FRONT OFFICE FOOD AND PRODUCT SAFETY

Assessment of the transfer and kinetics of PFOS in beef cattle and sheep in order to set guide values

Assessment requested by:	Office for Risk Assessment & Research (BuRO)
Assessment prepared by:	National Institute for Public Health and the Environment (RIVM) and Wageningen Food Safety Research (WFSR)
Date of request:	28-10-2025
Date of assessment:	18-12-2025 (draft) 16-02-2026 (final version, Dutch) 05-03-2026 (final version, English)
Project number:	V/093130

Subject

Animals that have grazed in the Verdronken Land van Saeftinghe nature reserve contain such high PFAS levels that they are likely to exceed the European maximum levels (MLs) in meat and edible organs. These animals are therefore not necessarily fit for human consumption. Prior to slaughter, it must first be plausibly demonstrated that the PFAS levels in meat (and organs, if they are to be made available for consumption) are below the MLs. This is currently done by determining PFAS levels in blood plasma. The Netherlands Food and Consumer Product Safety Authority (NVWA) developed this method step by step based on an earlier Front Office assessment. In the course of this process, the NVWA worked with provisional guide values that were refined in a conservative approach. This guide value was defined as the PFOS blood level (µg PFOS/L blood plasma) at which PFOS levels in meat and organs are very likely to be below the applicable MLs. At present (January 2026), the NVWA uses a provisional guide value of 2.5 µg PFOS/L blood plasma for meat and organs of beef cattle. The NVWA has recently gathered additional data that could serve as a basis for deriving the final guide value. The NVWA has asked the Front Office Food and Product Safety (FO) to perform a scientific analysis of these data as a follow-up to an earlier FO assessment.

Question

The NVWA's Office for Risk Assessment & Research (BuRO) has asked the Front Office Food and Product Safety (FO) the following questions:

- Based on the available data, what (maximum) plasma levels can be used as guide values to plausibly demonstrate that PFOS levels do not exceed the ML for:
    1. Beef cattle; for meat, kidney as well as liver.
    2. Sheep; for meat, kidney as well as liver.

- What is the confidence level regarding the derived value?

<u>Follow-up question:</u>

For the purpose of European harmonisation, the NVWA wants to take into account the guide values used by other EU Member States (as national policies) as much as possible when implementing this method further. From that perspective, the Front Office is being asked to reflect – based on the above analysis – on the plasma values currently used (January 2026) in Belgium (2.5 µg PFOS/L blood plasma for meat, liver and kidney of beef cattle) and Denmark (3.3 µg PFOS/L blood plasma for meat of beef cattle and 6.7 µg PFOS/L blood plasma for meat of sheep). Inquiries by the NVWA about the implementation in Belgium and Denmark show that their working method in practice leads to a similar approach, in which the guide values are used to make a statement about the entire carcass (including organs).

The question focuses primarily on a guide value for PFOS, which is by far the most prominent PFASs in the relevant area. A brief qualitative reflection on the available data is requested for the remaining PFASs. No statement on a guide value is required for these.

Conclusions

Beef cattle: For beef cattle, PFOS levels in plasma should not exceed 2.0 µg/L (protecting 99% of animals with 99% confidence) and 3.5 µg/L (protecting 90% of animals with 90% confidence) to avoid exceeding the ML for meat. If the exceeding of the ML for kidney and liver were to be considered with the same confidence levels, PFOS levels in plasma would be between 5.4 µg/L and 10.8 µg/L (kidney) and between 1.5 µg/L and 2.6 µg/L (liver).

For beef cattle, a PFOS level in plasma of 2.5 µg PFOS/L, as used by the FAVV, is sufficient to state with more than 99% confidence that the ML for meat and kidney is not exceeded in 95% of animals. This is not the case for liver. For liver, a PFOS level in plasma of 2.5 µg PFOS/L offers 70% confidence that the ML for liver is not exceeded in 95% of animals. A PFOS level in plasma of 3.3 µg PFOS/L, as used by the Danish authority, offers about 70% confidence that the ML for meat is not exceeded in 95% of animals. For kidney, a PFOS level in plasma of 3.3 µg PFOS/L offers more than 99% confidence that the ML for kidney is not exceeded in 95% of animals. For liver, a PFOS level in plasma of 3.3 µg PFOS/L offers less than 1% confidence that the ML for liver is not exceeded in 95% of animals.

Sheep: For sheep, PFOS levels in plasma should not exceed 5.3 µg/L (protecting 99% of animals with 99% confidence) and 10.0 µg/L (protecting 90% of animals with 90% confidence) to avoid exceeding the ML for meat. If the exceeding of the ML for kidney and liver were to be considered with the same confidence levels, PFOS levels in plasma would be between 3.3 µg/L and 6.0 µg/L (kidney) and between 0.7 µg/L and 1.3 µg/L (liver).

For sheep, a PFOS level in plasma of 6.7 µg PFOS/L, as used by the Danish authority, is sufficient to state with more than 99% confidence that the ML for meat is not exceeded in 95% of animals. However, this is not the case for kidney and liver. For kidney and liver, a PFOS level in plasma of 6.7 µg PFOS/L offers respectively 20% and less than 1% confidence that the MLs for kidney and liver are not exceeded in 95% of animals.

Other PFASs
Data collected by the NVWA showed that the analysed concentrations of the remaining PFASs (PFOA, PFNA, PFHxS and other PFASSs studied) were in almost all cases too low to quantify in the blood plasma, meat, liver and kidneys of beef cattle and sheep. It is therefore not possible to derive a guide value for these PFASs. The low concentrations of these PFASs relative to PFOS justify the assumption that the ML for the sum of PFOS,

PFOA, PFNA and PFHxS will not be exceeded if the ML for PFOS is also not exceeded in the animals that grazed in the VLS.

1. Introduction

Perfluorooctanesulfonic acid (PFOS) belongs to the per- and polyfluoroalkyl substances (PFASs). PFASs are man-made chemicals. These compounds are incorporated into many products or used in various industrial applications and processes for their favourable chemical properties, such as their ability to repel water, grease and dirt. The production and use of these products cause emissions into the environment. The chemical properties of PFASs make them very poorly biodegradable, which is why they are often found in soil, groundwater, surface water, drinking water and food, but also in human biological matrices.

In 2020, the European Food Safety Authority (EFSA) set a tolerable weekly intake for humans of 4.4 nanograms per kilogram body weight for the sum of 4 PFASs, i.e. perfluorooctanoic acid (PFOA), perfluorooctanesulfonic acid (PFOS), perfluorononanoic acid (PFNA) and perfluorohexanesulfonic acid (PFHxS) (EFSA, 2020). In 2023, the European Commission set maximum levels (MLs) for PFOA, PFOS, PFNA, PFHxS and the sum of these four PFASs in various edible animal products, including meat and edible offal from beef cattle and sheep (European Commission 2023). For PFOS, MLs of 0.3 µg PFOS/kg and 6.0 µg PFOS/kg are currently in effect for meat and offal of (beef) cattle (including kidneys and liver), respectively. The MLs for sheep are 1.0 µg PFOS/kg for meat and 6.0 µg PFOS/kg for offal.

Beef cattle and ewes are kept for nature grazing in the Verdronken Land van Saeftinghe (VLS). These animals serve mainly for breeding but can pass on PFOS to calves and lambs. The farmer will ultimately want to slaughter the animals. Animals that have grazed in the VLS contain such high levels that MLs for PFOS in meat and edible organs are likely to be exceeded, as described by the Front Office Food and Product Safety (2024, 2025). These animals and their offspring are therefore not necessarily suitable for human consumption. Prior to slaughter, it must first be plausibly demonstrated that the PFAS levels in meat (and organs, if they are to be made available for consumption) are below the MLs. This is currently done by measuring PFAS levels in blood plasma. The result is used to estimate whether the levels in meat and organs will comply with the MLs.

This assessment focuses on deriving maximum PFOS levels in plasma at which the MLs for PFOS in meat, kidney and liver are very unlikely to be exceeded. This guide value for PFOS is defined as the PFOS blood level (µg PFOS/L blood plasma), at which PFOS levels in meat and organs are very likely to be below the applicable MLs. The value that the NVWA currently uses (January 2026) as a provisional guide value for PFOS for meat and organs of beef cattle is 2.5 µg PFOS/L blood plasma (NVWA, 2026). Also in Belgium (FAVV 2025), a guide value of 2.5 µg PFOS/L blood plasma is used for meat, liver and kidney of beef cattle. In Denmark, a guide value of 3.3 µg PFOS/L blood plasma for meat of beef cattle and 6.7 µg PFOS/L blood plasma for meat of sheep applies (Danish Veterinary and Food Administration 2024).

2. Methods

For this assessment, we used PFOS levels in plasma, meat, kidney and liver of beef cattle and sheep to derive guide values. To this end, data collected by the NVWA were used. These data were partly described in a previous assessment (Front Office Food and Product Safety, 2025) and were supplemented with information provided by BuRO (FAVV, 2025;

Danish Veterinary and Food Administration, 2024; Albert et al., 2025). Based on these sources, two additional studies containing useful data were identified: we also used plasma and meat samples as described in Johnston et al. (2023) for (dairy) beef cattle, as well as kidney and liver samples described in a study by Lupton et al. (2025). PFOS levels covered in this study are shown in Tables S1 and S2 in Annex I.

The sections below explain how the data were analysed (Section 2.1) and how the guide values were derived (Section 2.2).

2.1 Analysis of available data

This assessment made use of plasma, meat, kidney and liver samples from beef cattle and sheep. To derive guide values, ratios were determined between total PFOS levels (sum of linear and branched) in tissues and plasma sampled at the same time. Since PFOS levels in tissues and plasma vary over time, tissue and plasma samples could only be used to derive a distribution if they were obtained simultaneously.

Of the data collected by the NVWA, plasma, meat, kidney and liver samples were used from six beef cattle and 18 sheep were used. These animals originated from farms that allowed part of their livestock to graze in the VLS. These data were then supplemented with PFOS levels in plasma and meat from 28 beef cattle collected by Johnston et al. (2023). For 20 of these beef cattle, Lupton et al. (2025) also described kidney and liver samples, which were also used in this study.

2.2 Derivation of guide values

A new method in which a ‘tolerance interval’ is calculated has been developed to derive PFOS guide values in plasma from beef cattle and sheep. The results of this method were compared with those that would be obtained using a regression analysis as performed by Belgium’s Federal Agency for the Safety of the Food Chain (FAVV).

A tolerance interval refers to the spread of individual values in a population. It indicates an interval within which a certain percentage (e.g. 95%) of individual values in the population fall with a given confidence level (e.g. 95%). Unlike a confidence interval, which indicates that the average tissue-to-plasma ratio of a population lies between the limits of the interval with a given confidence level, a tolerance interval can be used to indicate which tissue-to-plasma ratio is very likely to be exceeded by a large proportion of the population. Although very large differences are not expected between a confidence interval and a tolerance interval in practice, it was decided for the purpose of this assessment to use a tolerance interval as a starting point for deriving a guide value.

As part of this approach, we first used PFOS levels in plasma, meat, kidney and liver to determine tissue-to-plasma ratios for both beef cattle and sheep. Tolerance intervals were then derived for these ratios (meat:plasma, kidney:plasma, liver:plasma). This resulted in a total of six tolerance intervals: three for beef cattle and three for sheep. In deriving the tolerance intervals, a 95% probability and a 95% population proportion were assumed for illustrative purposes. This population percentage indicates that 95% of animals (with the given probability) have a tissue-to-plasma ratio lower than this upper limit.

The upper limits of the tolerance intervals of the tissue-to-plasma ratios, also referred to as the tolerance limits, were then used to derive a PFOS level in blood plasma for which the PFOS levels in meat, kidney and liver are very likely (95%) not to be exceeded for most animals (95%). This was done by dividing the MLs for the respective tissues by the upper limits of the tolerance intervals of the tissue-to-plasma ratios.

A method described by the National Institute of Standards and Technology (https://www.itl.nist.gov/div898/handbook/prc/section2/prc263.htm) was used to calculate the tolerance limits. More details about this calculation and the equations involved are given in Annex II.

3. Results

The tissue-to-plasma ratios found for beef cattle are visualised in Figure 1. As shown in this figure, the tissue-to-plasma ratios derived from the NVWA data overlap with the tissue-to-plasma ratios found by Lupton et al. (2025) for liver and kidney. However, the meat-to-plasma ratios found by the NVWA are lower than those reported by Johnston et al. (2023). On the other hand, high meat-to-plasma ratios lead to a more conservative estimate of the PFOS level in blood plasma that leads to the ML being exceeded, as shown in Table S3. Combining the data sources thus yielded a more conservative estimate of the PFOS level in blood plasma that leads to the ML for meat being exceeded. Figure 2 shows the tissue-to-plasma ratios for sheep.

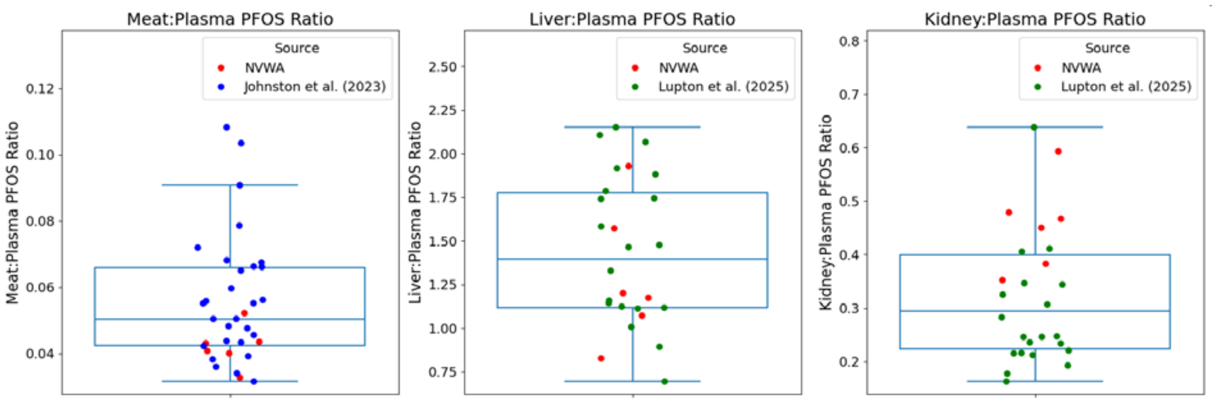

Figure 1. Visualisation of the ratios between PFOS levels in tissues (meat, liver and kidney) and blood plasma of the beef cattle included in this study. The box runs from the 25th percentile of the data to the 75th percentile. The 'whiskers' of the box plots run from the 5th percentile to the 95th percentile.

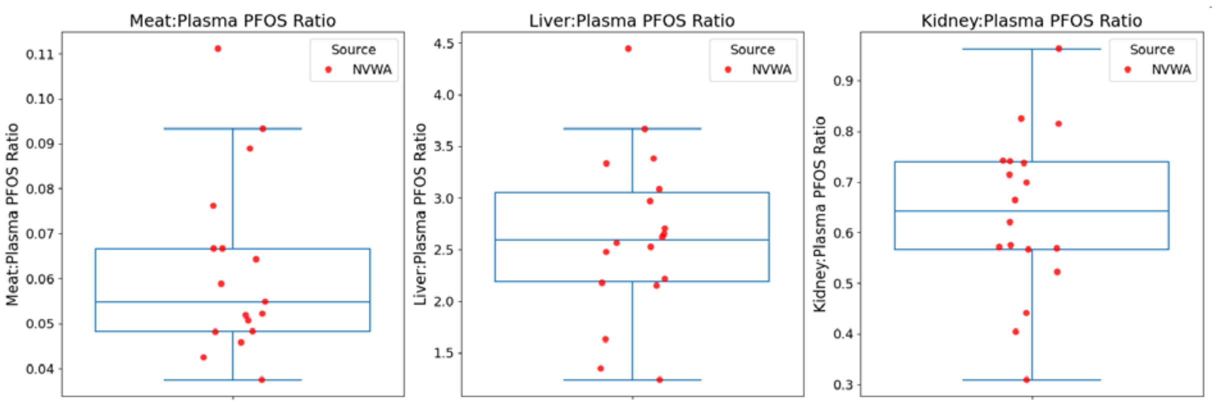

Figure 2. Visualisation of the ratios between PFOS levels in tissues (meat, liver and kidney) and blood plasma of the sheep included in this study. The box runs from the 25th percentile of the data to the 75th percentile. The 'whiskers' of the box plots run from the 5th percentile to the 95th percentile.

Figures 3 and 4 show the measured tissue-to-plasma ratios and the resulting tolerance limits of the ratios for beef cattle and sheep, respectively. A log-normal fit was also performed on the data and shown in the figures. The same analyses were also performed by data source (see Figures S1–S4). To interpret the figures properly, it is important to mention that the 'density' on the y-axis of the figures is the probability density, which can also be interpreted as the probability of finding a given tissue-to-plasma ratio. The sum of all probabilities, which is equal to the area under the fitted curve, is always equal to 1.

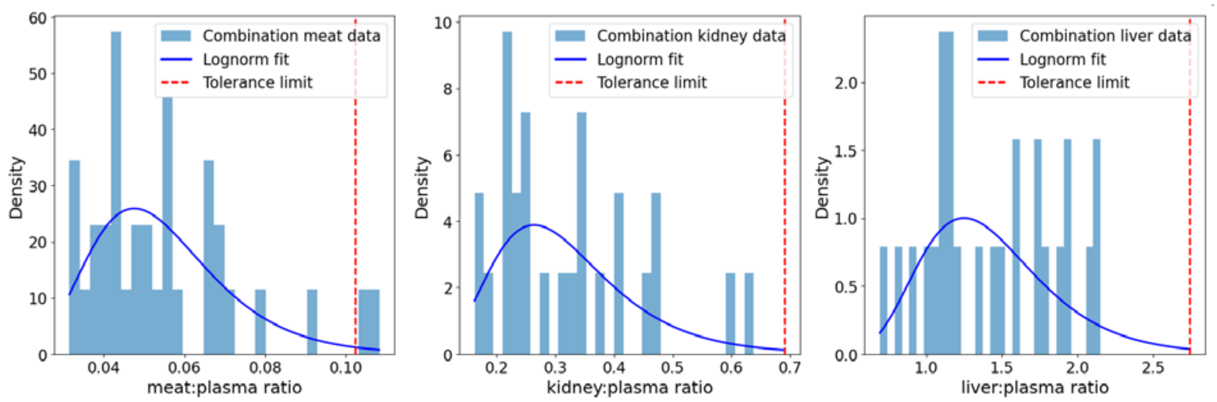

Figure 3. Histograms, fitted log-normal distributions of tissue-to-plasma ratios and tolerance limits for beef cattle based on available PFOS levels in plasma, meat, kidney and liver.

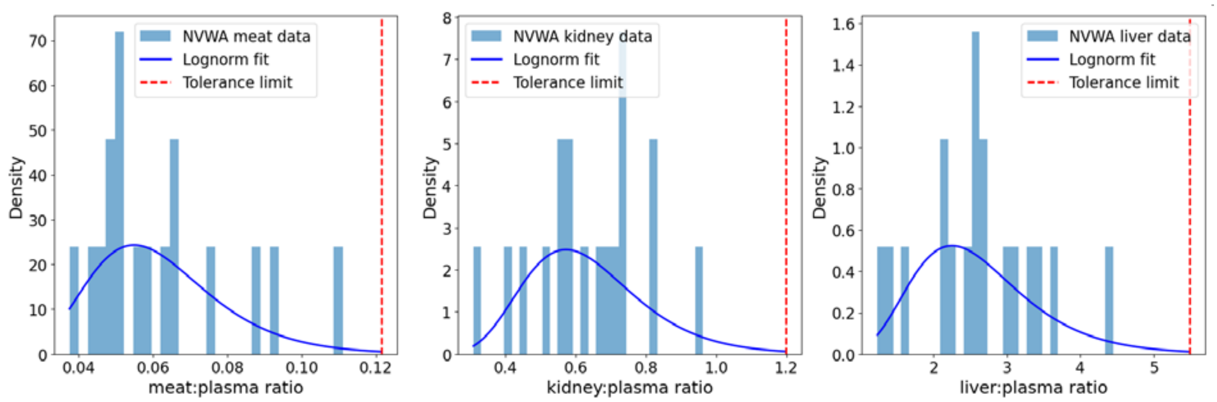

Figure 4. Histograms, fitted log-normal distributions of tissue-to-plasma ratios and tolerance limits for sheep based on available PFOS levels in plasma, meat, kidney and liver.

Based on the tolerance limits shown above, maximum PFOS levels in blood plasma were derived for which the MLs for beef cattle and sheep in meat, kidney and liver are very likely (95%) not exceeded in 95% of animals (Table 1). Table S3 (Annex II) also shows the guide values derived by data set (NVWA, Lupton et al. (2025) and Johnston et al. (2023)).

Table 1. Maximum PFOS levels in blood plasma for which the MLs for the three different tissues are not exceeded with 95% confidence in 95% of animals.

	Maximum PFOS level in blood plasma (µg PFOS/L plasma)	
Product	Beef cattle	Sheep
Meat	2.9	8.2
Kidney	8.7	5.0
Liver	2.2	1.1

Naturally, the maximum PFOS levels in blood plasma for which the MLs are not exceeded will decrease if more than 95% confidence is desired in the assessment, and increase if less than 95% confidence is desired. The same also applies to the percentage of animals whose products must be safe for consumption. To show the effect of the confidence and population percentages, Figures 5 and 6 plot the maximum PFOS levels in blood plasma against the confidence and population percentages. Table S4 shows these levels numerically.

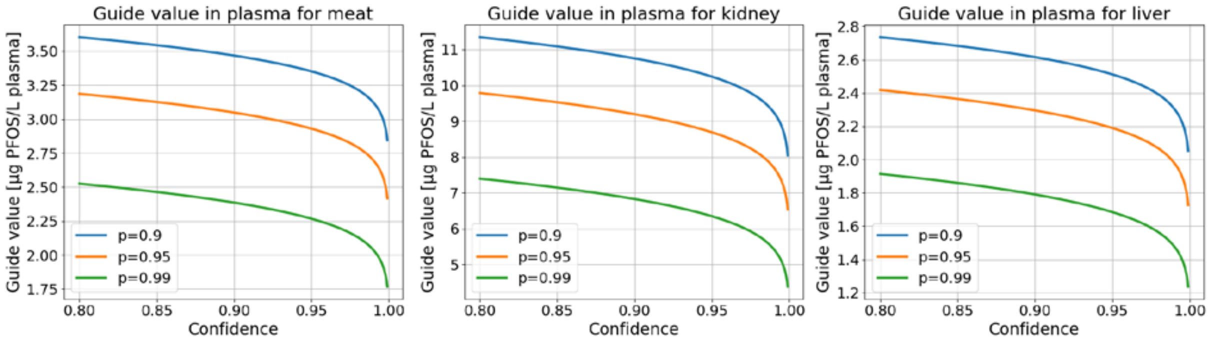

Figure 5. PFOS levels in plasma at which the MLs for meat, kidney and liver are not exceeded in beef cattle, as a function of the confidence and population percentages.

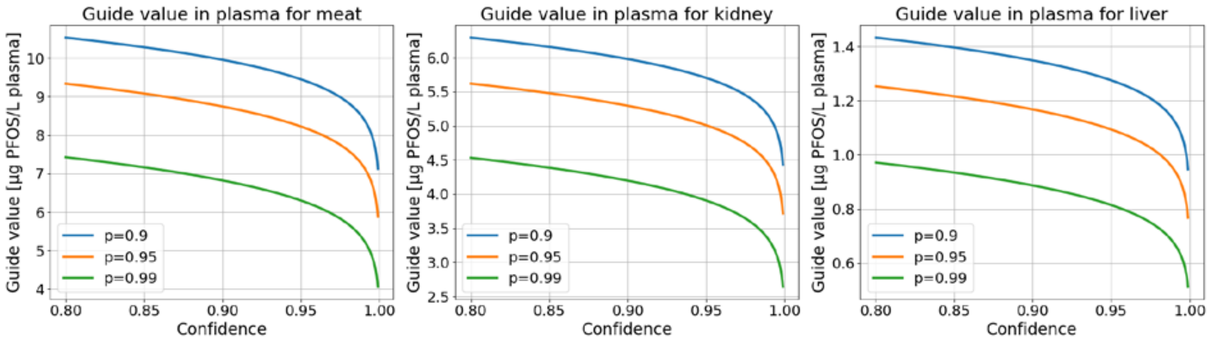

Figure 6. PFOS levels in plasma at which the MLs for meat, kidney and liver are not exceeded in sheep, as a function of the confidence and population percentages.

4. Discussion

For this assessment, we focused on the question of the PFOS levels in plasma that can be used as guide values to plausibly demonstrate that PFOS levels in meat, kidney and liver of beef cattle and sheep do not exceed the ML. We used PFOS measurements collected by the NVWA, and data reported by Lupton et al. (2025) and Johnston et al. (2023). Data from older studies reported in Death et al. (2021) were excluded because only averages and standard deviations were given, without the underlying raw data needed for the analyses.

The analyses showed that PFOS levels in plasma should not exceed 2.9 µg PFOS/L plasma, 8.7 µg PFOS/L plasma and 2.2 µg PFOS/L plasma, respectively, to plausibly demonstrate that the MLs for meat, kidney and liver of beef cattle are not exceeded with 95% confidence in 95% of animals (Table 1). For sheep, PFOS levels in plasma should not exceed 8.2 µg PFOS/L plasma, 5.0 µg PFOS/L plasma, and 1.1 µg PFOS/L plasma, respectively, to demonstrate that the MLs for meat, kidney and liver are unlikely to be exceeded (Table 1). The above figures are based on 95% confidence and a population percentage of 95%. Therefore, the above PFOS levels will not lead to MLs being exceeded in 95% of animals with 95% confidence. Using a different margin of confidence or population percentage will also lead to different maximum PFOS levels in blood plasma (see Figures 5 and 6 and Table S4).

The FAVV recently published an advisory document (2025) about the derivation of maximum PFOS levels in plasma at which the ML for beef cattle meat is not exceeded. The FAVV derived a maximum PFOS level of 2.5 µg PFOS/L plasma. This level is also used by the NVWA. A guideline issued by the Danish Veterinary and Food Administration set a PFOS level of 3.3 µg PFOS/L plasma for beef cattle (Danish Veterinary and Food Administration 2024).

For the current assessment, we estimated a maximum PFOS level in beef cattle plasma of 2.9 µg PFOS/L plasma at which the ML for beef cattle meat is unlikely to be exceeded. At a PFOS level of 2.5 µg PFOS/L plasma in beef cattle as proposed by the FAVV, it is more than 99% certain that the ML for meat (and kidney) is not exceeded. The PFOS level of 3.3 µg PFOS/L plasma in beef cattle as described in the Danish authority's guideline offers 70% confidence that the ML for meat is not exceeded in 95% of animals. It is important to note that the FAVV based their analyses only on the data of Johnston et al. (2023). As shown in Figure 1, these data are more conservative than those collected by the NVWA. It therefore comes as no surprise that the FAVV derived a lower PFOS level in blood at which the ML for meat is exceeded than was derived in the current assessment. The Danish authority used the meat-to-plasma ratio of 0.09 (= plasma-to-meat ratio of 11) reported by Death et al. (2021). This value is based on average PFOS levels in plasma and muscle tissue measured by Vestergren et al. (2013). By using the average plasma-to-meat ratio instead of the upper limits of these ratios, the Danish authority derived a less conservative PFOS level in plasma at which the ML for meat is exceeded.

The NVWA, the FAVV and the Danish authority all focus on the maximum PFOS level in plasma at which the ML for meat is unlikely to be exceeded. Kidney and liver MLs are also included in the current assessment. This shows that at PFOS levels of 2.2 µg PFOS/L plasma in beef cattle, it is highly plausible (95% confidence and 95% of animals) that the ML for liver in beef cattle is not exceeded. According to the current analyses, the PFOS level in beef cattle of 2.5 µg PFOS/L plasma as proposed by the NVWA and the FAVV provides reasonable (about 70%) confidence that the ML for liver is not exceeded in 95% of animals. The PFOS level in beef cattle of 3.3 µg PFOS/L plasma as proposed by the Danish authority provides almost no confidence (less than 1%) that the ML for liver is not exceeded in 95% of animals. For kidneys, the above PFOS levels all provide very high (more than 99%) confidence to protect 95% of animals from exceeding the ML.

The Danish Veterinary and Food Administration has also derived a PFOS level in plasma for sheep at which the ML for meat of sheep is unlikely to be exceeded. This PFOS level was 6.7 µg PFOS/L plasma. For the current assessment, a PFOS level in sheep plasma of 8.2 µg PFOS/L plasma was derived at which the ML for sheep meat is not exceeded with 95% confidence in 95% of animals. This PFOS level is higher than the PFOS level mentioned by the Danish authority in its guideline. However, the PFOS level in sheep plasma derived in the current assessment at which the ML for liver of sheep is not expected to be exceeded is much lower: 1.1 µg PFOS/L plasma. The level in plasma at which the ML for kidney is not expected to be exceeded is slightly less lower: 5.0 µg PFOS/L plasma. The PFOS level in sheep of 6.7 µg PFOS/L plasma as proposed by the Danish authority offers very high (more than 99%) confidence that the ML for meat of sheep is not exceeded in 95% of animals, while it offers little (about 20%) or almost no (less than 1%) confidence that the ML for kidney and liver is not exceeded in 95% of animals. The levels derived in the current assessment are also in line with the PFOS levels estimated in a previous FO assessment. In that assessment, PFOS levels in plasma of 6.6 and 1.1 µg/L had been reported at which the ML for meat and liver would be exceeded (Front Office Food and Product Safety 2024).

4.1 Assumptions and uncertainties

For this assessment, PFOS levels in plasma were derived at which PFOS levels found in meat, kidney and liver of beef cattle and sheep are very unlikely to exceed the ML.

However, in performing the analyses used to derive these concentrations, assumptions and choices were made that introduce uncertainties. These assumptions and uncertainties are discussed in this section.

A relevant assumption in this study is that the ratios between PFOS levels in plasma and tissues are constant and do not vary over time. This assumption only holds true in the case of a steady state. In practice, however, this is not always the case, e.g. immediately after the start or end of exposure. Because data from different sources were used in this assessment, there are also differences in the time period after exposure. The cows sampled by Lupton et al. (2025) were in a clean area for 14 days, for example, while some cows sampled by Johnston et al. (2023) stayed in the same area for almost six months. The beef cattle sampled by the NVWA were not from the VLS. Differences in, or the lack of, a depletion period may influence the distribution of PFOS between blood plasma and tissues, since no steady state exists during these periods.

A similar uncertainty is found in breed, age, growth stage and other physiological differences between the animals included in this assessment. These uncertainties may lead to different PFOS distributions in the body, potentially affecting the estimated maximum PFOS levels in plasma.

To map out the differences between the various data sources, the analyses for this assessment were also performed for each individual data set (Table S3). It follows from this that the maximum PFOS level in plasma for which the ML for meat of beef cattle is not exceeded turned out lower (= more conservative) with the addition of the data from Johnston et al. (2023) (Table S3). However, Table S3 also shows that this is the other way around for kidney of beef cattle. The addition of the data from Lupton et al. (2025) leads to an increase in the maximum PFOS level in plasma at which the ML for kidney is not exceeded. However, the effect of the additional data is minimal for the liver. A similar analysis was not performed for sheep due to the lack of data additional to the samples collected by the NVWA. However, for both beef cattle and sheep, additional data for animals from the VLS may lead to different estimates of maximum PFOS levels in plasma.

Finally, it should be noted that there are uncertainties in the analytical methods used to derive PFOS levels in tissues and plasma.

Additional animals could be sampled to refine and make wide use of the maximum PFOS levels in plasma at which the MLs for meat, kidney and liver are not exceeded. These should preferably be representative animals for which the maximum PFOS levels in plasma will be used, taking into account the variation between animals with regard to exposure, exposure duration, age, breed and sex.

5. Conclusions

Beef cattle: For beef cattle, PFOS levels in plasma should not exceed 2.0 µg/L (protecting 99% of animals with 99% confidence) and 3.5 µg/L (protecting 90% of animals with 90% confidence) to avoid exceeding the ML for meat. If the exceeding of the ML for kidney and liver were to be considered with the same confidence levels, PFOS levels in plasma would be between 5.4 µg/L and 10.8 µg/L (kidney) and between 1.5 µg/L and 2.6 µg/L (liver).

For beef cattle, a PFOS level in plasma of 2.5 µg PFOS/L, as used by the FAVV, is sufficient to state with more than 99% confidence that the ML for meat and kidney is not exceeded in 95% of animals. This is not the case for liver. For liver, a PFOS level in plasma of 2.5 µg

PFOS/L offers 70% confidence that the ML for liver is not exceeded in 95% of animals. A PFOS level in plasma of 3.3 µg PFOS/L, as used by the Danish authority, offers about 70% confidence that the ML for meat is not exceeded in 95% of animals. For kidney, a PFOS level in plasma of 3.3 µg PFOS/L offers more than 99% confidence that the ML for kidney is not exceeded in 95% of animals. For liver, a PFOS level in plasma of 3.3 µg PFOS/L offers less than 1% confidence that the ML for liver is not exceeded in 95% of animals.

Sheep: For sheep, PFOS levels in plasma should not exceed 5.3 µg/L (protecting 99% of animals with 99% confidence) and 10.0 µg/L (protecting 90% of animals with 90% confidence) to avoid exceeding the ML for meat. If the exceeding of the ML for kidney and liver were to be considered with the same confidence levels, PFOS levels in plasma would be between 3.3 µg/L and 6.0 µg/L (kidney) and between 0.7 µg/L and 1.3 µg/L (liver).

For sheep, a PFOS level in plasma of 6.7 µg PFOS/L, as used by the Danish authority, is sufficient to state with more than 99% confidence that the ML for meat is not exceeded in 95% of animals. However, this is not the case for kidney and liver. For kidney and liver, a PFOS level in plasma of 6.7 µg PFOS/L offers respectively 20% and less than 1% confidence that the MLs for kidney and liver are not exceeded in 95% of animals.

Other PFASs

Data collected by the NVWA showed that the analysed concentrations of the remaining PFASs (PFOA, PFNA, PFHxS and other PFASs studied) were in almost all cases too low to quantify in the blood plasma, meat, liver and kidneys of beef cattle and sheep. It is therefore not possible to derive a guide value for these PFASs. The low concentrations of these PFASs relative to PFOS justify the assumption that the ML for the sum of PFOS, PFOA, PFNA and PFHxS will not be exceeded if the ML for PFOS is also not exceeded in the animals that grazed in the VLS.

References

Albert C, Knappstein K, Lamp J, Aßhoff N, Krause T, Jira W, Bemsmann T, Stahl T, Esselen M, Maul R. 2025. Transfer and elimination of per- and polyfluoroalkyl substances (PFAS) in growing lambs. Poster for PFAS conference 'PFAS – Challenges and Scientific Perspectives in Human Health Risk Assessment' (8–10 October 2025)

Danish Veterinary and Food Administration. 2024. 'Guidance on per- and polyfluoroalkyl substances (PFAS) in cattle and sheep. VEJ No 9986 of 29/11/2023'

Death, C., Bell, C., Champness, D., Nilne, C., Reichman, S., Hagen, T. (2021). Per- and polyfluoroalkyl substances (PFAS) in livestock and game species: A review. *Science of The Total Environment,* 774: 144795

FAVV. 2025. 'Correlation between PFAS levels in beef cattle blood and levels in the meat and offal of these animals. SciCom 2024/10'

Front Office Food and Product Safety. 2024. 'Assessment of the transfer and kinetics of PFOS in lamb, sheep and beef cattle'. https://www.rivm.nl/documenten/beoordeling-over-overdracht-en-kinetiek-van-pfos-in-lam-schaap-en-rund.

Front Office Food and Product Safety. 2025. 'Assessment of the transfer and kinetics of PFOS in lamb and sheep'. https://www.rivm.nl/sites/default/files/2025-10/Beoordeling-over-de-overdracht-en-kinetiek-van-PFOS-in-lam-en-schaap.pdf.

Johnston, John J., Eric D. Ebel, Michael S. Williams, Emilio Esteban, Sara J. Lupton, Eric J. Scholljegerdes, Shanna L. Ivey, Mark R. Powell, and David J. Smith. 2023. 'Blood-Based Ante-Mortem Method for Estimating PFOS in Beef from Contaminated Dairy Cattle', *ACS Agricultural Science & Technology*, 3: 835–44.

Lupton, S. J., D. J. Smith, E. B. Howey, A. S. Predgen, C. E. Schmidt, E. Scholljegerdes, S. Ivey, E. Esteban, and J. J. Johnston. 2025. 'Tissue histology and depuration of per- and polyfluoroalkyl substances (PFAS) from dairy cattle with lifetime

exposures to PFAS-contaminated drinking water and feed', *Food Addit Contam Part A Chem Anal Control Expo Risk Assess*, 42: 223–39.
NVWA, 2026. 'Guide values for PFAS in cattle blood'. https://www.nvwa.nl/onderwerpen/runderen/richtwaarden-voor-pfas-in-bloed, accessed January 2026.
European Commission. 2023. 'Commission Regulation (EU) 2023/915 of 25 April 2023 on maximum levels for certain contaminants in food and repealing Regulation (EC) No 1881/2006 (Text with EEA relevance)'. In *Official Journal of the European Union*, edited by the European Commission.
Vestergren, R., Orata, F., Berger, U. et al. 2013. Bioaccumulation of perfluoroalkyl acids in dairy cows in a naturally contaminated environment. *Environ Sci Pollut Res* 20, 7,959–7,969. https://doi.org/10.1007/s11356-013-1722-x

Annex I Raw data used in the modelling

Table S1. PFOS levels in blood plasma, meat, liver and kidney of beef cattle used in the modelling in this study.

	PFOS level (µg/L plasma or µg/kg tissue)[1]				
ID	**Plasma**	**Kidney**	**Liver**	**Meat**	**Source**
1	1.4	0.67	2.7	0.073	NVWA
2	1.5	0.70	1.8	0.049	NVWA
3	1.4	0.63	1.5	0.056	NVWA
4	1.4	0.83	2.2	0.057	NVWA
5	2.3	0.88	1.9	0.10	NVWA
6	2.3	0.81	2.7	0.099	NVWA
7	113.8	32.2	166.8	10.3	Lupton et al. (2025)
8	116.8	48.5	198.2	7.9	Lupton et al. (2025)
9	78.7	22.5	131.2	8.5	Lupton et al. (2025)
10	29.0	31.9	148.1	3.0	Lupton et al. (2025)
11	108.3	18.5	62.4	6.1	Lupton et al. (2025)
12	122.7	25.3	751	6.2	Lupton et al. (2025)
13	94.1	26.4	109.5	7.4	Lupton et al. (2025)
14	81.6	23.1	138.8	5.9	Lupton et al. (2025)
15	156.3	18.0	93.3	8.6	Lupton et al. (2025)
16	100.3	22.9	103.5	4.8	Lupton et al. (2025)
17	114.6	47.9	157.2	6.3	Lupton et al. (2025)
18	85.2	17.8	116.1	5.1	Lupton et al. (2025)
19	69.5	39.7	128.0	2.4	Lupton et al. (2025)
20	52.6	29.3	134.9	2.0	Lupton et al. (2025)
21	65.6	11.3	133.2	2.4	Lupton et al. (2025)
22	29.3	20.9	171.8	1.6	Lupton et al. (2025)
23	40.0	12.4	108.7	1.3	Lupton et al. (2025)
24	61.1	16.2	117.2	2.8	Lupton et al. (2025)
25	36.9	10.9	87.9	1.6	Lupton et al. (2025)
26	16.4	12.0	61.5	1.1	Lupton et al. (2025)
27	149.2	-	-	10.2	Johnston et al. (2023)
28	104.1	-	-	6.9	Johnston et al. (2023)
29	98.5	-	-	3.9	Johnston et al. (2023)
30	50.6	-	-	2.2	Johnston et al. (2023)
31	27.1	-	-	1.8	Johnston et al. (2023)
32	39.7	-	-	1.7	Johnston et al. (2023)
33	15.2	-	-	0.88	Johnston et al. (2023)
34	25.3	-	-	1.2	Johnston et al. (2023)

[1] Sum of PFOS, 3-Me-PFOS and 6-Me-PFOS

Table S2. PFOS levels in blood plasma, meat, liver and kidney of sheep used in the modelling in this study.

	PFOS level (µg/L plasma or µg/kg tissue)[1]				
ID	**Plasma**	**Kidney**	**Liver**	**Meat**	**Source**
1	3.1	2.3	9.2	0.17	NVWA
2	8.3	5.8	22	0.38	NVWA
3	2.9	1.8	7.6	0.14	NVWA
4	1.6	0.91	4.1	0.068	NVWA
5	1.2	0.69	3.7	<0.077	NVWA
6	3.0	1.7	10	0.28	NVWA
7	0.99	0.73	2.5	0.066	NVWA
8	2.1	1.5	5.2	0.14	NVWA
9	4.2	1.3	5.2	0.27	NVWA
10	1.4	0.93	3.1	0.071	NVWA
11	2.3	0.93	3.1	0.12	NVWA
12	2.7	2.2	4.4	0.14	NVWA
13	1.8	0.94	6.6	0.16	NVWA
14	2.7	2.6	12	0.30	NVWA
15	4.0	3.3	8.6	0.15	NVWA
16	3.4	1.5	7.4	0.20	NVWA
17	2.1	1.2	7.1	0.16	NVWA
18	2.7	2.0	7.3	0.13	NVWA

[1] Sum of PFOS, 3-Me-PFOS and 6-Me-PFOS

Annex II Calculation of tolerance intervals

In this assessment, we used tolerance intervals of tissue-to-plasma ratios. In other words, we calculated ratios between PFOS levels in tissues and PFOS levels in plasma. These ratios were then taken to calculate a tolerance interval with a corresponding tolerance limit.

A tolerance interval with a one-sided tolerance limit was chosen for the calculations in this assessment. A method described by the National Institute of Standards and Technology (https://www.itl.nist.gov/div898/handbook/prc/section2/prc263.htm) was used for this purpose.

The tolerance limit in this case is the upper limit of the interval, and indicates with some confidence that a large proportion of animals have a tissue-to-plasma ratio lower than this upper limit. The upper limit of the one-sided tolerance interval, Y_U, can be calculated as follows:

$$Y_U = \bar{Y} + k_1 s$$

where $\bar{Y}$ is the mean tissue-to-plasma ratio and *s* is the standard deviation. k_1 is a factor that can be calculated as a function of confidence, α, and percentage of population, *p*:

$$k_1 = \frac{t_{\alpha,\upsilon,\delta}}{\sqrt{N}}$$

$$\delta = z_p \sqrt{N}$$

$t_{\alpha,\upsilon,\delta}$ is the non-central t distribution as a function of confidence, the number of degrees of freedom, υ, and a non-centrality parameter, δ. N is the number of data points and the number of degrees of freedom is equal to N-1. The non-centrality parameter, δ, can be calculated by multiplying the critical value of the normal distribution with probability *p*, z_p, by the square root of the number of data points.

The tolerance limit can be calculated by choosing values for the confidence level, α, and the percentage of the population, *p*. This assessment assumes 95% confidence and a population percentage of 95%. Analyses were performed using the Python package *scipy*.

Separate analyses were performed for each data set, because tolerance limits depend heavily on the data included. Thus, for beef cattle, three analyses were performed based on 1) the data collected by the NVWA, 2) the data reported by Lupton et al. (2025), and 3) a combination of these two data sets. A single analysis was performed for sheep, based on data collected by the NVWA and described in Front Office Food and Product Safety 2024. Figures S1–S4 show the results of these analyses.

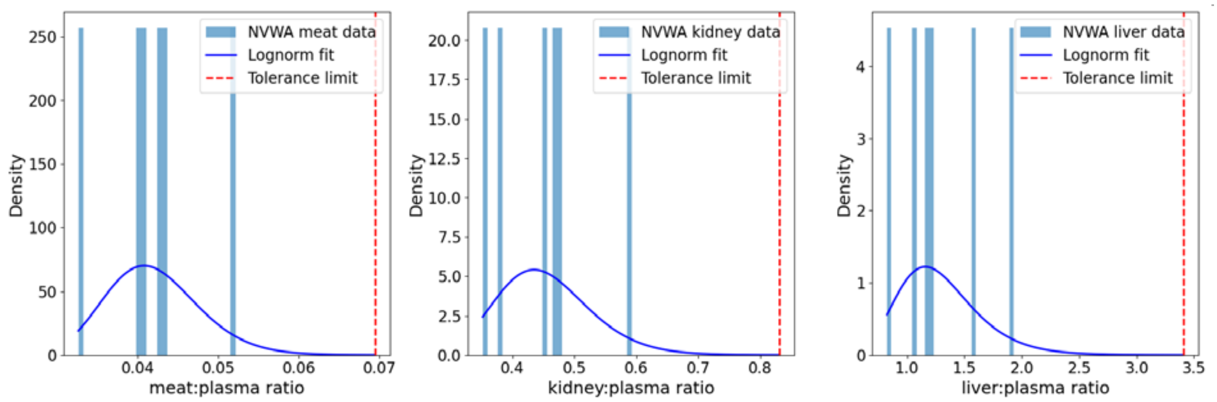

Figure S1. Histograms, log-normal fits of tissue-to-plasma ratios and tolerance limits for beef cattle based on NVWA data.

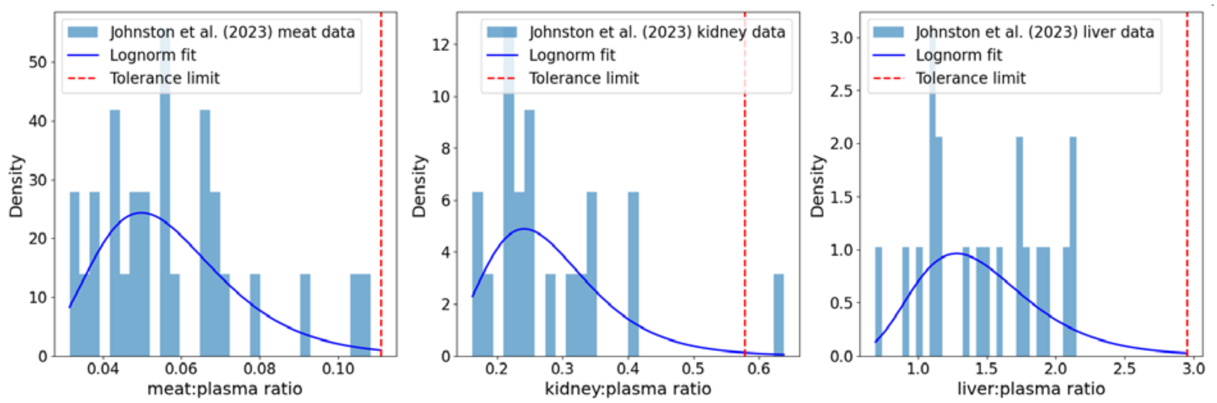

Figure S2. Histograms, log-normal fits of tissue-to-plasma ratios and tolerance limits for beef cattle based on Johnston et al. (2023) for meat data and Lupton et al. (2025) for kidney and liver data.

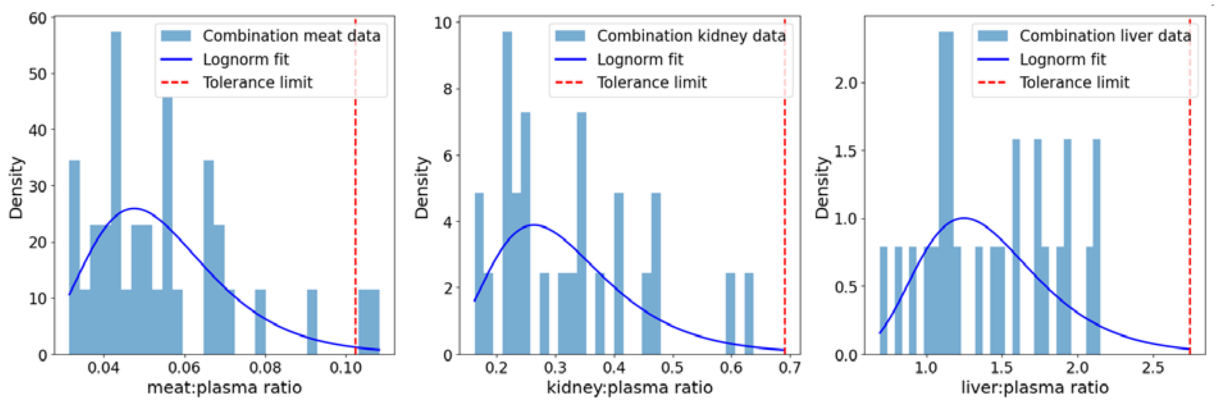

Figure S3. Histograms, log-normal fits of tissue-to-plasma ratios and tolerance limits for beef cattle based on the combined data.

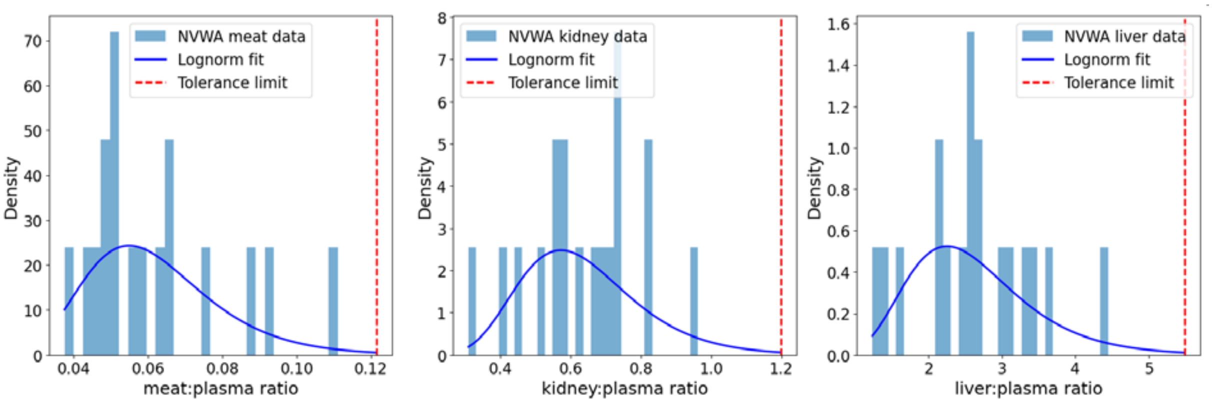

Figure S4. Histograms, log-normal fits of tissue-to-plasma ratios and tolerance limits for sheep based on NVWA data.

Using the calculated tolerance limits, the PFOS levels in plasma were calculated at which the MLs for meat, kidney and liver were exceeded. Table S3 shows these levels.

Table S3. PFOS levels in plasma at which the MLs for meat, kidney and liver are not exceeded with 95% confidence in 95% of animals.

Tissue	PFOS levels in beef cattle blood (µg PFOS/L blood plasma)				PFOS levels in sheep blood (µg PFOS/L blood plasma)
	NVWA data	Johnston et al. (2023)	Lupton et al. (2025)	Combination	NVWA data
Meat	4.3	2.7	-	2.9	8.2
Kidney	7.2	-	10.4	8.7	5.0
Liver	1.8	-	2.0	2.2	1.1

Table S4. PFOS levels in plasma at which the MLs for meat, kidney and liver are not exceeded in sheep, as a function of the confidence and population percentages.

Confidence	Population percentage	PFOS levels in beef cattle blood (µg PFOS/L blood plasma)			PFOS levels in sheep blood (µg PFOS/L blood plasma)		
		Meat	Kidney	Liver	Meat	Kidney	Liver
80%	80%	4.2	13.5	3.2	12.2	7.2	1.7
85%	80%	4.1	13.3	3.1	11.9	7.1	1.6
90%	80%	4.0	13.0	3.1	11.6	6.9	1.6
95%	80%	3.9	12.4	3.0	11.1	6.6	1.5
99%	80%	3.7	11.5	2.8	10.1	6.1	1.4
80%	85%	3.9	12.5	3.0	11.4	6.8	1.6
85%	85%	3.9	12.3	2.9	11.2	6.7	1.5
90%	85%	3.8	11.9	2.9	10.9	6.5	1.5
95%	85%	3.7	11.4	2.8	10.4	6.2	1.4
99%	85%	3.4	10.4	2.5	9.4	5.7	1.3
80%	90%	3.6	11.3	2.7	10.5	6.3	1.4
85%	90%	3.5	11.1	2.7	10.3	6.2	1.4
90%	90%	3.5	10.8	2.6	10.0	6.0	1.3
95%	90%	3.4	10.2	2.5	9.4	5.7	1.3
99%	90%	3.1	9.2	2.3	8.4	5.1	1.1
80%	95%	3.2	9.8	2.4	9.3	5.6	1.3
85%	95%	3.1	9.5	2.4	9.1	5.5	1.2
90%	95%	3.1	9.2	2.3	8.7	5.3	1.2
95%	95%	2.9	8.7	2.2	8.2	5.0	1.1
99%	95%	2.7	7.7	2.0	7.2	4.4	0.9
80%	99%	2.5	7.4	1.9	7.4	4.5	1.0
85%	99%	2.5	7.2	1.9	7.2	4.4	0.9
90%	99%	2.4	6.8	1.8	6.8	4.2	0.9
95%	99%	2.3	6.4	1.7	6.3	3.9	0.8
99%	99%	2.0	5.4	1.5	5.3	3.3	0.7