Persistent Organic Pollutants* (POPs), a convention that seeks to eliminate some of the world's most dangerous chemicals. Its sister chemical, PFOS, was also well known in 3M's Scotchguard products. It is an extremely persistent industrial chemical that does not break down.

At the October 2015 meeting of the UN POP Review Committee, the expert group of the Stockholm Convention, committee members concluded that PFOA met all criteria for further evaluation as a persistent organic pollutant; a decision that starts its journey to global elimination. In a consensus decision, the experts agreed that PFOA causes - *"kidney and testicular cancer, disruption of thyroid function and endocrine disruption in women."* [6] In addition, they concluded PFOA was highly persistent, and does not undergo any degradation under environmental conditions.

The Committee also noted that PFOA was detected at sites remote from known point sources indicating that it has the potential for long-range transport via ocean currents and via atmospheric transport of volatile precursors of PFOA, and that it biomagnifies in animals, threatening the food chain. They stated that mothers excrete PFOA via breast milk and transfer PFOA to infants. After giving birth and at the end of breast feeding PFOA re-accumulates in maternal blood. For the next stage of assessment, the Risk Profile, the committee has called for information on the range of PFOA related products on the marketplace including those that will eventually breakdown to PFOA.

PFOS is already listed on the Stockholm Convention as a POP. PFOS is toxic and travels the world in water and air currents, contaminating ecosystems and their inhabitants.

Australian citizens have both PFOS and PFOA in their blood, urine and breast milk. These chemicals are not manufactured in Australia but are found in many imported products and in current stockpiles of old, but still used, fire-fighting foams. The use of these fire-fighting foams has led to extensive contamination of groundwater and soil with PFOS and PFOA affecting rural and regional communities across Australia.

Currently there are investigations into environmental contamination with PFOS and PFOA in Victoria at the Fiskville Country Fire Authority's (CFA) training college in Victoria, at the Williamstown Air Base, NSW and the Army Aviation Centre near the rural town of Oakey, in Queensland.[7] The serum levels of PFCs in fire fighters were approximately 10 to 15 times higher compared to the general population levels in Australia.[8]

3 How toxic are perfluorinated compounds?

Everyone is exposed to mixtures of perfluorinated chemicals through exposure to dust, indoor and outdoor air, food, water and PFC containing products. PFCs including PFOS and PFOA are found in human blood, urine, breast-milk and babies umbilical cord blood. Due to their long half-life in human beings (PFOS 5.4 years and PFOA 3.8 years approx.), there is an increasing risk over time that the exposure will cause adverse effects.

Mixtures of PFCs have been shown to interfere with the functioning of hormones. Research has demonstrated that at least five PFCs are endocrine disrupting compounds (EDCs) and can affect sex hormones like the estrogen and androgen receptor. In some cases, the mixture effect of exposure to multiple PFCs is more than just additive and researchers emphasised the importance of considering

the combined action of PFCs when assessing health risks.[9] Unfortunately, other than PFOA and PFOS, there is little information on the toxicology and health impacts of the suite of fluorochemicals people are exposed to.[10]

Based on the data of 3,974 adults sampled in the US National Health and Nutrition Examination Survey (NHANES), researchers concluded that higher concentrations of serum PFOA and PFOS are associated with current thyroid disease in the general adult population.[11]

In laboratory animals, PFOS has caused testicular and pancreatic tumours, reproductive and developmental impacts, neurotoxicity and immunotoxicity,[12] as well as affecting the liver.[13] PFOA is a reproductive toxin causing increased mortality in rat pups. It is also a developmental toxicant with prenatal exposure to PFOA causing significant delays in mammary developmental in the female offspring.[14]

The US EPA review concluded that PFOA poses a risk for childbearing women; the estimated exposure range for humans, based on rat studies, having already overlapped with what the US EPA deem as unacceptable for toxic substances.[15] In Europe, PFOA is classified as reproductive toxin and is required to be labelled, "May damage the unborn child".

Both PFOA and PFOS suppress immune responses in adult mice [16] and exposed humans. Elevated levels of PFOA and PFOS have also been associated with significant changes in clinical markers of immune and inflammatory responses.[17] There is mounting evidence to suggest that immune suppression occurs at serum concentrations below, within, or just above the reported range for highly exposed humans and wildlife. For PFOS, some human and wildlife species have serum concentrations that exceed the threshold for PFOS-induced immune effects, suggesting a potential risk for altered disease resistance. Thus, the risk of immune effects for humans and wildlife exposed to PFCs cannot be discounted, especially when bioaccumulation and exposure to multiple PFCs are considered. [18]

PFOA has been shown to affect the expression of genes[19,20], while other researchers have demonstrated that PFOA has 'genotoxic' effects[21] on human liver cells.[22] Genotoxic chemicals damage the genetic information within a cell, which can cause mutations and lead to cancer. These chemicals may have no safe level of exposure. The US EPA's expert committee recommended that PFOA be considered 'likely to be carcinogenic to humans.[23]

Following the class action between DuPont (a manufacturer of Teflon which contains PFOA) and US residents in the vicinity of a major contamination incident, the jointly established *C8 Science Panel* concluded that PFOA can cause kidney cancer, testicular cancer, ulcerative colitis, thyroid disease, pregnancy-induced hypertension and medically diagnosed high cholesterol in humans.[24]

To assess health risks from environmental contamination with PFCs, all PFCs should be included in monitoring and their human exposure assessed. More research studies on toxicity, bioaccumulation, carry-over rates and exposure pathways for the other approximately 1000 PFAS are needed in addition to the gaps of PFOS exposure pathways. [25]

4 Perfluorinated compounds in the Australian population

People and animals are exposed to PFCs via food, drinking water, direct contact with products and exposure from indoor and ambient air. PFCs remain in the human body for many years, accumulating primarily in the blood, kidneys and liver. Most Australians have accumulated perfluorochemicals (e.g. PFOS and PFOA) in their bodies.

The UN PFOS risk profile reports, *"Pooled serum samples from 3802 Australian residents, collected 2002-2003 and divided in relation to age, gender and region, were analysed for*

perfluoroalkylsulfonates, perfluoroalkylcarboxylates and PFOSA. PFOS and PFOSA were quantified in all pooled serum samples with a total range of 12.7-29.5 ng/ml (mean 17.2 ng/ml) and 0.36-2.4 ng/ml (mean 0.81 ng/ml), respectively."

When compared to monitoring results from around the world, concentrations of PFOS and PFOA in the Australian population in 2010-2011 are similar or higher than our overseas counterparts. Concentrations in Australian women of child-bearing age are almost twice that found in pregnant women from Germany and PFOS and PFOA concentrations are 1.5 and twice those found in adults from the USA.[26]

PFOS and PFOA concentrations have been decreasing in Australian adults[27], most likely due to the decline in global use of the chemicals since 2002. PFOS serum levels in 2008/09 ranged from 5.3–19.2 ng/ml and declined to 4.4–17.4 ng/ml in 2010/11. However given the latest research (see below) on endocrine disruptors these levels may still be dangerously high. PFOA was the next highest concentration at 2.8–7.3 ng/ml (2008/09) and 3.1–6.5 ng/ml (2010/11). All other measured PFCs were detected at concentrations <1 ng/ml with the exception of perfluorohexane sulfonate, which in 2010-11 was detected at 1.4–5.4 ng/ml. [28]

Perfluorinated compounds in Australian firefighters

A 2014 study of 149 Queensland firefighters detected multiple PFCs in their serum. The three most prevalent and detected in all samples were PFOS, perfluorohexanesulfonic acid (PFHxS) and PFOA. Their serum levels of PFOS were approximately six to ten times higher than those found in the general population in Australia. The median/mean level in firefighters was 66/74 ng/mL compared to 12 ng/mL (mean) and 6.8 (median) ng/mL in the general population in Australia. The serum levels of other PFCs like PFHxS in firefighters were approximately 10 to 15 times higher compared to the general population levels in Australia. Even ten years after the phase out of 3M AFFF Industrial Fire Fighting Foam, PFOS serum levels remained above 100 ng/mL and 200 ng/mL in 27% and 3% of the participating firefighters, respectively.[29]

5 Is there a 'safe' level for perfluorinated compounds?

In 2006, the Biomonitoring Commission of the German Federal Environmental Agency established preliminary reference values for PFOA and PFOS in plasma of children and adults. They recommended a maximum permissible serum level for PFOA of 10 µg/l for all groups[30]. For PFOS, it recommended 10 µg/l for children at school beginner age, 15 µg/l for adult females and 25 µg/l for adult males.[31 ,32]

Recent research suggests that PFOS concentrations at current population levels may already be causing adverse health impacts,[33, 34] which indicates that even these values may be too high. A recent study[35] argues that the mean serum levels of PFOS of 14.1 ng/ml are associated with impacts on DNA methylation, suggesting that PFOS may be epigenetically active.[36] Methylation modifies the function of the DNA, typically acting to suppress gene transcription, which in turn may be associated with the development of cancer.[37]

In 2014, the US EPA released a draft [38] of its proposed new reference dose for PFOS of 0.00003 milligrams/kilogram/per day based on developmental toxicity and adverse liver effects. This would be an estimate of how much a person can safely consume daily over a lifetime.

The proposed reference dose for PFOA is 0.00002 mg/kg/day due to adverse changes in the liver linked to developmental effects and adverse changes in the kidney. That proposed reference dose would translate to a legal limit for PFOA of 0.1 ppb in drinking water. While a significant reduction on current advisory level of 0.4ppb, it is dismissed by some researchers as not protective enough of

human health, based on new research. These proposed changes to the reference dose have been criticised by state regulators for EPA's failure to consider infant and neonatal exposure levels to two perfluorochemicals (PFCs). [39]

The US state of New Jersey has set their own advisory level for PFOA in drinking water of 0.04 ppb – ten times more protective than EPA's advisory level but still well above Grandjean and Clapp 2015 recommended 0.001 ppb (based on a serum concentration of 0.1 ng/mL).[40]

As PFOS and PFOA do not break down, are passed from one generation to the next via breast milk and *in utero*, and have in some cases demonstrated changes in gene expression at very low levels, it is possible that like lead and mercury, there may be no safe level of exposure to PFOS and /or PFOA.

6 Perfluorinated compounds in the environment

PFCs are released into the air and water from waste sites, manufacturing facilities, sewerage treatment works and fire-fighting operations. They migrate out of consumer products such as all-weather clothing, carpets and camping gear into the air, household dust, food, soil, as well as ground and surface water.

PFCs are extremely persistent in the environment and travel the globe via air and water currents. In the air, volatile PFCs (eg polyfluorinated fluorotelomer alcohol (FTOH) and sulfonates) are transported thousands of kilometres and others are carried by suspended particulate matter, which is eventually washed out and deposited in rain and snow. PFCs are also found in water, soil and wildlife and now contaminate every ecosystem in the world from the remote Arctic to the tropics. In recent sampling of snow in remote locations and water from mountain lakes, PFCs were present in nearly all the samples.[41] These data include short chain PFCs, which industry is increasingly using, arguing that they are less harmful than long chain PFCs like PFOS.[42] Unfortunately, like many of the PFCs, there is a dearth of information on toxic effects of short chain PFCs, however, their detection in remote places is of concern, and there are indications that some of the new PFCs are as hazardous as their predecessors.

PFOS has shown no evidence of degradation in the environment [43] and the results of various degradation tests and field monitoring data support the conclusion that no biodegradation of PFOA occurs either.[44] Additionally PFOA-related substances can degrade to PFOA under environmentally relevant conditions. PFOS and PFOA bioaccumulate in fish, birds and mammals with concentrations increasing further up the food chain.

The use of PFCs, particularly in fire-fighting foams has been linked to environmental contamination of groundwater in Germany, Sweden and the US. [45] In 2006 in Sauerland, Germany PFOS contamination of water, pasture, forage and animal products occurred from industrially contaminated biosolids applied to land, while in 2007 there was broad scale contamination of groundwater with PFOS from firefighting foams in Düsseldorf, Germany. In 2013, surface, ground and tap water was found to be contaminated with PFOS in Italy, downstream from a PFAS production plant. In October 2015, an Ohio woman was awarded $1.6 million in compensation after a jury ruled that PFOA from US company DuPont plant contaminated drinking water and contributed to her development of kidney cancer[46]. This was just the first of many cases against Dupont. Dupont is facing the litigation from an additional 3,500 residents near one of its plants in West Virginia who have also accused the company of contaminating their drinking water with PFOA, resulting in sickness including cancer.

Since biodegradation and adsorption is not known to occur in the aquifers and soils, PFOS and PFOA are transported at nearly the same rate as groundwater, [47] with the concentrations decreasing only with distance from the source due to diffusion and dispersion.

The 2015 *Madrid Statement* on Poly- and Perfluoroalkyl Substances (PFASs) signed by scientists and

environmental health specialists from across the globe called for urgent action noting: *"PFASs are highly persistent, as they contain perfluorinated chains that only degrade very slowly, if at all, under environmental conditions."* [48]

7 International regulatory responses

In 2000, the Organisation for Economic Cooperation and Development (OECD) undertook a hazard assessment on PFOS and its salts, concluding that the persistence of PFOS in the environment, its toxicity and bioaccumulation potential indicated cause for concern for the environment and human health.[49]

In 2002, under pressure from the United States Environmental Protection Agency (US EPA), the major manufacturer of PFOS and its precursors, 3M, ceased production. Canada prohibited the manufacture, use, sale, offer for sale and import of PFOS and related substances. In 2006, the European Union adopted a resolution restricting the marketing and use of PFOS and related substances. [50] The US EPA severely restricted the use of PFOS and other perfluoroalkyl substances (PFASs) to uses where no safer alternative is available[51].

In 2010, PFOS was formally listed on the United Nation's *Stockholm Convention on Persistent Organic Pollutants*, a convention for some of the world's most dangerous chemicals. Its listing on Annex B permitted some limited ongoing uses. Work by the conventions scientific and technical committee continues to phase out the remaining uses and in May 2015, the Stockholm Convention's conference of parties removed six of those permitted uses. Despite being a signatory to the Convention, Australia has not yet ratified the listing of PFOS.

In October 2015, PFOA was nominated for listing on the United Nation's *Stockholm Convention on Persistent Organic Pollutants*. DuPont had agreed to phase out production of PFOA by 2015.

8 Conclusions

Urgent regulatory action is needed to ensure Australian citizens are protected from ongoing exposures to to perfluorinated compounds in consumer products. This requires priority phase out of all perfluorinated compounds in consumer products and immediate cessation of the PFOS and PFOA and those products that degrade to PFOS and PFOA. During the phase out period perfluorinated compounds should be labelled to inform consumers, users and waste managers.

Particular attention should be given to the waste phase of perfluorinated compounds with national regulators ensuring access to non-combustion destruction technologies. Special consideration must also be given to ensuring contaminated sites are cleaned up and firefighter's and other relevant worker's health is monitored.

9 Endnotes

[1] Department of Defence, Oakey - Army Aviation Centre - Groundwater Investigation Project. http://www.defence.gov.au/id/oakey/Documents.asp

[2] http://www.nytimes.com/2003/04/15/science/epa-orders-companies-to-examine-effects-of-chemicals.html?pagewanted=all Also see Preliminary Risk Assessment of the developmental toxicity associated with exposure to Perfluorooctanoic acid and its salts. U.S. Environmental Protection Agency Office of Pollution Prevention and Toxics Risk Assessment Division, April 10, 2003

[3] http://www.pops.int

[4] Grandjean, P. and E. Budtz-Jørgensen (2013). Immunotoxicity of perfluorinated alkylates: calculation of benchmark doses based on serum concentrations in children. *Environmental Health(*12).:

[5] Watkins, D. J., G. A. Wellenius, et al. (2014). Associations between Serum Perfluoroalkyl Acids and LINE-1 DNA Methylation. *Environment International* (63): 71-76.

[6] http://www.pops.int

[7] Department of Defence, Oakey - Army Aviation Centre - Groundwater Investigation Project. http://www.defence.gov.au/id/oakey/Documents.asp

[8] Rotander, A. Toms, LL. Kay, M. Mueller, JF. (2015). Elevated levels of PFOS and PFHxS in fire fighters exposed to aqueous film forming foam (AFFF). *Environment International* 82: 28-34.

[9] Kjeldsen LS., Bonefeld-Jørgensen EC. (2013). Perfluorinated compounds affect the function of sex hormone receptors. *Environmental Science & Pollution Research International.* 20(11):8031-44.

[10] Taxvig, C. Rosenmai, AK. Vinggaard, AM. (2014) Polyfluorinated alkyl phosphate ester surfactants - current knowledge and knowledge gaps. *Basic & Clinical Pharmacology & Toxicol*ogy 115(1):41-4.

[11] Proposal to list pentadecafluorooctanoic acid (CAS No: 335-67-1, PFOA, perfluorooctanoic acid), its salts and PFOA-related compounds in Annexes A, B and/or C to the Stockholm Convention on Persistent Organic Pollutants.

[12] Miralles-Marco, A. and S. Harrad (2015). Perfluorooctane sulfonate: A review of human exposure, biomonitoring and the environmental forensics utility of its chirality and isomer distribution. *Environment International* 77: 148-159.

[13] Preliminary Risk Assessment of the developmental toxicity associated with exposure to Perfluorooctanoic acid and its salts. PERFLUOROOCTANOIC ACID AND ITS SALTS, U.S. Environmental Protection Agency Office of Pollution Prevention and Toxics Risk Assessment Division, April 10, 2003.

[14] Tucker, DK. Macon, MB. Strynar, MJ. Dagnino, S. Andersen, E. Fenton, SE. (2015). The mammary gland is a sensitive pubertal target in CD-1 and C57BI/6 mice following perinatal perfluorooctanoic acid (PFOA) exposure. *Reproductive Toxicology* 54: 24-36. Available: www.ncbi.nlm.nih.gov/pubmed/25499722

[15] http://www.nytimes.com/2003/04/15/science/epa-orders-companies-to-examine-effects-of-chemicals.html?pagewanted=all. Also see: Preliminary Risk Assessment of the developmental toxicity associated with exposure to Perfluorooctanoic acid and its salts. U.S. Environmental Protection Agency Office of Pollution Prevention and Toxics Risk Assessment Division, April 10, 2003.

[16] Dewitt, JC. Peden-Adams, MM. Keller, JM. Germolec, DR. (2012). Immunotoxicity of Perfluorinated Compounds: Recent Developments *Toxicologic Pathology* 40: 300-311.

[17] Ibid.

[18] Ibid.

[19] Gene expression is the process by which inheritable information from a gene is translated and made into a functional gene product in the cell

[20] Guruge, KS. Yeung, LW. Yamanaka, N. Miyazaki, S. Lam, PK. Giesy, JP. Jones, PD. Yamashita, N. (2005). Gene Expression Profiles in Rat Liver Treated With Perfluorooctanoic Acid (PFOA). *Toxicological Sci*ences 89: 93-107.

[21] Genotoxicity describes the property of chemical agents that damages the genetic information within a cell causing mutations, which may lead to cancer. While genotoxicity is often confused with mutagenicity, all mutagens are genotoxic, however, not all genotoxic substances are mutagenic.

[22] Yao X. and Zhong L. (2005). Genotoxic risk and oxidative DNA damage in HepG2 cells exposed to perfluorooctanoic acid. *MutationResearch/Genetic Toxicology and Environmental Mutagenesis* 587 (1-2) 38-44.

[23] EPA Science Advisory Board SAB review of EPA's draft risk assessment of potential human health effects associated with PFOA and its salts. (2006). Report to the EPA Administrator. Washington, DC: U.S. Environmental Protection Agency

[24] http://www.hpcbd.com/Personal-Injury/DuPont-C8/The-Science-Panel.shtml

[25] Brambilla, G. D'Hollander, W. Oliaei, F. Stahl, T. Weber, R. (2015). Reviewing the pathways and factors for food safety and food security at PFOS contaminated sites. *Chemosphere* 129: 192-202.

[26] Ibid.

[27] Toms, LM. Thompson, J. Rotander, A. Hobson, P. Calafat, AM. Kato, K. Ye, X. Broomhall, S. Harden, F. Mueller, JF. (2014). Decline in perfluorooctane sulfonate and perfluorooctanoate serum concentrations in an Australian population from 2002 to 2011. *Environment International* 71: 74-80.

[28] Ibid.

[29] Rotander, A. Toms, LL. Kay, M. Mueller, JF. (2015). Elevated levels of PFOS and PFHxS in fire fighters exposed to aqueous film forming foam (AFFF). *Environment International* 82: 28-34.

[30] Note: ng/mL is equivalent to μg /L

[31] Wilhelm, M. Angerer, J. Fromme, H. Hölzer J. (2009). Contribution to the evaluation of reference values for PFOA and PFOS in plasma of children and adults from Germany. *International Journal of Hygiene and Environmental Health* 212 (1): 298-309.

[32] Miralles-Marco, A. and S. Harrad (2015). Perfluorooctane sulfonate: A review of human exposure, biomonitoring and the environmental forensics utility of its chirality and isomer distribution. *Environment International* 77: 148-159.

[33] Grandjean, P. and E. Budtz-Jørgensen (2013). Immunotoxicity of perfluorinated alkylates: calculation of benchmark doses based on serum concentrations in children. *Environmental Health(*12). http://www.ehjournal.net/content/12/1/35

[34] Watkins, D. J. and G. A. Wellenius(2014). Associations between Serum Perfluoroalkyl Acids and LINE-1 DNA Methylation. *Environment International* (63): 71-76.

[35] Ibid.

[36] Epigenetics refers to heritable changes in gene expression (active versus inactive genes) that does not involve changes to the underlying DNA sequence (source: http://www.whatisepigenetics.com/fundamentals/)

[37] Watkins, D. J. and G. A. Wellenius(2014). Associations between Serum Perfluoroalkyl Acids and LINE-1 DNA Methylation. *Environment International* (63): 71-76.

[38] http://drinkingwateradvisor.com/2014/03/12/reference-dose-rfd-proposed-for-pfoa-pfos/

[39] http://iwpnews.com/201406202474682/EPA-Daily-News/Daily-News/states-urge-epa-to-weigh-childrens-exposure-in-draft-pfc-analysis/menu-id-1046.html

[40] Grandjean, P. and R. Clapp (2015). Perfluorinated Alkyl Substances: Emerging insights into health risks, *New Solutions: A Journal of Environmental and Occupational Health Policy*. 25(2): 147–163.

[41] Cobbing, M. Jacobson, T. Santen, M. (2015). Footprints in the snow - Hazardous PFCs in remote locations around the globe. September 2015. Available at www.greenpeace.de

[42] Ibid.

[43] http://www.nicnas.gov.au/chemical-information/information-sheets/existing-chemical-info-sheets/pfc-derivatives-and-chemicals-on-which-they-are-based-alert-factsheet

[44] Proposal to list pentadecafluorooctanoic acid (CAS No: 335-67-1, PFOA, perfluorooctanoic acid), its salts and PFOA-related compounds in Annexes A, B and/or C to the Stockholm Convention on Persistent Organic Pollutants. http://chm.pops.int/Convention/POPsReviewCommittee/Chemicals/tabid/243/Default.aspx

[45] Rotander, A. Toms, LL. Kay, M. Mueller, JF. (2015). Elevated levels of PFOS and PFHxS in fire fighters exposed to aqueous film forming foam (AFFF). *Environment International* 82: 28-34.

[46] Teflon on trial: Ohio woman wins $1.6mn lawsuit alleging DuPont chemical led to cancer. https://www.rt.com/usa/318032-dupont-chemical-cancer-lawsuit/

[47] Stage 3 Risk Assessment and Remediation Design at Army Aviation Centre Oakey Remediation Action Plan - Perfluorocarbons in Groundwater, June 2013 Department of Defence. Available at http://www.defence.gov.au/id/_Master/docs/Oakey/0207AACOakey2013EI2-RAP-PFOSGroundwater-PBJun2013.pdf

[48] http://ehp.niehs.nih.gov/1509934/

[49] http://www.oecd.org/env/ehs/risk-management/perfluorooctanesulfonatepfosandrelatedchemicalproducts.htm

[50] The resolution set the maximum concentrations of 0.1% by mass for PFOS-containing semifinished products or articles, 0.005% by mass for PFOS preparations, and 1 µg/m2 PFOS for textiles or other coated materials. http://www.nicnas.gov.au/communications/publications/information-sheets/existing-chemical-info-sheets/pfc-derivatives-and-chemicals-on-which-they-are-based-alert-factsheet

[51] Zushi, Y. Hogarh, JN. Masunaga, S. (2012). Progress and perspective of perfluorinated compound risk assessment and management in various countries and institutes. *Clean Technology Environmental Policy* (14): 9-20.