Risks of Perfluorinated Compounds to Predatory Birds in Coastal Marine Environments in Asia

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Properties of Fluorinated Organic Compounds

F is the most electronegative element. This confers a strong polarity to the C-F bond. C-F bond is the strongest of known covalent bonds (~110 kcal/mol).

Even in the high-energy environment of the stratosphere, the C-F bonds in CFCs are exceptionally stable.

Three non-binding electrons in F atom can form a protective sheath that yields PFCs very stable. C-F bond can withstand boiling with 100% sulfuric acid without any defluorination.
Most fluorochemicals in the environment are anthropogenic.

Biologically produced fluorochemicals contain only one fluorine atom e.g., MFA
Structures of Sulfonated Fluorochemicals

**POSF: Perfluorooctanesulfonylfluoride**

- POSF is the starting material for polymer production

**PFOS: Perfluorooctanesulfonate**

- PFOS is the ultimate degradation product of POSF-based compounds and the compound found in the environment

PFOS: $\text{C}_8\text{F}_{17} \text{S} - \text{O}^{-}$

POSF: $\text{C}_8\text{F}_{17} \text{S} - \text{F}$
Structures of Sulfonated Fluorochemicals

FOSA: Perfluorooctanesulfonamide

\[ \text{C}_8\text{F}_{17} \text{S} - \text{NH}_2 \]

PFOA or POAA: Perfluorooctanoic acid

\[ \text{C}_7\text{F}_{15} \text{CO}^- \]
## Compounds of Interest

<table>
<thead>
<tr>
<th>Compound</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tridecafluoroheptanoate (C7)</td>
<td>$C_6F_{13}COO^-$</td>
</tr>
<tr>
<td>Pentadecafluorooctanoate (C8; PFOA)</td>
<td>$C_{7}F_{15}COO^-$</td>
</tr>
<tr>
<td>Heptadecafluorononoate (C9)</td>
<td>$C_{8}F_{17}COO^-$</td>
</tr>
<tr>
<td>Nonadecafluorodecanoate (C10)</td>
<td>$C_{9}F_{19}COO^-$</td>
</tr>
<tr>
<td>Perfluoroundecanoate (C11)</td>
<td>$C_{11}F_{21}COO^-$</td>
</tr>
<tr>
<td>Perfluorododecanoate (C12)</td>
<td>$C_{12}F_{23}COO^-$</td>
</tr>
<tr>
<td>Perfluorooctane sulfonate (PFOS)</td>
<td>$C_{8}F_{17}SO_3^-$</td>
</tr>
</tbody>
</table>
Production
Electrochemical fluorination

\[ 2\text{C}_8\text{H}_{17}\text{SO}_2\text{F} + 34 \text{HF} \rightarrow (4.5-7.0 \text{ V}) \rightarrow 2\text{C}_8\text{F}_{17}\text{SO}_2\text{F} + 17 \text{H}_2 \]

1-Octanesulfonayl fluoride

Perfluorooctanesulfonayl fluoride (POSF)

The product is not pure, but rather a mixture of isomers and homologues. Commercial POSF is approx. 70 % straight chain and 30 % branched.
Production
Telomerization

YZ (Telogen) + nA (Taxogen) → Y - (A)n-Z (Telomer)

This process results in only molecules containing only even numbers of carbon atoms
Production

• Total production of carboxylated and sulfonated PFCs is unknown
• 3M Produced $6.5 \times 10^6$ pounds in 2000
  – 37 % used in surface treatments
  – 42 % used on paper products for oil and grease resistance
• Fire fighting foams (AFFF) was $6.8 \times 10^6$ liters in 1985 (3 and 6 % concentrates)
Perfluoroalkane Surfactants

Used singly or in combination with other compounds to make polymers
Uses of Fluorinated Surfactants

Adhesives: Wetting agents
Antifogging: Glass surfaces
Antistatic agents: Microchip manufacture
Cement additives: Reduce shrinkage of cement
Cleaners for hard surfaces: Floor Polishes
Coatings: Paint additives, waxes
Cosmetics: Hair-conditioning
Electronics: Insulators
Electroplating: Chromium, copper and nickel
Etching: Glass
Fire-Fighting Foams: Formulated to float on flammable liquids
Herbicides and Insecticides: Wetting agents
Leather: Provide water and oil repellency
Paper: Oil and water repellency
Textiles: Polyester etc. to impart soil, oil and water repellency. Major use is in carpeting.
Ecotoxicological Assessment For PFOS: Rationale for Testing

Discovery of PFOS in environmental Samples

Reliable, sensitive analytical methods now available

Generate hazard data for environmental risk evaluation
Northern Bobwhite (Colinus virginianus)

- Order Galliformes, Family Odontophoridae
- Ground-dwelling upland game bird
- Feeds primarily on weeds, woody plants and grasses. Adults and chicks also consume insects and other invertebrates
Mallard (Anas platyrhynchos)
- Order Anseriformes, Family Anatidae
- Surface feeding dabbling duck (waterfowl)
- Feed primarily on aquatic plants and aquatic insects
Avian Ecotoxicological Studies

- Studies were designed according to OECD, FIFRA and OPPTS guidelines for avian species
- All studies conducted with a well characterized PFOS stock
- Studies conducted under TSCA Good Laboratories Procedures
- Exposure concentrations determined analytically
- Dose concentrations (liver and blood) determined analytically
- Analytical methods validated for each matrix
Endpoints Criteria in Avian Ecotoxicology Studies

• Mechanistically clear
• Ecologically relevant
• Useful in Environmental Risk Assessments
Avian Ecotoxicological Studies
Northern Bobwhite: Acute Toxicity Test

• Exposure Route: Dietary

• Test Phases:  
  Acclimation: 10 days  
  Exposure: 5 days  
  Post-Exposure/Recovery: 3 or 17 days

• Quail Age: 10 days old at test initiation

• Experimental Design:  
  • Doses: 0 (control), 17.6, 35.1, 70.3, 141, 281, 562 and 1125 mg PFOS/Kg feed  
  • Replicates: Six replicates in the control and two replicates per treatment. Five quail per replicate.  
  • Total of 30 quail in the control and 10 quail per treatment
## Northern Bobwhite Acute Toxicity: Conclusions

<table>
<thead>
<tr>
<th>Endpoint A</th>
<th>NOAEL B</th>
<th>LOAEL</th>
<th>TD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dietary (mg PFOS/kg in feed)</td>
<td>70.3</td>
<td>141</td>
<td>103</td>
</tr>
<tr>
<td>Average Daily Intake (mg PFOS/kg/d)</td>
<td>23.8</td>
<td>44.7</td>
<td>32.6</td>
</tr>
<tr>
<td>Serum (µg PFOS/ml)</td>
<td>41.2</td>
<td>41.5</td>
<td>41.4</td>
</tr>
<tr>
<td>Liver (µg PFOS/g, ww)</td>
<td>44.0</td>
<td>70.3</td>
<td>55.6</td>
</tr>
</tbody>
</table>

**A**All values were based on the reduction of body weight in treated quail. Liver and serum PFOS concentrations are based on Day 8 data.

**B**NOAEL and LOAEL values for diet and the ADI are reported as dietary concentrations. Serum and liver effect values are measured tissue values.
Northern Bobwhite Chronic Toxicity Reproduction Test: Methods

Test Chemical: PFOS

Exposure Route: Dietary

Test Bird Age: 24 Weeks Old at Test Initiation

Replicates:
- 16 Adults pairs per Treatment for Reproduction
- 4 Adult Pairs per Treatment for Blood Monitoring

Test Phases:
- Dietary Exposure for 7 Weeks
- Photostimulation at Week 7 to initial egg laying
- Egg production evaluated on a weekly basis
- Chicks maintained on control diet for 14 days post hatch
Northern Bobwhite Chronic Toxicity Reproduction Test: Methods

Test Termination:
- Adults euthanized after 21 weeks. Body weight, Blood collection, Gross Necropsy and tissue collection (liver)
- Chicks euthanized 14-days post hatch. Body weight, Blood and liver collection, Gross Necropsy

PFOS Analyses:
- Feed throughout study
- Liver and Sera at test termination
- Sera and Red blood cells collected at Week 5, 10, and 20 from additional adult pairs
- Eggs collected from 10 mg PFOS/kg treatment
## Northern Bobwhite Chronic Toxicity

### Reproduction Test: Experimental Design

<table>
<thead>
<tr>
<th>Treatment (mg PFOS/kg)</th>
<th>Exposure Period (week)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>21</td>
</tr>
<tr>
<td>10</td>
<td>21</td>
</tr>
<tr>
<td>50</td>
<td>21</td>
</tr>
<tr>
<td>150</td>
<td>21</td>
</tr>
</tbody>
</table>
Northern Bobwhite: Chronic Toxicity
Reproduction Test: Methods

Endpoints Examined

Health, body weight, feed consumption, gross morphology and histopathology of body organs, egg production, embryo viability, hatchability, offspring health and survival, PFOS concentrations in liver, egg membrane, yolk, albumin, and blood serum of adult and offspring quails.
Northern Bobwhite: Chronic Toxicity
Results-Reproduction

Mortalities and Clinical Observations

• 10 mg PFOS/kg body weight Treatment
  - No treatment-related mortality in adult male and female quail
  - Clinical signs in adults included reduced reaction to stimuli, ruffled appearance, and lethargy
Mortalities and Clinical Observations

- 50 mg PFOS/kg body weight Treatment
  - Five treatment mortalities by Week 5
  - Clinical signs of toxicity included reduced reaction to stimuli, wing droop, loss of coordination, convulsions, lethargy, prostrate position
  - Surviving adults euthanized at Week 7
Northern Bobwhite: Chronic Toxicity
Results-Reproduction

Mortalities and Clinical Observations

150 mg PFOS/kg body weight Treatment
- Three treatment mortalities by Week 5
- Overt signs of toxicity similar to that observed at 50 mg PFOS/kg
- Surviving adults euthanized at Week 5
Northern Bobwhite: Chronic Toxicity
Results-Reproduction

Non-Lethal Endpoints

• **10 mg PFOS/kg body weight treatment**
  - No treatment-related effects on body weight in adult quail
  - No treatment-related effects on feed consumption
  - No treatment-related effects on adult male liver weight
  - Significant increase in adult female liver weight
  - No treatment-related histopathological effects in females
  - Significant increase in incidence of small testes in adult males
    - No morphological changes in spermatogenesis noted

• **50 and 150 mg PFOS/kg body weight treatments**
  - Treatment-related reductions in body weight at both treatments levels
  - Treatment-related reductions in feed consumption at both treatment levels
Reproduction Endpoints

- Reproduction only evaluated for control and 10 mg PFOS/kg treatment
- No treatment-related effects on egg production
- Slight but not statistically significant reductions in:
  - Number of viable embryos as percentage of eggs set
  - Number of hatchlings as percentage of live 3-week old embryos
  - Number of 14-day old survivors as percentage of hatchlings
- Slight but statistically significant reduction in:
  - Number of 14-day old survivors as percentage of number of eggs set
Northern Bobwhite: Chronic Toxicity Results—Tissue Concentrations

Concentrations of PFOS in liver and serum of adult quail at study termination (Week 20)

<table>
<thead>
<tr>
<th>Treatment (mg PFOS/kg)</th>
<th>Sex</th>
<th>Liver Conc. (mg PFOS/g)</th>
<th>Serum Conc. (mg PFOS/mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control M</td>
<td>M</td>
<td>&lt; LOQ B</td>
<td>&lt; LOQ</td>
</tr>
<tr>
<td>Control M</td>
<td>F</td>
<td>&lt; LOQ</td>
<td>&lt; LOQ</td>
</tr>
<tr>
<td>10 M</td>
<td>M</td>
<td>88.5 ± 28.5</td>
<td>141 ± 30</td>
</tr>
<tr>
<td>10 F</td>
<td>F</td>
<td>4.9 ± 1.0</td>
<td>8.7 ± 2.6</td>
</tr>
</tbody>
</table>

A All values are reported as means and standard deviations on a wet weight basis.

B LOQ = Limit of quantitation; for liver it was 0.0502 µg/g while for serum it was 400 µg/ml
## Northern Bobwhite Reproduction Test

**Final LOAEL Values**

### Measures of PFOS Exposure

<table>
<thead>
<tr>
<th>Measures</th>
<th>LOAEL</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ADULT MALES</strong></td>
<td></td>
</tr>
<tr>
<td>Dose (ppm)</td>
<td>10</td>
</tr>
<tr>
<td>ADI (mg PFOS/kg body weight/day) over 21-week period</td>
<td>0.772</td>
</tr>
<tr>
<td>Serum (mg PFOS/mL) at study termination (21-weeks)</td>
<td>141</td>
</tr>
<tr>
<td>Liver (mg PFOS/g) at study termination (21-weeks)</td>
<td>88.5</td>
</tr>
<tr>
<td><strong>ADULT FEMALES</strong></td>
<td></td>
</tr>
<tr>
<td>Dose (ppm)</td>
<td>10</td>
</tr>
<tr>
<td>ADI (mg PFOS/kg body weight/day) over 21-week period</td>
<td>0.772</td>
</tr>
<tr>
<td>Serum (mg PFOS/mL), pre-reproductive phase (5-weeks)</td>
<td>84</td>
</tr>
<tr>
<td>Serum (mg PFOS/mL), reproductive phase, (21-weeks)</td>
<td>8.7</td>
</tr>
<tr>
<td>Liver (mg PFOS/g) at study termination (21-weeks)</td>
<td>4.9</td>
</tr>
<tr>
<td><strong>OFFSPRING</strong></td>
<td></td>
</tr>
<tr>
<td>Yolk (mg PFOS/mL)</td>
<td>62</td>
</tr>
</tbody>
</table>

*LOAEL was based on a decrease in the 14-day old survivability of offspring, increased incidence of small testes in adult males, and a statistically significant increase in adult female liver weight. All concentrations are reported on a wet weight basis.*
# Mallard Definitive Reproduction Study
## Final NOAEL and LOAEL Values

<table>
<thead>
<tr>
<th>Measures of PFOS Exposure</th>
<th>ADULT MALES</th>
<th>NOAEL</th>
<th>LOAEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dose (mg PFOS/kg body weight)</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ADI (mg/PFOS/kg body weight per day) over 21-weeks</td>
<td>1.49</td>
<td>1.49</td>
<td></td>
</tr>
<tr>
<td>Serum (µg PFOS/ml) at study termination (21-weeks)</td>
<td>87.3</td>
<td>87.3</td>
<td></td>
</tr>
<tr>
<td>Liver (µg PFOS/ml) at study termination (21-weeks)</td>
<td>60.9</td>
<td>60.9</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Measures of PFOS Exposure</th>
<th>ADULT FEMALES</th>
<th>NOAEL</th>
<th>LOAEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dose (mg PFOS/kg body weight)</td>
<td>10</td>
<td>10</td>
<td>1.49</td>
</tr>
<tr>
<td>ADI (mg/PFOS/kg body weight per day) over 21-weeks</td>
<td>1.49</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Serum (µg PFOS/ml) pre-reproductive phase (5-weeks)</td>
<td>76.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Serum (µg PFOS/ml) at study termination (21-weeks)</td>
<td>16.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Liver (µg PFOS/g) at study termination (21-weeks)</td>
<td>10.8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Measures of PFOS Exposure</th>
<th>OFFSPRING</th>
<th>NOAEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yolk (µg PFOS/ml)</td>
<td>52.7</td>
<td></td>
</tr>
</tbody>
</table>

*LOAEL based on increased incidence of small testes in adult males. wet weight basis.*

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Zoology Dept., National Food Safety Center and Center for Integrative Toxicology
Michigan State University
Derivation of Toxicant Reference Values (TRVs)

• Based on whole-life in vivo studies with bobwhite and mallards
• Application of uncertainty factors
# Uncertainty Factors for a Generic Trophic Level 4 Predator Exposed to PFOS

<table>
<thead>
<tr>
<th>UNCERTAINTY FACTORS (UF)</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inter-taxon Extrapolation (A)</td>
<td>5</td>
</tr>
<tr>
<td>Exposure Duration (B)</td>
<td>1</td>
</tr>
<tr>
<td>Toxicological Endpoint (C)</td>
<td>3</td>
</tr>
<tr>
<td>Modifying Factors (D)</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Overall UF for TRV

UF = (5 x 1 x 3 x 1.5) = 22.5
### Avian Threshold Doses for PFOS

<table>
<thead>
<tr>
<th>Threshold Dose</th>
<th>Average Daily Intake (mg PFOS/kg/d)</th>
<th>Serum (µg PFOS/ml)</th>
<th>Liver (µg PFOS/g, wet wt)</th>
<th>Egg Yolk (µg PFOS/ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOAEL</td>
<td>0.77</td>
<td>35</td>
<td>21</td>
<td>62</td>
</tr>
<tr>
<td>TRV</td>
<td>0.034</td>
<td>1.6</td>
<td>0.93</td>
<td>2.8</td>
</tr>
<tr>
<td>PNEC</td>
<td>0.038</td>
<td>1.7</td>
<td>1.0</td>
<td>3.1</td>
</tr>
</tbody>
</table>

**a** Threshold dose for each end point is based on the geometric mean of female and male values. The LOAEL based on the 10 ppm PFOS treatment in the bobwhite reproduction study.

**b** Average daily intake in units of mg PFOS/kg body weight per day. TRV calculation based on an overall uncertainty factor (UF) of 22.5
Derivation of a Safe Water Concentration: PFOS in Birds
Surrogate Avian Species Used in Wildlife Value Estimates

Herring Gull (*Larus argentatus*)
- Order Charadriiformes, Family Laridae
- Feeds on a variety of foods including fish, crustacea, molluscs, insects, small mammals and birds, and garbage

Bald Eagle (*Haliaeetus leucocephalus*)
- Order Falconiformes, Family Accipitridae
- Opportunistic feeder that consumes fish, birds, and small mammals depending on availability

Belted Kingfisher (*Ceryle alcyon*)
- Order Coraciiformes, Family Alcedinidales
- Generally feeds only on fish but when available, will also consume crayfish.
Derivation of Safe Water Concentrations for the Protection of Wildlife

Wildlife Value = \( \frac{\text{Test Dose} \times BW}{\text{Overall Uncertainty Factor} \left( W + \sum (F_{TLi} \times BAF_{WL}^{TLi}) \right)} \)

- \( WV \) = Wildlife Value in milligrams of PFOS per liter (mg/L)
- \( TD \) = Test dose or threshold dose in mg of PFOS per kg per day (mg/kg body weight-day).
- \( UF \) = Overall Uncertainty factor interspecies, toxicological endpoint and exposure duration extrapolations.
- \( BW \) = Average body weight in kilograms (kg) for the representative species.
- \( F_{TLi} \) = Species specific average daily amount of food consumed (kg/day) for trophic level \( i \)
- \( W \) = Species specific average daily amount of water consumed (L/day)
- \( BAF_{WL}^{TLi} \) = Bioaccumulation factor for wildlife food in trophic level \( i \). For consumption of piscivorous birds by other birds, the BAF is derived by multiplying the Trophic Level 3 BAF by the biomagnification factor (BMF).
### Biomagnification Factor for PFOS in Avian Species

<table>
<thead>
<tr>
<th>Species</th>
<th>Feed (ug PFOS/g)</th>
<th>Liver (ug PFOS/g)</th>
<th>BMF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mallard</td>
<td>10</td>
<td>61</td>
<td>6.1</td>
</tr>
<tr>
<td>Quail</td>
<td>10</td>
<td>88</td>
<td>8.8</td>
</tr>
<tr>
<td>Geometric mean</td>
<td></td>
<td></td>
<td>7.3</td>
</tr>
</tbody>
</table>

Geometric mean of mallard and bobwhite quail BMFs used in the calculation of wildlife values.  \( \text{BMF} = 7.3 \)
Accumulation of PFOS by birds from water

BAF

Water → BCF → Food → BMF → Bird Liver

1,994 → 7.3 → 14,556
# PFOS Wildlife Values Concentration for Avian Species

<table>
<thead>
<tr>
<th>Species</th>
<th>Wildlife Value (µg PFOS/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Herring Gull</td>
<td>0.079</td>
</tr>
<tr>
<td>Bald Eagle</td>
<td>0.026</td>
</tr>
<tr>
<td>Kingfisher</td>
<td>0.038</td>
</tr>
<tr>
<td>Geometric Mean</td>
<td>0.043</td>
</tr>
</tbody>
</table>
Hazard Assessment

HQ = Total Concentration
TRV

MOS = 1/HQ

HQ = Hazard Quotient
MOS = Margin of safety

Hazard based on PFOS only
Sampling Locations in China

Sampling stations in 2003 (Hong Kong: July; Pearl River Delta: September)

Sampling stations in 2004 (Hong Kong and Pearl River Delta: January)
Sampling Locations in Korea
Margins of Safety: China

- **Summer**
- **Winter**

MOS (x10)

MOS
Margins of Safety: Hong Kong

Zoology Dept., National Food Safety Center and Center for Integrative Toxicology
Michigan State University
## Margins of Safety for waters in Asia

<table>
<thead>
<tr>
<th>Location (N)</th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hong Kong</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Summer (6)</td>
<td>73.7</td>
<td>61.9</td>
<td>14-167</td>
</tr>
<tr>
<td>Winter (6)</td>
<td>166</td>
<td>202.9</td>
<td>14-333</td>
</tr>
<tr>
<td><strong>China</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Summer (8)</td>
<td>34.8</td>
<td>28.4</td>
<td>17-100</td>
</tr>
<tr>
<td>Winter (6)</td>
<td>38.4</td>
<td>38.4</td>
<td>4.3-&gt;1000</td>
</tr>
<tr>
<td><strong>Korea (11)</strong></td>
<td>205.4</td>
<td>30.4</td>
<td>0.06-&gt;1000</td>
</tr>
</tbody>
</table>
# PFOA:PFOS Ratios

<table>
<thead>
<tr>
<th>Location</th>
<th>Mean</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hong Kong</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Winter (8)</td>
<td>2.1</td>
<td>1.3-3.7</td>
</tr>
<tr>
<td>Summer (6)</td>
<td>2.8</td>
<td>1.8-8.3</td>
</tr>
<tr>
<td><strong>China</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Winter (6)</td>
<td>2.3</td>
<td>1.2-12.5</td>
</tr>
<tr>
<td>Summer (6)</td>
<td>2.0</td>
<td>1.6-3.5</td>
</tr>
<tr>
<td><strong>Korea</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Except station 8 (10)</td>
<td>3.2</td>
<td>1.3-50</td>
</tr>
<tr>
<td>Station 8</td>
<td><strong>0.48</strong></td>
<td>0.48</td>
</tr>
</tbody>
</table>
Conclusions

• Threshold concentrations were determined for PFOS concentrations in bird tissues and water.
• Most PFFAs were PFOA except at one location in Korea.
• Most concentrations of PFFAs were less than the threshold concentrations in water, except at one location in Korea.
• Additional work is needed on toxicity of PFOA.
• Additional work is needed to determine the sources of PFOS in Korea.
Questions ????????
Thank You

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