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ARSENIC AND FISH CONSUMPTION

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ABSTRACT

This report summarizes available data on human intake of inorganic arsenic by consumption of fish and shellfish and arsenic in drinking water. It estimates total exposure to inorganic arsenic from these vehicles under a variety of exposure scenarios.

Much of the arsenic in fish and shellfish is present in the form of organic compounds rather than as inorganic arsenic. For this report, EPA utilized published data on the concentrations of total arsenic and inorganic arsenic in a variety of fish and shellfish species. These data along with data from the U.S. Department of Agriculture Food Consumption Survey on fish/shellfish intake of consumers and non consumers were used to generate estimates for the inorganic arsenic intake for several exposure scenarios. The scenario for the group with the highest potential exposure (90 μg/day) was individuals consuming a diet high in fish and shellfish and having a preference for shellfish. An scenario for the average fish consumer estimated an intake of 4 μg/day and the scenario for the general consumer with only occasional fish/shellfish intake estimated an intake of 0.6 μg/inorganic arsenic per day. Scenarios for consumer groups with other fish/shellfish consumption patterns were evaluated as well.

The evaluation of inorganic arsenic exposure from fish and shellfish provides support for utilizing the existing MCL of 50 ppb for arsenic as an ambient water criterion in some areas until EPA updates its risk assessment for arsenic and revises the MCL. The exposure evaluation also illustrates a need for site specific criterion when high consumption of fish and shellfish is coupled with arsenic contamination of drinking water. Toxicity concern related to the arsenic in marine fish and shellfish is mitigated by the fact that it is largely present as arsenobetaine, a metabolically stable compound that is rapidly excreted. Additional studies of the forms of organic arsenic in fresh water species are needed.

1.0 INTRODUCTION

The U.S. Environmental Protection Agency's (EPA) guidance for arsenic under the Safe Drinking Water Act and the Clean Water Act are different. EPA's drinking water standard, or maximum contaminant level (MCL) for arsenic is 50 ppb and was developed by the Public Health Service in the 1940's. The Ambient Water Quality Criterion under the Clean Water Act is 0.018 ppb based on an estimated one in a million cancer risk (EPA, 1980). EPA has

recognized that there is considerable uncertainty in the cancer risk value and is presently in the process of developing a new risk analysis in order to propose a new MCL. Under legislative requirements, the EPA will issue a proposal for an arsenic MCL in the year 2000. Until that time the 50 ppb will remain in effect for public potable water sources.

The question has been raised as to whether the 50 ppb MCL for arsenic in drinking water can also serve as an Ambient Water Quality Criterion for arsenic until the risk assessment revision is complete and whether fish/shellfish consumption from the same waters adds significantly to the inorganic arsenic exposure. According to the Clean Water Act Criteria Document for arsenic (EPA, 1980), trivalent and pentavalent, inorganic, arsenic compounds are the most toxic species. This document accepts that premise and updates the Criteria Document in terms of the forms of arsenic in fish and shellfish.

The following report examines the available quantitative data on arsenic in fish and shellfish as well as its speciation (inorganic vs. organic). Estimates are made for human exposures to inorganic arsenic from fish/shellfish and drinking water under several exposure scenarios that apply to the average and high end of the distribution curve for fish/shellfish consumption. An exposure assessment for the average consumer within the general population (which includes nonconsumers) is also presented. The document is a technical summary of the available data on the arsenic in fish and shellfish as well as an exposure evaluation for inorganic arsenic.

2.0 ARSENIC IN FISH

The quantitative data on arsenic concentrations and speciation in fish are limited but are generally consistent with the hypothesis that most and sometimes all of the arsenic in fish is organic rather than inorganic. The available analytical data on arsenic in fish are presented below. The data are grouped by the source of the fish and the type of arsenic. All data are reported in terms of wet mass. The following presents data on total arsenic in marine species and then freshwater species followed by inorganic arsenic for marine species and then freshwater species.

Total Arsenic in Marine and Estuarine Species. Ballin et al. (1994) analyzed samples of 13 species of marine fish for total arsenic. Average concentrations ranged from 0.6 to 37 ppm. Only two of 20 samples had values greater than 10 ppm, one of three plaice samples and a catfish sample. In cases where samples for a given species originated from different source waters, there was considerable variability in total arsenic concentration. Total arsenic concentrations from three different herring samples ranged from 0.7 to 4 ppm; there was also variability among the results for 5 samples from the same fish. The two species with the highest average levels of total arsenic were plaice from Fladenground (32 ppm; standard deviation 14) and catfish from Gr. Fisherbank (37 ppm; standard deviation 28).

In another study, Lawrence et al. (1986) obtained samples of fish muscle from different areas in Canada. Both Atlantic and Pacific fish species were evaluated. The average total arsenic concentrations for replicate samples ranged from 1.1 ppm (herring) to 13.2 ppm (sole) for Atlantic species and 0.31 (salmon) to 7.4 ppm (cod) for Pacific Species. A total of 6 Atlantic species and 5 Pacific species were evaluated. Slight differences were apparent in the Atlantic versus Pacific samples of the same species. For example the sole sample from the Atlantic had 13.2 ppm while that from the Pacific had 5.2 ppm and the cod sample from the Atlantic had 5.2 ppm while that from the Pacific had 7.4 ppm. Based on the sample variability observed by Ballin et al. (1994), these differences are most likely a reflection of variability in samples rather than differences that result because of the arsenic in the source water. Additional support for this conclusion is provided by analysis of a sample of sole purchased locally in Ottawa which had only 0.10 ppm total arsenic, a value far lower than that for either the Atlantic or Pacific samples. The low value for this sample may represent loss during storage and shipping. Le et al. (1994) found that up to 48% of the total arsenic could be released in defrost liquid.

In order to evaluate microwave assisted distillation with atomic absorption spectrometry as a method for determining inorganic arsenic, Lopes et al. (1994) analyzed commercially purchased canned or frozen samples of anchovies, tuna, sardines, hake and sole for total as well as inorganic arsenic. Total arsenic concentrations ranged from 0.82 ppm (tuna) to 7.76 ppm (sole)

In a report developed for Region 10 of the U.S. EPA, Chew (1996) summarized data from the published literature on the concentrations of total arsenic and inorganic arsenic in fish and shellfish. The data apply primarily to samples from Japan and all but one sample came from the Pacific Ocean. Total average arsenic concentrations ranged from values less than 1 to 10 ppm for fish with two outliers: skate (64 ppm) and stingray (17 ppm).

Total Arsenic in Fresh Water Species. Ballin et al. (1994) examined the total arsenic in fresh water fish from rivers in Northern Germany, the River Elbe or from a fish hatchery. Seven species were examined; the average total arsenic concentrations were lower than those for marine fish and ranged from the detection limit to 1.5 ppm. The highest concentration was present in rainbow trout specimens from a fish hatchery and the lowest concentration was found in perch from a river in Northern Germany. The trout sample was the only one with a concentration of greater than 0.1 ppm.

The lower levels of total arsenic in fresh water fish are substantiated by analysis of the muscle tissue of several species collected in Ontario and Alberta, Canada (Lawrence et al., 1986). Concentrations ranged from 0.007 ppm (yellow perch) to 0.24 ppm (striped perch). Nine replicate samples were analyzed. Among the 23 samples of fresh water fish analyzed by Ballin et al (1994) and Lawrence et al. (1986), the total arsenic was less than 0.3 ppm for 22.

Inorganic Arsenic in Marine and Estuarine Species. In the data summarized by Chew (1996), average inorganic arsenic concentrations ranged from the detection limit to 0.2 ppm. The species with the highest average percentage of arsenic as inorganic arsenic were shark (9.5%), sturgeon (6.9%) and sucker (8.5%). In all other cases the percent of inorganic arsenic was less than 4 %. The two species with the highest average concentrations of total arsenic (skate, stingray) had none of their arsenic present as inorganic arsenic and the species with the highest concentrations of inorganic arsenic (shark, sturgeon, sucker) had low average total arsenic concentrations (2.1, 0.6 and 0.2 ppm respectively). In the study by Lopez et al. (1994), the percent inorganic arsenic in the 5 fish samples analyzed was less than 5% in all samples when analyzed by microwave-assisted distillation and atomic absorption spectrometry.

Ballin et al. (1994) did not analyze the fish for either inorganic arsenic or total organic arsenic. They did analyze the tissues for arsenobetaine and phospholipid arsenic, the major organic forms of arsenic in fish. In marine fish, the arsenobetaine accounted for 96% to 100% of the total arsenic and the phospholipid arsenic for 0.17 to 4.12 % of the total. Assuming, no other organic arsenic forms were present in the fish examined, the maximum amount of inorganic arsenic present was 2%.

Lawrence et al. (1986) analyzed 11 replicate samples of fish muscle for arsenobetaine and arsenocholine using purification by high performance liquid chromatography (HPLC) and identification with atomic absorption spectrometry and fast atom bombardment mass spectrometry. In addition to arsenobetaine and arsenocholine, the method was able to identify two unknown organic compounds containing arsenic. In all fish samples except salmon, the only compound identified was arsenobetaine which accounted for 78 to 88% of the total arsenic. In salmon an unidentified form of organic arsenic was present in addition to arsenobetaine. The arsenobetaine was 41% of the total arsenic and the unknown compound was 42 % of the total arsenic.

Caution must be used in evaluating the Lawrence et al. (1986) data because the percent recovery from samples spiked with arsenobetaine was 80 to 84% quite similar to the percent of arsenic reported to be present as arsenobetaine in most samples. Thus, this method could under report the amount of arsenic present as organic arsenic because of recovery problems. The authors point out that when the results are corrected for recovery they indicate that arsenobetaine accounted for "essentially all of the arsenic present in the marine samples analyzed". It must also be remembered that Lawrence et al. (1986) did not analyze the samples for phospholipid containing arsenic which Ballin et al. (1994) demonstrated to be present in marine fish tissues.

Inorganic Arsenic in Fresh Water Species. In analysis of 9 replicate samples of fresh water fish, Lawrence et al. (1986) did not identify either arsenobetaine or arsenocholine. An unknown organoarsenic compound was present in all samples. This compound accounted for 71 to 85% of the total arsenic. Caution must be used in evaluating these data since it was not possible to

quantify the recovery for the unidentified compound. The same unknown compound was present in all fresh fish samples whether they were from Manitoba or Alberta. Elution of the unidentified compound from the HPLC column indicated that it was more hydrophilic than arsenobetaine.

3.0 ARSENIC IN SHELLFISH

Total Arsenic. Total arsenic concentrations in shellfish tend to be higher than those for finfish. In the data summarized by Chew (1996), average total arsenic concentrations for shellfish ranged from 0.2 to 126 ppm. The highest concentrations were seen in two mollusk samples. However, mollusk values were highly variable among the 20 samples tested (range: 1-126 ppm; Chew, 1996). In the study by Ballin et al. (1994), the total arsenic in 4 species of shellfish ranged from 2.6 to 21 ppm; the highest concentration was found in lobster. The average value from pooled samples of blue mussels (40 samples) was 2.6 ppm (Ballin et al., 1994). Lawrence et al. (1986) found the total arsenic in replicate lobster, scallop and shrimp samples to be 5.2 ppm, 0.68 ppm and 20.8 ppm respectively. The concentrations of total arsenic in a samples of lobster purchased commercially in Ottawa was 4.7 ppm and in a shrimp sample was 7.2 ppm. Lopez et al. (1994) found values of 4.01 ppm, 0.34 ppm and 2.95 ppm for commercially purchased samples of cockles, prawns, and mussels respectively.

Inorganic Arsenic. The average amount of arsenic present as inorganic arsenic in shellfish was less than 3% in all cases but one among the data summarized by Chew (1996). In the case of *Barnea dilatata*, the one exception, 98% of the arsenic was inorganic but the total arsenic was low (0.2 ppm) making the net exposure to inorganic arsenic low despite the high percentage present. Lopez et al. (1994) found the inorganic arsenic to account for 8% of the total in cockles and 11% in muscles. The amount of inorganic arsenic in the prawns was below the limit of detection (0.023 ppm).

The data by Ballin et al. (1994) are of minimal value for deriving an estimate of the inorganic arsenic in shellfish because samples were not analyzed for inorganic arsenic and the authors felt that two organic forms of arsenic monitored (arsenobetaine and phospholipid arsenic) did not account for all of the organic arsenic.

Ballin et al. (1994) evaluated shrimp, lobster, mussels and oysters for their arsenobetaine and arsenic containing phospholipids. Oysters and blue mussels had the lowest concentrations of arsenobetaine plus phospholipid arsenic (30 and 40%). The authors hypothesized that water soluble arsenocholine, the metabolic precursor to arsenobetaine, accounted for most of the difference between the arsenobetaine and total arsenic concentrations rather than inorganic arsenic. Oysters and muscles had a fair amount of their arsenic present in the fat soluble phospholipid phase (10 to 20%) suggesting that some arsenocholine had been incorporated in the choline-containing phospholipids or sphingolipids.

In shrimp, Ballin et al. (1994) found that 87% of the arsenic was present as arsenobetaine and 4% as phospholipid arsenic while Lawrence et al.(1986) found that 76% was present as arsenobetaine and 15% as arsenocholine. In lobster, 59% of the arsenic was present as arsenobetaine and 2 % as phospholipid arsenic according to Ballin et al. (1994) and Lawrence et al. (1886) found 87% as arsenobetaine and none as arsenocholine. As discussed above, one cannot infer from these data that the remaining arsenic is present in inorganic compounds. Le et al. (1994) found arsenobetaine to be the primary organic arsenic compound in shrimp and prawns.

Table I summarizes the data on total, organic and inorganic concentrations of arsenic in fish and shellfish. The organic arsenic data are extrapolated from either the total arsenic and inorganic arsenic data (Chew, 1996) or the total arsenic plus the arsenobetaine, arsenocholine and/or phospholipid arsenic data (Ballin et al., 1994; Lawrence et al., 1986). In general, the data support the conclusion, that, in fish, less than 10% of the total arsenic is inorganic (Chew, 1996). Indeed, it was 4% or less for all fish species other than shark, sturgeon and sucker evaluated by Chew (1996); a total of 40 species were evaluated.

Table 1
Arsenic in Fish and Shellfish

Genus	Total Arsenic ppm.	Inorganic Arsenic ppm	Organic Arsenic ppm or%	Reference
Fish	0.6-37	ND	>98%	Ballin et al., 1994
	0.¢-64	DL-0.¢2	0.¢-64 ppm	Chew. 1996
	1.¢-13.2	NA	78-88 %	Lawrence et al., 1986
	0.82-7.76	<0.023-<5	NA	Lopez et al., 1994
Shellfish	2.6-21	ND	NA	Ballin et al., 1994
	0.2-126	DL-0.6	<.01-126 ppm	Chew, 1996
	0.68-20.8	NA	87-91%	Lawrence et al., 1986
	0.34-2.95	<0.023-11	NA	Lopez et al., 1994

Weights expressed as ppm wet weight
ND= Not Determined
NA= Not Applicable
DL = Detection Limit

4.0 SPECIATION OF ORGANIC ARSENIC IN FISH AND SHELLFISH

The predominant organic arsenic compounds in marine fish and shellfish are arsenobetaine and arsenocholine (Ballin et al., 1994). Some of the arsenocholine is found in tissue phospholipids. The amount of arsenobetaine exceeds the arsenocholine (Chew, 1996). In both compounds, arsenic has replaced the nitrogen of the natural metabolite (choline; betaine). Arsenic is incorporated into the betaine molecule by microorganisms, phytoplankton, zooplankton and algae (Ballin et al., 1994). The fish obtain arsenobetaine from their food supply. The principle organic form of arsenic in freshwater fish is neither arsenobetaine or arsenocholine according to data collected by Lawrence wt al. (1986). A single compound was isolated from all samples and accounted at least 70 to 85% of all the arsenic present if recovery was complete. The composition of this compound was not identified but it appeared to be more hydrophilic than arsenobetaine.

Betaine is formed metabolically from choline through oxidation and becomes an excretory nitrogen metabolite. Betaine excretions vary between species. In addition, betaine can serve as a methyl donor in biological systems, becoming N,N-dimethyl glycine (Montgomery, 1990). Betaine acts as an osmolyte in marine species (Neufield and Wright, 1996) and as a chemosensory agent (Knutsen, 1992). A study of feeding behavior in North Sea turbot and Dover sole suggest that betaine is one of a number of water-soluble, nitrogen-containing compounds that stimulate feeding behavior in fish larvae and may help to attract the larvae to the plankton layer (Knutsen, 1992). Betaine is probably released to water in plankton-rich areas producing an betaine-enriched microenvironment.

Arsenobetaine is metabolically inert in mammalian systems. Almost all of the radiolabeled arsenic in arsenobetaine administered orally or intravenously to rats, mice or guinea pig was excreted in three days (Vahter et al., 1983; Yamauchi et al. 1986). In rats and mice, more than 99% of the excreted label was found in the urine as arsenobetaine. In comparable studies using arsenocholine, there was greater label retention with 70-80% excreted in three days (Marafante et al., 1984). Extracts from mouse urine showed that more than 90% of the water soluble arsenic excreted was present as arsenobetaine. It can be assumed that some of the retained arsenocholine is incorporated in membranes as phosphatidyl choline compounds or in lipoprotein complexes and, thus, will have little tendency to bioaccumulate as inorganic arsenic.

Small amounts of methylarsonic acid and dimethylarsinic acid have been identified in fish and shellfish (Buchet et al., 1994; Chew 1996). Chew (1996) reported data from a study of fish at the ASARCO Tacoma Smelter Site in Washington state. The amount of methylarsonic acid in striped sea perch was 0.02 ppb and that in rock sole was 0.002 ppb. The dimethylarsinic acid in these two species was 0.02 ppb and $\leq$ 6.6 ppb, respectively. In mussels there was 0.02 ppb for both the methylarsonic and dimethylarsinic acid. The total arsenic concentration was only available for the rock sole and the total arsenic data were not internally consistent with the speciation data. Therefore, it is difficult to evaluate the significance of these results. Buchet et al. (1994) found that the recovery of methylarsonic acid and dimethylarsinic acid varied with the

extraction technique and between samples for the same fish.

The data available on the speciation of arsenic in fish and shellfish mitigate some of the concerns generally associated with arsenic exposure. In most cases, more than 95% of the arsenic is present as organic rather than inorganic compounds (Chew, 1996). The most prevalent of the organic species, especially in marine fish, is arsenobetaine (Ballin et al., 1994; Lawrence et al. 1986), a compound with minimal tissue retention in the animals species studied and a compound that is excreted without metabolic alteration. The compound present in the next highest concentration is arsenocholine. The arsenocholine is estimated to be less than 1% of the total arsenic (Edmonds and Francesconi, 1993). Most of the arsenocholine is converted to arsenobetaine and excreted. A small portion may become incorporated in phospholipids and retained; another small amount may be converted to trimethylarsine oxide (Chew, 1996).

Arsenobetaine and arsenocholine and the unidentified organic arsenic compound in freshwater fish are hydrophilic and have little tendency to bioaccumulate in edible fish tissues. They are unlikely to be present in adipose deposits due to their hydrophilic nature although some arsenocholine may be present in membrane phospholipids. Organic arsenicals, especially arsenobetaine, appear to be significantly less toxic than inorganic arsenic species (Edmonds and Francesconi, 1993). Each of these factors diminishes human health concerns related to exposure to organic arsenic compounds in fish and shellfish. Additional support for a conclusion that the organic arsenic compounds from fish and shellfish do not bioconcentrate is provided by data showing that samples of human milk from 88 mothers from the Faroe Islands did not show elevated arsenic in their transition milk despite consumption of diets rich in seafoods (Grandjean et al., 1995).

5.0 ESTIMATED ARSENIC IN FISH AND SHELLFISH FROM WATER CONTAINING 50 PPB ARSENIC

5.1 EPA Bioconcentration Factors for Arsenic

The EPA bioconcentration factor for total arsenic in a fish and shellfish is 44 (EPA, 1980, 1984). It applies to bioconcentration from a mixture of fish and shellfish (roughly 10-15% shellfish). The arsenic concentration by shellfish exceeds that for fish by nearly two orders of magnitude (EPA, 1980). The shellfish value (350) came from a 112 day test of a saltwater oyster species exposed to trivalent arsenic while the bioconcentration factor for bluegill was 4 after a 28 day exposure (EPA, 1980).

The EPA bioconcentration factors were derived from laboratory studies where the water was spiked with trivalent inorganic arsenic. Thus, they may not be representative of what happens in a natural ecosystem where inorganic arsenic is processed through a number of trophic levels

before it reaches the fish or shellfish.

The data presented in Sections 2.0 and 3.0 of this report do not include any information on the amount of arsenic in the source waters from which samples were obtained. Thus, it is not possible to evaluate the bioaccumulation that lead to the tissue levels of arsenic measured in the fish or shellfish. In general, the average total arsenic in clean costal and ocean waters is low, about 1 to 3 ug/L. Levels are much higher in estuary systems receiving arsenic discharges (Neff, 1997). The arsenic concentration for most lakes and rivers is less than 5 ug/L (Crecelius, 1997).

A comparison of the amounts of total arsenic in some of the fish and shellfish samples collected from the marine environment with normal background levels of inorganic arsenic in the water, suggests that, for at least the marine environment, arsenic accumulated to a greater extent than suggested by laboratory bioconcentration factor of 4 measured for a freshwater species in a laboratory study. The data on the accumulation of arsenic in fresh water species is conceptually closer to laboratory bioconcentration factors.

5.2 Estimated Total Arsenic

For this report, concentrations of total and inorganic arsenic in edible tissues from fish and shellfish are estimated using the EPA bioconcentration factor for arsenic and the arsenic concentration in ambient water. Deficiencies in the bioconcentration factor are part of the uncertainty for the analysis.

In cases where the fish and shellfish come from water containing 50 ppb arsenic, the estimated total arsenic concentration in edible tissues is 2.2 mg/kg or 2.2 ppm when calculated using the EPA bioconcentration factor.

$$50\ \mu g/L \times 44\ L/kg(BCF) \times 1\ mg/1000\ \mu g = 2.2\ mg/kg\ \text{total arsenic}$$

This estimate is within the range observed for fish and shellfish in the most recent USFDA Total Diet Study (0.75 ppm for fish sticks to 2.8 for cod/haddock; MacIntosh, 1997; personal communications). In the data for fish collected by Chew (1996), 70% of the samples had total arsenic concentrations below 2.2 ppm. In the studies by Ballin et al. (1994 and Lawrence et al. (1986) over 60% of the combined marine and fresh water fish data set fell below this value. Because nothing is known concerning the arsenic concentrations in the source water for the field sample data presented by Ballin et al. (1994), Chew (1996) Lawrence et al. (1986) or Lopez et al. (1994), the comparison of the calculated concentration for fish and shellfish with the field data merely supports the calculated value as plausible.

5.3 Estimated Inorganic Arsenic

The maximum inorganic arsenic in fish and shellfish used for this estimate is 4% as discussed in Sections 2.0 and 3.0 above. The median inorganic arsenic value for the fish and shellfish data reported by Chew (1996) is 0.4 %. No inorganic arsenic was detected in 23 of 42 fish samples

and 18 of 50 shellfish samples. Therefore, the median value reflects the higher inorganic arsenic concentrations found in shellfish and is a conservative value.

Using a 4% maximum inorganic arsenic value for a mixed fish and shellfish diet, 2.2 ppm total arsenic in fish/shellfish is equivalent to 0.09 ppm inorganic arsenic.

$$2.2 \text{ mg/kg As}_{\text{total}} \times 4 \text{ g As}_{\text{inorganic}}/100 \text{ g As}_{\text{total}} = 0.09 \text{ mg/kg As}_{\text{inorganic}}$$

Using 0.4% as the median inorganic arsenic concentration for a mixed fish and shellfish diet, 2.2 ppm total arsenic in fish/shellfish is equivalent to 0.01 ppm inorganic arsenic.

$$2.2 \text{ mg/kg As}_{\text{total}} \times 0.4 \text{ g As}_{\text{inorganic}}/100 \text{ g As}_{\text{total}} = 0.01 \text{ mg/kg As}_{\text{inorganic}}$$

6.0 ESTIMATED INORGANIC ARSENIC EXPOSURE FROM FISH/SHELLFISH CONSUMPTION

Inorganic arsenic exposure estimates for high and average fish and shellfish consumers can be derived using the inorganic arsenic concentrations estimates above and information on population fish/shellfish consumption. The following exposure scenarios are presented for this report based on available data.

High fish/high arsenic - The 99.9th percentile fish/shellfish consumer and the estimated maximum inorganic arsenic concentration for a mixed fish/shellfish diet (4%). This group eats the maximum amount of fish and shellfish on a daily basis and consistently chooses species that have the higher percentages of inorganic arsenic.

High fish/average arsenic -The 99.9th percentile fish/shellfish consumer and the median inorganic arsenic concentration (0.4%). This group eats the maximum amount of fish and shellfish on a daily basis and chooses species with a variety of inorganic arsenic concentrations over a range from low to high.

Average fish/high arsenic - The 50th percentile fish/shellfish consumer and the estimated maximum inorganic arsenic concentration for a mixed fish /shellfish diet. This group has a diet that includes fish and/or shellfish frequently but is not totally dependant on fish/shellfish as a dietary protein source. The group preferences tend towards the fish/shellfish species that have the higher concentrations of inorganic arsenic.

Average fish/ average arsenic - The 50th percentile fish/shellfish consumer and the median inorganic arsenic concentration. This group has a diet that includes fish and/or shellfish frequently but is not totally dependant on fish/shellfish as a dietary protein source.
The group preferences include a variety of fish and shellfish species with inorganic arsenic concentrations that range from low to high.

The fish consumption values used for these calculation were derived from the 1989-1991 dietary records from the USDA Continuing Survey of Food Intake (USEPA, 1995). The USDA food consumption survey collects data on three consecutive days of food intake. Data for one day is provided through a 24-hour recall interview and data for two days through food intake records kept by the respondent. Fish-consumers were segregated from all respondents based on their consumption of fish at least once during the three day survey period. The population data used for the exposure estimates described above apply only to the fish-consuming population rather than the entire population Therefore the data may represent a rather skewed distribution. For the purpose of defining a exposure on the high end of the distribution curve the data are appropriate and useful.

The 99.9th percentile value for females (461 g/day) is used to simulate the eating habits of subsistence fishers such as the Eskimos and other native Indian tribes that consume a diet that is very high in fish and shellfish. This is the highest intake value reported. The 99.9th percentile value or maximum reported value is more than 4 times the 95th percentile value (USEPA, 1995). The 50th percentile value from the USDA data for males was used for the exposure estimate rather than that for females because it is a higher value.

Eskimo's and other native Indian tribes in Alaska have the highest consumption of fish and shellfish within the United States (Wolfe, 1996). In one study of 351 Eskimos, Indians and Aleuts, average fish and shellfish consumption was 109 g/day (Nobmann et al., 1992). This intake lies between the 75th and 95th percentiles of fish consumers in the country as a whole (EPA, 1995). Wolfe (1996) found that the average intake of wild foods by the subsistence populations in Alaska was slightly greater than one pound of wild food per day with 61% of this total contributed by fish and shellfish. In some areas the average consumption of wild foods was two pounds per day. In studies of the Tulalip and Squaxin Island tribes of Puget Sound the mean fish/shellfish consumption for a 70 Kg adult was 71 g/day and the 95% percentile value was 226 g/day (Toy et al., 1995). In a study of the Native Tribes of the Columbia River Basin, the mean value for the adult fish consuming population was 63 g/day and the 99th percentile value was 389 g/day (CRITFC, 1994). These data support the fish/shellfish intake values used for the exposure estimates.

Two addition exposure estimates are also included in this report. These groups are identified as follows:

High fish (shellfish preference)/high arsenic -The 99.9% fish/shellfish consumer who is also at the 99% for shellfish consumption (125 g/day). These individuals consume a high percent of their fish/shellfish in the form of shellfish and select species with the high concentrations of inorganic arsenic.

General population/high arsenic - The average person who consumes fish or shellfish only occasionally but selects species with the high concentrations of inorganic arsenic.

The first of the added groups cover subsistence users of fish and shellfish who have a greater than average intake of shellfish. The arsenic exposure for this group includes separate calculations for the arsenic in fish and shellfish using a fish bioconcentration factor of 4 for fish and a factor of 350 for shellfish (USEPA, 1980, 1985). The 99th percentile shellfish consumption from the USDA data (125 g/day) was used for the shellfish portion of the diet and the difference between the 99.9th percentile fish/shellfish value (461 g/day) and the shellfish value was used for fish consumption (336 g/day).

The first five exposure scenarios defined above apply to those individuals who routinely consume fish and/or shellfish as a dietary protein source. However, most of the general population consumes fish and shellfish only occasionally, and some individuals never eat fish or shellfish. Thus, the general population has a lower exposure averaged over time. The EPA uses a daily fish intake of 6.5 g/day to represent these individuals (EPA, 1989). This is a normalized concentration which recognizes that, on the days that fish and/or shellfish are consumed, the intake will be higher than 6.5 grams but there will also be many days in the course of a year that there is no consumption of either fish or shellfish. This group is identified as "General Population" in subsequent tables. As a worst case, the higher inorganic arsenic concentration was used for the general population arsenic exposure calculation. Individuals who consume fish or shellfish only occasionally tend to have a few species they favor (e.g. tuna, shrimp) and the species of preference may be among the higher arsenic species.

Inorganic arsenic exposures from fish and shellfish under the different exposure scenarios listed above are summarized in Table 2. The fish/shellfish consumption values apply to total fish/shellfish consumption and include marine, estuarine and freshwater species. They are calculated using the following equation:

$$2.2 \text{ mg As}_{total}/\text{ kg fish/shellfish} \times \text{fish/shellfish intake (kg/day)} \times \text{mg As}_{inorganic}/100 \text{ mg As}_{total} = \text{mg As}_{inorganic}/\text{day}$$

Units have been adjusted so that the inorganic arsenic concentrations are expressed in μg/ day in Table 2. The USEPA limitation on arsenic in marine waters is 36 ppb (USEPA, 1992). Therefore, the estimates based on all fish and shellfish being from waters containing 50 ppb is an

overestimate in situations where a mixture of marine, estuarine and freshwater species are consumed.

Table 2
Inorganic Arsenic Exposure from Fish and Shellfish Consumption

Consumer Category	Inorganic Arsenic %	Fish/Shellfish Consumption g/day	Inorganic Arsenic Exposure µg/day
High Fish - High Arsenic	4	461*	41
High Fish - Average Arsenic	0.4	461*	4
Average Fish - High Arsenic	4	42 *	4
Average Fish -Average Arsenic	0.4	42*	0.4
High Fish (shellfish preference)- High Arsenic	4	125 (shellfish) 336 (fish)	87.5 shellfish 2.7 fish 90 total
General Population	4	6.5**	0.6

* 1989-1991 data from the USDA Continuing Survey of Food Intake (USEPA, 1995)

** 1973-1974 data from the National Purchase Dairy Survey (USEPA, 1989)

Other dietary components can have an impact on the net inorganic arsenic exposure for the for all consumer groups. Macintosh et al. (1996) found that other foods in the Total Diet Study such as chicken and rice contributed to the total arsenic exposure. The form of arsenic in food may also contribute to the effect of a given food material on the total body arsenic load.

7.0 INORGANIC ARSENIC EXPOSURE FROM FISH, SHELLFISH AND POTABLE WATER

The data on inorganic arsenic from fish and shellfish from Table 2 can be combined with data on arsenic concentrations in potable water to obtain a profile for net inorganic arsenic exposures in the population groups characterized above. The high estimate for the arsenic concentration in potable water is 20 ppb and the average estimate is 5 ppb. These values were obtained from a study of arsenic in potable water sources conducted by the University of Colorado at Boulder and Malcolm Pirnie, Inc. (1997). Water consumption is estimated as 2 liters/day.

In the University of Colorado at Boulder/ Malcolm Pirnie Study (1997), 88 % or more of the ground water samples analyzed in the Western United States in three separate surveys had

concentrations of 20 ppb or less. Concentrations were 5 ppb or less in more than 50% of the ground water systems evaluated. The highest arsenic concentration from ground water sources were in the Western region. None of the surface water systems surveyed in the Western United States contained greater than 5 ppb arsenic. In one survey, there were a few surface water systems in the North Central region of the country that exceeded 20 ppb arsenic (12%). Most arsenic in potable water is inorganic and ground water sources contain higher arsenic concentrations than surface water sources. The highest arsenic concentrations in the country are concentrated on the west coast.

Table 3 presents the estimates for net exposure to inorganic arsenic when the estimates from fish and shellfish consumption are combined with the data on the average and high concentrations of arsenic in Public Water supplies across the country. The value used as the high arsenic concentrations is 20 ppb based on survey data rather than the Arsenic MCL and is exceeded by only about 10% of Public Water Systems. Each of the exposure estimates for inorganic arsenic intakes from fish, shellfish and water is less than the exposure that results from ingesting 2 L of water containing the 50 ppb arsenic except for the High fish/shellfish preference scenarios.

Table 3
Total Inorganic Arsenic Exposures Fish/Shellfish and Water
for High and Average Fish Consuming Populations

Consumer Category	Fish/shellfish* μg/day	Water** μg/day	Total μg/day
High Fish - High Arsenic	41	40	81
	41	10	51
High Fish - Average Arsenic	4	40	44
	4	10	14
Average Fish - High Arsenic	4	40	44
	4	10	14
Average Fish - Average Arsenic	0.40	40	40
	0.40	10	10
High Fish (Shellfish Preference)- High Arsenic	90	40	130
	90	10	100
General Population	0.6	40	41
	0.6	10	11

* Based on a maximum 4% of the total arsenic being inorganic arsenic in an mixed fish/shellfish diet

** Water consumption is estimated as 2 liters/ day.

There are some regions in the western part of the country where arsenic levels in potable water from public systems are equal to the MCL and other private systems where the arsenic may exceed the MCL. For Public Water Systems where the potable water concentration is equal to the MCL, fish and shellfish consumption by the general populations does not increase the risk from arsenic exposure since it represents a less than a 1 μg (1%) increase in the net arsenic exposure. However, for regions where high levels of arsenic in the potable water are accompanied by high levels of fish and shellfish consumption the net increase in inorganic arsenic exposure would be greater and site-specific criteria can be developed for surface waters and for fish consumption.

In developing site-specific criteria the state should characterize the size and location of the population of concern and determine their fish/shellfish and water intake rate. The fish and shellfish consumption should consider the species and dietary intake per species. Actual total arsenic and inorganic arsenic values for the species consumed and actual concentrations in drinking water should be used in the exposure calculations wherever possible. Other sources of arsenic exposure should also be considered and quantified.

8.0 UNCERTAINTY

There are a number of uncertainties in the preceding exposure assessment for inorganic arsenic from fish and shellfish originating from water containing 50 ppb arsenic. The exposure estimates assume a mixed fish and shellfish diet in which average inorganic arsenic concentration is no greater than 4% of the total arsenic. This would not apply to any diet with high consumption of shark, sturgeon and sucker. However, these species are not used by the Eskimo and other northern Indian tribes that serve as an example of a 99.9 percentile fish/shellfish-consuming population. Species that constitute the fish component of the diet for Eskimo's and other northern Indians are salmon, halibut, herring, whitefish, sheefish, blackfish and cod (Wolfe, 1996).

The exposure assessments for all but the High Fish (Shellfish Preference) group are also based on a bioconcentration factor that applies to a mixed fish/shellfish diet. It does not apply to a diet that is heavily weighted towards shellfish, particularly mollusks. In the Eskimo and other northern Indian tribes, shellfish is a maximum of 9% of the diet (Wolfe, 1996) a value that is representative of the fish/shellfish biconcentration factor used for the inorganic arsenic exposure calculations. However, shellfish consumption for the Tulalip tribe of Washington State is about 60% of the fish/shellfish intake (Toy et al., 1996). Thus, the inorganic arsenic exposure estimates presented above would not apply to this group.

There is also some uncertainty in the bioconcentration factor since it results from laboratory studies in which the water was spiked with inorganic arsenic. The values obtained may not be representative of natural ecosystems where arsenic can passes through various trophic levels before entry into fish tissues. The data suggest that bioaccumulation through the food chain is more complex in marine species than in fresh water species.

There is some uncertainty in the toxicological assessment for organic arsenic compounds. To the extent that most of the organic arsenic species in the fish are trimethylated species such as arsenobetaine, arsenocholine and trimethylarsine oxide, toxicokinetic data support the conclusion that there is little, if any interaction of the arsenic metabolite with other biomolecules. Thus, the toxicity of these compounds is low. However, in cases where dimethylarsinic acid is found in fish/shellfish species, low toxicity cannot be assumed because there are some data that suggest that dimethylarsinic acid is a tumor promotor (Chew, 1996). If dimethylarsinic acid is a promotor, it could become a risk factor for carcinogenicity. A weight-of-evidence determination for the promoting properties of dimethylarsinic acid has not been established. Lack of data on the nature of the organoarsenic compound or compounds present in freshwater fish contributes additional uncertainty in cases where most fish consumed are freshwater species.

9.0 REFERENCES

Ballin, U., Kruse, R., and H.S. Russel. 1994. Determination of total arsenic and speciation of arseno-betaine in marine fish by means of reaction-headspace gas chromatography utilizing flame-ionization detection and element specific spectrometric detection. Fresenius J Anal Chem 350:54-61.

Buchet, J.P., Pauwels, J., and R. Lauwerys. 1994. Assessment of exposure to inorganic arsenic following ingestion of marine organisms by volunteers. Environ. Res. 66:44-51.

Chew, C. 1996. Toxicity and exposure concerns related to arsenic in seafood: An arsenic literature review for risk assessments. Prepared for USEPA Region 10 ESAT. Seattle Washington as Technical Instruction Document 10-9601-815 under Work Unit document 4038.

Columbia River Inter-Tribal Fish commission (CRITFC). 1994. A fish consumption survey of the Umatilla, Nez Perce, Yakama and Warm Springs Tribes of the Columbia River Basin. CRITFC Technical Report No. 94-3. Portland, OR.

Crecelius, E.A.. 1997. Review of EPA-822-R-97-002 (May 15, 1997) draft report entitled "Arsenic and Fish Consumption"' Letter to Dennis McCauley, Great Lakes Environmental Center, Traverse Center, MI. August 18.

Edmonds, J.S.D. and KA Francesconi. 1993. Arsenic in seafood: human health aspects and

regulations. Marine Pollution Bulletin 26:665-674.

Grandjean, P., Weihe, P., Needham, L.L., Burse, V.W., Patterson, D.G., Sampson, E.J., Jorgesen, P.J., and M. Vahter. 1995. Relation of a seafood diet to mercury, selenium, arsenic, and polychlorinated biphenyl and other organochlorine concentrations in human milk. Environ. Res. 71:29-38.

Knutsen, J.A. 1992. Feeding behavior of North Sea turbot (*Scophhalmus maximus*) and Sover sole (*Solea solea*) larvae elicited by chemicals stimuli. Marine Biology 113:543-548.

Lawrence, J.F., Michalik, P., Tam, G., And H.B.S. Conacher. 1986. Identification of arsenobetaine and arsenocholine in candian fish and shellfish by high-performance liquid chromatography with atomic absorption detection and confirmation by fast atom bombardment mass spectrometry. J. Agric. Food Chem. 34:315-319.

Le, Sean X.C., Cullen, W.R., and K.J. Reimer. 1994. Speciation of arsenic compounds in some marine organisms. Environ. Sci. Technol. 28:1598-1604.

Lopez. J.C., Montoro, R., Cervera, M.L. and M. de la Guardia. 1994. Determination of inorganic arsenic in sea food products by microwave-assisted distillation and atomic aabsorption spectrometry. J. Analyt. Atom. Spec. 9:651-656.

MacIntosh, D. L., Spengler, J.D., Ozkaynak, H., Tsai, L, and P.B. Ryan. 1996. Dietary exposures to selected metals and pesticides. Environ Health Perspect 104:202-209.

MacIntosh, D.L. 1997. Personal Communication. Rollins School of Public Health, Emory University, Atlanta, GA 30322.

Marafante, E., Vahter, M., and L. Dencker. 1984. Metabolism of arsenocholine in mice, rats. and rabbits. The Science of the Total Environment 34:223-240.

Montgomery, R., Conway, T.W. and A.A. Spector. 1990. Biochemistry: A Case Oriented Approach. The C.V. Mosby Company. St. Louis, MO.

Neff, J.M.. 1997. Ecotoxicology of arsenic in the marine environment. Environ. Toxicol. Chem. 16:917-927.

Neufield, D.S., and S.H. Wright. 1996. Salinity change and cell volume: the response of tissues from the estuarian mussel Geukensia demissa. J. Exp. Biol. 199:1619-1630.

Nobmann, E.D., Beyers, T., Lanier, A.P., Hankin, J.H, and M.Y. Jackson. 1992. The diet of

Alaska Native adults. 1977-1988. Am. J. Clin. Nut. 55:1024-1032.

Toy, K.A. Polissar, N.L., Liao, S. and G. D. Mittelstaedt. 1996. A fish consumption survey of the Tulalip and Squaxin Island tribes of the Puget Sound region. Tulalip Tribes, Department of Environment, 7615 Totem Beach Road, Marysville, Washington 98271.

University of Colorado at Boulder and Malcolm Pirnie, Inc.1997. National Compliance Assessment and Costs for Regulation of Arsenic in Drinking Water. Water Industry Technical Action Fund.

USEPA. 1980.. Ambient Water Quality Criteria for Arsenic. United States Environmental Protection Agency. Office of Water Regulations and Standards (OWRS). EPA 440/5-80-021.

USEPA. 1984. Ambient Water Quality Criteria for Arsenic. United States Environmental Protection Agency. Office of Water Regulations and Standards (OWRS). EPA 440/5-84-033.

USEPA. 1989. Exposure Factors Handbook. United States Environmental Protection Agency. Office of Health and Environmental Assessment. EPA 600 8-89-043.

USEPA. 1992. National Toxics Rule: Criterion continuous concentration. United States Environmental Protection Agency. Federal Register 57:60848.

USEPA. 1995 Draft. Mercury Study Report to Congress, Volume III: An Assessment of Exposure from Anthropogenic mercury Emissions in the United States. United States Environmental Protection Agency, Office of Air Quality Planning and Standards; Office of Research and Development.

Vahter, M.. Marafante, E., and L. Dencker. 1983. Metabolism of arsenobetaine in mice, rats and rabbits. Sci. Tot. Environ, 30:197-211.

Wolfe, R.J.. 1996. Subsistence-food harvests in rural Alaska and food safety issues. Paper presented to the Institute of Medicine, National Academy of Sciences Committee on Environmental Justice. Spokane, Washington. August 13.