Evaluating the Impact of Cooking Processes on the Level of PCBs in Fish

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1.0 INTRODUCTION

In 1991, EPA issued a Phase I Report for the Reassessment RI/FS in which the Agency evaluated the potential human health risks for the Hudson River Superfund site. In this report, EPA (1991) determined that any risks to human health from PCBs in sediment occur through indirect exposure through the fish consumption pathway. Under Superfund Guidance (EPA, 1989), evaluation of such exposures are specifically required not to consider the impact of any fishing regulations. However, fishing restrictions have been imposed by the State of New York, and thus the estimates of PCB exposure developed for the Upper Hudson River are hypothetical and an overestimation of actual exposures.

In the Phase I document, EPA (1991) concluded that the effects of cooking should not be considered in the determination of exposures to PCBs from the consumption of contaminated fish. EPA based this decision on the variability of results in the published literature including some findings of PCB increases. In its comments on the Phase I report, GE advocated that in the risk assessment, the PCB levels consumed by recreational anglers should be reduced due to the loss of PCBs in fish tissue with cooking. GE made this recommendation based on an evaluation of the research that showed that cooking can lead to a significant amount of PCB loss. GE's conclusions were further supported by New York State (NYSDEC, 1991). In the New York State fishing regulations, the New York State Department of Environmental Conservation (NYSDEC) strongly recommended that anglers use a cooking method that does not reuse the fish oils, thereby acknowledging that cooking can lead to a reduction in fish PCB levels (Appendix A). In response to the Phase I comments, EPA (1992) agreed to review the available literature and determine if an adjustment for cooking loss is appropriate.

GE believes that the published data support the conclusion that PCB levels in fish are reduced via different cooking methods. Because the actual dose of PCBs received by an angler is determined by the amount of PCBs in each fish meal the angler consumes, any reduction in the amount of PCBs in fish that occurs during the cooking process will result in a reduction in the angler's dose. In this paper an analysis of the available data and an approach for evaluating the impact of cooking loss on PCB exposure from fish consumption are presented. The analysis is largely drawn from the attached published manuscript entitled *The Effect of Cooking Processes on PCB Levels in Edible Fish Tissue* (Sherer and Price, 1993).

2.0 REDUCTIONS IN PCB LEVELS AS A RESULT OF COOKING

Results reported in the literature

Numerous studies have been conducted that evaluate the effectiveness of different cooking methods to reduce PCB levels in fish (Table 1). Although most studies report some amount of PCB loss with cooking, reported reductions have varied over an extremely large range. In addition, results have not been reported in a consistent manner. Authors have reported reductions as the amount of PCBs lost per gram of fat, per gram of fish wet weight, per gram of fish dry weight, or in total mass of PCBs lost. This inconsistency in methods has hampered comparisons and compilations of results to date. Specifically, the variability in reporting has increased the uncertainty associated with the determination of a single cooking loss value or a percentage loss of PCBs from each of the different cooking methods.

To address this issue, Sherer and Price (1993) analyzed the available literature to determine if a pattern could be identified. The authors converted the results of each study to a percent loss of PCBs on a total mass basis. Conversion of all study results to the same units allowed the authors to compare and compile the results to determine an average PCB loss for each cooking method.

Results of Sherer and Price (1993) analysis

The results of Sherer and Price (1993) clearly demonstrate that cooking leads to a reduction of PCB levels in fish. The investigators determined the average percent reduction of PCBs for different cooking processes, including frying, broiling, baking, and microwave cooking. Although the reductions from individual studies ranged from 0 to 74 percent, the investigators accounted for this variability by analyzing the studies in a consistent manner and by grouping the reductions made by each cooking method (Sherer and Price, 1993).

Volatilization of PCBs and separation of the contaminated lipid from the fish tissue are two mechanisms that have been proposed to explain how cooking removes PCBs from fish (Zabik et al., 1979; Trotter et al., 1989; Shubat, 1992). In volatilization, the high heat of cooking causes

Table 1. Identification of Research Conducted on PCB Losses from Cooking Fish

Study	Method	Fish Species
Ambruster et al. (1987)	poaching baking pan frying broiling	Striped Bass
Ambruster et al. (1989)	poaching baking pan frying broiling	Bluefish
Cichy et al. (1979)	broiling irradiation	Lake Trout
Puffer and Gossett (1983)	pan frying	White Croaker
Skea et al. (1981)	baking deep frying broiling	Brown Trout Smallmouth Bass
Smith et al. (1973)	poaching baking baking in nylon bag	Chenook Salmon Coho Salmon
Trotter et al. (1989)	baking	Bluefish
Zabik et al. (1979)	broiling roasting microwave cooking	Lake Trout
Zabik et al. (1982)	poaching deep-fat frying charbroiling roasting microwave cooking	Carp
Zabik et al. (1993)	baking deep frying charbroiling	Chinook Salmon Walleye Lake Trout
Daubenmire et al. (1993)	baking pan frying charbroiling	White Bass

PCBs to be released from the fish into the air. Loss of lipids is also a function of the temperature and cooking duration, with higher temperatures and longer cooking times causing a greater loss of fat from the edible tissue. As a result, cooking methods such as frying, baking, or broiling are more effective at removing PCBs. These cooking methods are also effective because they do not reuse the removed fat. In comparison, cooking methods such as making fish soup or fish casseroles where the fat is reused, are not effective means of reducing PCB levels.

In addition, fish with higher lipid contents tend to lose a greater amount of PCBs compared to fish with lower lipid contents. Since PCBs accumulate in lipid tissues, those fish with greater amounts of fat will lose greater amounts of PCBs during effective cooking processes. Frying may be particularly effective at removing PCBs because this method may actually extract lipids into the volume of cooking oil used in this type of preparation.

As Sherer and Price (1993) reported, not all studies showed losses from cooking. For example, when expressed on a wet weight basis, the PCB concentrations following cooking often appear to be greater than those present before cooking (Smith et al., 1973; Skea et al., 1981; Trotter et al., 1989). These increases in PCB levels have been attributed to the substantial loss of moisture in comparison to the loss of contaminant. However, when these same data are expressed on a dry mass basis, they consistently show a reduction in PCB concentration. Other increases in PCB levels have been attributed to tthe methods employed during the actual measurement of pre- and post-cooking tissues. For example, the extraction of phospholipid-associated PCBs is more efficient from cooked fish as compared to extractions from raw tissue (Paul and Palmer, 1972). This effect is most often seen in fish with lower fat concentrations, since the small amount of PCBs lost during cooking are offset by the greater amounts of PCBs extracted from cooked tissue during the laboratory analysis (Sherer and Price, 1993).

3.0 APPLYING THE RESULTS OF COOKING LOSS TO THE HUDSON RIVER EXPOSURE ASSESSMENT

The results of Sherer and Price (1993) indicate that cooking leads to substantial reductions in PCB levels in fish. These findings are significant for the Hudson River reassessment because they demonstrate how cooking methods that are commonly used for New York freshwater fish can remove PCBs and lower anglers' exposures. It is likely that the uncertainties that prevented EPA from including cooking losses in the Phase 1 document can be attributed to the reporting method or extraction technique used. Although some variability in individual cooking losses will still exist between fish meals, this variability in the short-term will be insignificant in any long-term analysis of exposure.

Research has shown that freshwater anglers in the northeastern United States typically use cooking methods that reduce PCB levels in self-caught fish. Studies on the cooking methods used by recreational anglers have been conducted by ChemRisk (1992) and Connelly et al. (1992). Connelly et al. (1992) surveyed anglers in the State of New York on a variety of topics including fish preparation and cooking practices. However, the survey was not designed to determine the specific frequency for each cooking practice (Table 2). ChemRisk surveyed anglers in the State of Maine (ChemRisk, 1992; Ebert et al., 1993). This survey did ask what cooking methods were typically used by freshwater anglers. Table 2 presents the distribution of cooking methods favored by anglers in the ChemRisk study.

While the ChemRisk study was performed in Maine, the findings are believed to be appropriate for the Hudson River anglers for the following reasons. First, the ChemRisk and Connelly et al. studies generally agreed that anglers tend to favor cooking methods that reduce PCB concentrations such as frying or broiling (Table 2). Second, the population of anglers in the ChemRisk (1992) survey and the survey of New York anglers conducted by Connelly et al. (1992) are similar in age, income, and other demographic criteria. Fish consumption rates are also similar for the two surveyed populations, and the species of fish found in the Hudson River are similar to the fish commonly harvested in Maine (e.g., bass, trout, and bullhead).

The results of Connelly et al. (1992) further indicate that most anglers trim their fish in addition to cooking. Although the loss of PCBs associated with trimming has not been specifically evaluated as part of this discussion, studies indicate that trimming can lead to substantial reductions in PCBs (Skea et al., 1981; Shubat, 1992; Armbruster et al., 1989). In addition, NYSDEC recommends that trimming fish is an appropriate method to reduce PCB levels. These findings indicate that the losses associated with cooking, reported by Sherer and Price (1993), are likely to underestimate the actual amount of PCBs lost during the preparation of fish meals.

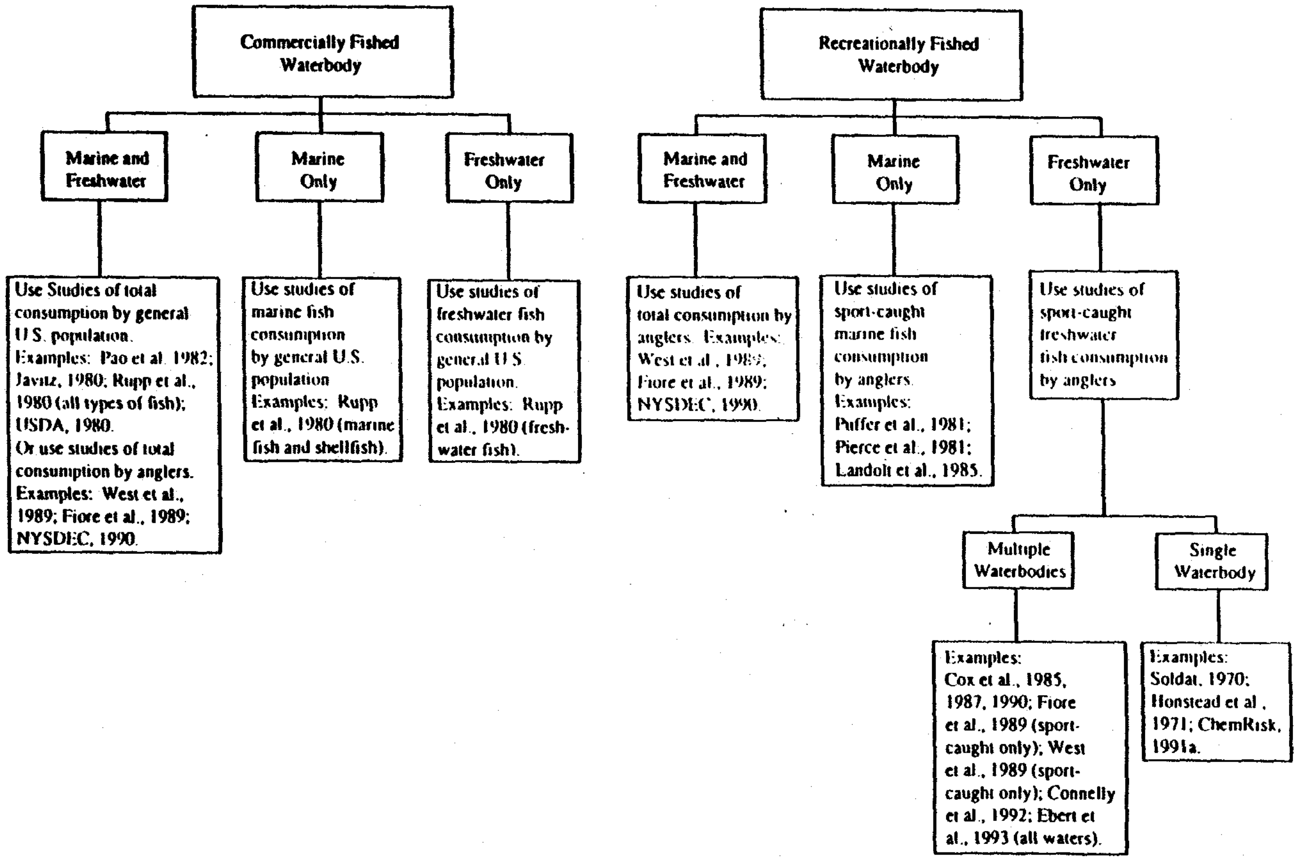

FIGURE 2. Selection of fish consumption rates based on type of waterbody and potentially exposed population.

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TABLE 3. Estimates of Average Fish Consumption Rates Per Sources of Consumed Fish(g/d)

Source and Waterbody Type	Range of Average Rates	Reference
General Population Surveys[a]		
Marine, freshwater, and estuarine	12.7 to 54	Javitz et al., 1980 Rupp et al. 1980 USDA, 1980 Pao et al., 1982
Marine only	8.8	Rupp et al., 1980
Freshwater only	1.2	Rupp et el., 1980
Angler Surveys[b]		
Marine, freshwater, and estuarine	18.3 to 28	West et al., 1989 Fiore et al., 1989 NYSDEC, 1990
Marine only	15 to 37[c]	Pierce et al., 1981 Puffer et al., 1981 Landolt et al., 1985
Freshwater-multiple waterbodies	6.4 to 21.8	Cox et al., 1985, 1987, 1990 Fiore et al., 1989 West et al., 1989 Connelly et al., 1992 Ebert et al., 1993
Freshwater-multiple standing waters	4.2 to 16	Richardson and Currie, 1993 ChemRisk, 1991b
Freshwater-multiple flowing waters	3.7	Ebert et al., 1993
Freshwater-single waterbody	1.8 to 7.7[c]	Soldat, 1970 Honstead et al., 1971 Turcotte, 1983 ChemRisk, 1991a

[a] Estimates of consumption by the general population of the United States, including anglers and non-anglers.
[b] Estimates of consumption by anglers only.
[c] These rates are likely to be overestimated due to the oversampling of more frequent anglers during creel surveys.

estimates from the long-term surveys are not subject to short-term variability, they are preferred for estimating average annual consumption rates by risk assessors. This analysis suggests that consumption rates for the general angler population rarely reach the levels of between 140 and 180 g/d frequently recommended for evaluating "high-end" intake (EPA, 1989a,b). Although Puffer et al. (1981) reported a 95th percentile value in exceedance of 180 g/d, Price et al. (1994) have recently demonstrated that this high estimate is not representative of the 95th percentile of the total angler population using the fishery. Reanalysis of the Puffer et al. (1981) data to correct for sampling bias has resulted in an estimated 95th percentile of approximately 35 g/d.

TABLE 4. A Comparison of Estimated Rates of Self-Caught Fish Consumption Per Duration of Recall Period

Recall Period	Range of "High-End" Intakes (g/d)	Reference
1 day	54 to 339	Pierce et al., 1981[b] Puffer et al., 1981[b]
3 day	128	Pao et al., 1982
30 days	42	Javitz, 1980
365 days	26 to 37	Fiore et al., 1989 Connelly et al., 1992 Ebert et al., 1993

[a] All values are reported 95th percentile except Connelly et al. (1992) for which the reported value represents the 92nd percentile.
[b] Reanalyses of these data by Price et al. (1994) have resulted in substantially lower estimates of "high-end" intakes.

The EPA (1989b) has acknowledged that there are substantial regional- and site-specific variations in consumption rates and, as a result, has recommended that site- or region-specific consumption estimates be used wherever possible. Clearly this is preferable due to the variability that can occur among fisheries because of differences in lengths of fishing seasons, the availability of fisheries, the availability of target species, fishing regulations, and the cultural or ethnic backgrounds of the fish consumers.

Unfortunately, due to time constraints or resource limitations, it is not always possible to collect site-specific information or to have the complete distribution. In lieu of these, it becomes necessary to select the most representative consumption estimate based on the population, region, waterbody type, and fishery type of interest.

In risk assessments performed for regulatory purposes, it is important that the fish consumption rate selected be derived from studies that are consistent with the type of waterbody and target population being evaluated. Freshwater fish consumption estimates should not be based on studies of marine fisheries because there are likely to be differences in the species present, the relative productivities of the waters, and the preferences of the anglers. If fish ingestion from a single waterbody is being evaluated, it is best that the rate of intake be based upon a valid intake study from a similar, individual waterbody. It is particularly important to consider whether there are any commercial fisheries on the waterbody of interest.

If there are none, then the rates of intake used should be based on studies which have considered only the intake of sport-caught fish and should not include consumption of fish that have been obtained from restaurants, markets, or other, non-angling sources. General guidance on the selection of appropriate fish consumption estimates is provided in Figure 2.

It is also important to consider the species and size of fish available in the waterbody of interest. Because the species targeted vary among fisheries and among regions, and because different species vary in their propensity to bioaccumulate persistent compounds, exposure potentials may differ substantially. Thus, for risk assessment purposes, it would be ideal to derive species-specific rates of consumption for individual anglers and to combine the intake rates with species-specific fish tissue levels to more accurately define exposures.

It is important to note that a discussion of the selection of consumption rates for subpopulations that may consume more fish than recreational anglers is beyond the scope of this paper. In conducting an exposure assessment, careful consideration must be given to whether such a sensitive subpopulation exists due to income level or ethnic background. If it does, it may be appropriate to select consumption rates that are based on either site-specific studies or studies of similar populations.

In the absence of site-specific information, the selection of a fish consumption rate to be used in the assessment of risks from a contaminated area involves three critical factors. First, the population most likely to be affected must be identified. Second, if possible, the selection of a fish consumption rate for a particular geographic area should be based on a study that has evaluated similar areas with similar resources. Differences in climate, target species, length of fishing season, availability of marine and freshwater fisheries, and cultural/ethnic background can substantially influence rates of consumption. Lastly, waterbody and fishery types are important considerations. Often the population that is most likely to be affected includes anglers who fish the contaminated waters. If contamination is widespread throughout an area, then it may be appropriate to select a consumption estimate from a study that has evaluated total consumption of sport-caught fish by anglers (Fiore et al., 1989; Ebert et al., 1993). If the area affected is a marine area, then estimates of marine fish consumption are most appropriate. Conversely, if the area affected is an inland area, then estimates of freshwater fish consumption should be used. Finally, if only a single waterbody is affected by contamination, the fish consumption rate selected for the evaluation should, if possible, be a rate that has been derived from a study of a waterbody that is similar in nature to the one of interest. If it is not possible to identify a single waterbody within a given region that is directly comparable with the waterbody being evaluated, then a more general estimate of consumption, based on the most comparable study, may serve as a useful surrogate.

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Table 2. Distribution of Cooking Preferences

	ChemRisk (1992)	Connelly et al. (1992)
Baking	0.179	0.24[a]/0.37[b]
Boiling	0.002	
Broiling	0.164	
Frying	0.621	0.514/0.31
Poaching	0.009	0.24/0.37
Microwave	0.009	
Raw	0.006	
Soup	0.02	0.017/0.13

a. Always/usually use cooking method
b. Sometimes use cooking method

4.0 CONCLUSION

The recent summary of PCB literature has demonstrated that cooking processes are very effective at removing PCBs from fish (Sherer and Price, 1993). The actual amounts of PCBs consumed by recreational anglers are likely to be much less than the levels of PCBs collected from uncooked fillets. Studies by Connelly et al. (1992) and Ebert et. al. (1993) indicate that most anglers do use some type of cooking method that has a high likelihood of reducing PCBs before consumption. NYSDEC supports these findings and has recommended that all recreational anglers cook and trim their fish before consumption. At a minimum, General Electric recommends the incorporation of a cooking loss factor into the analysis. A more realistic evaluation would also include an adjustment factor for trimming. Incorporation of both these factors will assure that the adjustment selected for cooking loss will be an accurate estimate of the true reduction in PCBs that may be experienced by the recreational angler.

The most appropriate method to incorporate the reduction in PCBs with cooking is through the use of a probabilistic exposure assessment using synthetic life history or Microexposure Monte Carlo analysis. This type of analysis can account for the variations in cooking methods that an individual angler may use over the course of a lifetime. Specifically, a Microexposure Monte Carlo analysis selects a different cooking method and PCB reduction value for each meal eaten by a recreational angler and appropriately adjusts the original PCB concentration of the species selected.

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APPENDIX A

Appendix A
REDUCING CHEMICAL EXPOSURES[1]

Everyone can benefit from eating fish they catch and can minimize their chemical contaminant intake by following these general recommendations:

- Choose fish from water bodies which are not listed in the DOH advisory.
- If you choose to eat fish from water bodies with a DOH advisory, choose fish species not listed in the advisory.
- Choose smaller fish within a species consistent with DEC regulations, since they may have lower contaminant levels. Older (larger) fish within a species may be more contaminated because they have had more time to accumulate contaminants in their bodies.
- Levels of PCBs, mirex, DDT and other contaminants of concern (except mercury) can be reduced by removing the skin and fatty portions along the back, sides and belly of fish. Most contaminants are associated with the fats in fish.
- Cooking methods such as broiling, poaching, boiling and baking, which allow fats to drain out, are preferable. Pan frying is not recommended.[2] The cooking liquids of fish from contaminated waters should be avoided since these liquids may retain contaminants (NYSDEC).

1. Source: New York State 1993-1994 Fishing Regulations Guide, p. 72.

2. While the oils removed during frying still remain in the pan, many researchers have shown that pan frying can effectively reduce PCBs in fish (Skea et al., 1981; Puffer and Gossett 1983).

ATTACHMENT:

The Effects of Cooking Processes on PCB Levels in Edible Fish Tissue

QUALITY ASSURANCE GOOD PRACTICE, REGULATION, AND LAW
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The Effect of Cooking Processes on PCB Levels in Edible Fish Tissue

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A significant factor in estimating human intake of polychlorinated biphenyls (PCBs) from fish consumption is the loss of PCBs during cooking. The total amount of PCBs actually consumed in the cooked fish may be significantly lower than the PCB level present before cooking because lipids and lipophilic compounds like PCBs tend to be removed from the fish during cooking. Several studies investigating the extent of loss of PCB compounds during the cooking process have been published in the peer-reviewed literature. However, because of what is perceived as inconsistent and inadequate data on the removal of these compounds, federal and state regulators typically do not assume that cooking reduces contaminant levels (EPA, 1990; 1991). In this paper, an attempt was made to reduce the uncertainty in the findings of these studies on PCB losses during the cooking process. This was accomplished by (1) eliminating studies that lacked statistical power to determine the degree of reduction, (2) reporting all of the results in a common format, and (3) characterizing studies by cooking method. In addition, the studies that reported increases in PCB concentration after cooking were carefully reviewed to provide a possible explanation of this occurrence. Based upon this analysis, it was concluded that cooking processes such as baking, broiling, microwave cooking, poaching, and roasting remove approximately 20 to 30% of the PCBs. Frying appears to remove more than 50%. PCB cooking losses also appears to be a function of the initial lipid concentration in the fish. Based upon this analysis, it is clear that the information from these studies do provide a reasonable basis for federal and state regulators to permit a quantitative adjust of PCB intakes. © 1993 Academic Press, Inc.

INTRODUCTION

A significant issue in estimating human intake of PCBs from fish consumption is the loss of PCBs that occurs during cooking. Because PCBs are concentrated in body lipids of fish (Reinert *et al.*, 1972; Skea *et al.*, 1981; Armbruster *et al.*, 1987), and lipids tend to be removed from fish during cooking, it then seems reasonable to assume that this loss of lipids can result in a reduction of PCBs in the fish tissue. In addition, PCBs may also be lost by direct volatilization during cooking. As a result of these processes, the total amount of PCBs actually consumed in the cooked fish may be significantly lower than the amount occurring in the raw fish.

Several studies investigating the extent of loss of PCBs during the cooking process have been published in the peer-reviewed literature. Although most of these studies have documented significant reductions in total PCB levels after the cooking process.

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the degree of reduction reported in each of the studies has varied greatly. In addition, certain studies have reported increases in the concentrations of PCB after cooking. Because of what is perceived as inconsistent and inadequate data regarding the effects of cooking on PCB levels in fish, federal and state regulators have been hesitant to assume that cooking reduces PCB levels (EPA, 1990, 1991).

In this paper the authors examine the available literature with the goal of developing specific recommendations for incorporating cooking reductions into quantitative exposure assessments. Based upon this analyses, there does appear to be a reasonable basis for quantitatively adjusting estimates of PCB intake from the consumption of fish based on cooking practices. This paper reviews the currently available studies that address changes in PCB levels as a result of cooking. Estimates of cooking-method-specific alterations in PCB levels are developed based on this literature review.

REVIEW OF LITERATURE

The authors began their study by performing a literature search for peer-reviewed articles that dealt with PCB cooking losses on fish tissue. This search identified nine studies. Two other studies were identified but are not discussed in this paper because they investigated PCB cooking losses in crabs (Zabik *et al.*, 1991) and turkey (Zabik *et al.*, 1990).

The nine articles identified from the literature search contain information on a variety of fish species and cooking methods. Species investigated in the various studies include chinook and coho salmon (Smith *et al.*, 1973), lake trout (Cichy *et al.*, 1979; Zabik *et al.*, 1979), brown trout (Skea *et al.*, 1981), smallmouth bass (Skea *et al.*, 1981), carp (Zabik *et al.*, 1982), white croaker (Puffer and Gossett, 1983), striped bass (Armbruster *et al.*, 1987), and bluefish (Armbruster *et al.*, 1989; Trotter *et al.*, 1989). Cooking methods include boiling, poaching, microwave cooking, broiling, baking, roasting, pan frying, and deep frying.

The analytical methods used in all of the studies are variations of the method developed by Yadrick *et al.* (1972). This process consists of a Soxhlet hexane–acetone extraction of the freeze-dried tissue, acetonitrile partitioning, and florisil–celite column cleanup. Characterization and quantification of PCBs were conducted using gas chromatographic analyses.

A major difficulty, however, in comparing the results of the studies is that PCB losses are not reported in a consistent manner. Reductions in PCBs have been expressed in terms of the amount of PCBs lost per gram of fat, per gram of fish (wet weight), per gram of fish (dry weight), or in total mass of PCB lost. These different reporting methods confound the comparison of the results of the studies and obscure the significance of the literature. It is, therefore, critical to present the results in a consistent manner. In this study, the effect of cooking on the amount of PCBs in the fish is evaluated on a mass basis as follows:

Percentage of total PCB mass lost during cooking

$$= \frac{\text{Total PCB mass in uncooked fillet} - \text{Total PCB mass in cooked fillet}}{\text{Total PCB mass in uncooked fillet}} \times 100.$$

The advantage of presenting data on a total mass basis is that the loss of PCB can be used to directly estimate the impact of cooking losses on the intake of PCBs.

Discussion of Individual Studies

While most of the nine studies reported evidence of cooking losses, only five of the studies were deemed usable in quantifying the PCB cooking losses. Some of the studies were not usable because of experimental methodologies that are inconsistent with the objectives of this study (refer to subsequent discussions regarding Armbruster *et al.* (1989) and Cichy *et al.* (1979)). Other studies were not included because the results lacked statistical significance. These studies typically reported reduction in PCB levels; however, the results were not statistically significant due to small sample sizes and high variability in initial PCB levels in the fish tissue samples. In addition, some studies also lacked sufficient data in order to determine total mass loss of PCBs. Table 1 lists the nine studies under consideration and whether they were included in the final quantification estimates of PCB cooking loss. The following paragraphs briefly discuss the studies and their usefulness in quantifying PCB cooking losses.

Armbruster *et al.* (1987) studied the effects of six different cooking methods on PCB concentrations in striped bass. The authors reported that, although declines occurred with most methods, the declines were not statistically significant due to the high variability in PCB levels in the fish tested and the small sample sizes.

Armbruster *et al.* (1989) reported the combined effects of trimming and cooking on the concentrations of PCBs in bluefish from Long Island Sound. Forty raw bluefish fillets were trimmed and then 10 randomly selected fillets were baked, broiled, fried, or poached. The study found that a combination of trimming and cooking resulted in PCB reductions of 60% by poaching, 68% by baking, 68% by pan frying, and 71% by broiling. Data were reported on a dry weight basis. No data were presented for fat content of the raw fillets. While the study results suggest that cooking processes did reduce PCB levels in fish, it is not possible to clearly determine the fraction of the decline that was due to cooking versus that resulting from trimming.

Cichy *et al.* (1979) studied the combined effects of irradiation and broiling on the levels of PCBs in lake trout fillets. Significant reductions in PCB concentrations were observed during the broiling of irradiated fillets. Because of the study design, which focused on the effects of irradiation and did not investigate the effects of cooking on

TABLE 1

Summary Evaluation of Studies

Study	General findings	Was method appropriate?	Were results statistically significant?	Was a quantitative estimate of mass loss possible?
Armbruster *et al.*, 1987	Small reduction	Yes	No	No
Armbruster *et al.*, 1989	Large reduction	No	Yes	No
Cichy *et al.*, 1979	Small reduction	No	No	No
Puffer and Gossett, 1983	Large reduction	Yes	Yes	Yes
Skea *et al.*, 1981	Large reduction	Yes	Yes	Yes
Smith *et al.*, 1973; Smith, 1972	Small reduction	Yes	Yes	Yes
Trotter *et al.*, 1989	Large reduction	Yes	Yes	Yes
Zabik *et al.*, 1979	Large reduction	Yes	Yes	Yes
Zabik *et al.*, 1982	Slight increase	No	No	No

fish that had not been irradiated, this study was not used to quantitatively estimate PCB losses due to cooking processes.

Puffer and Gossett (1983) studied the effects of pan frying on PCB and DDT concentrations in fillets of white croaker from two locations in California. Five composites from each location were tested. Mean fat contents of the raw fillets were 1.2% for Santa Monica Bay samples and 0.9% for Orange County samples. The results of the analyses were presented from a wet weight and a total PCB and DDT mass basis. PCB losses were 65% for Santa Monica Bay samples and 28% for Orange County samples on a mass basis. The authors attributed the greater losses in Santa Monica Bay samples to the fact that PCB concentrations from that location were 11 times higher than concentrations in Orange County samples.

Skea *et al.* (1981) reported the combined effects of trimming and cooking in reducing the levels of PCBs (Aroclor 1254), Mirex, and DDE compounds in brown trout and smallmouth bass. For smallmouth bass, baking of 20 untrimmed, unskinned fillets (mean fat content of 2.8%) reduced total PCB mass levels by 16% and deep frying of 20 trimmed fillets (mean fat content of 1.3%) in corn oil reduced total PCB mass levels by 74%. For brown trout, smoking of 30 untrimmed fillets (mean fat content of 16.5%) reduced total PCB levels by 27%, and broiling of 30 skinned, fat-trimmed fillets (mean fat content of 8.8%) showed no reduction of PCBs. However, the apparent lack of PCB reduction by broiling brown trout fillets may have been an analytical error since significant reductions of other lipophilic compounds, Mirex and DDE, 26 and 20% respectively, were observed after broiling.

Smith *et al.* (1973) analyzed PCB concentrations in 10 raw samples and 20 cooked samples of chinook salmon. PCB levels were expressed as micrograms of PCB per gram of fat in the fish samples. Also, two raw samples and four cooked samples of coho salmon were analyzed. The average percentage of fat content was 2.65% in the raw chinook steaks and 3.59% in raw coho steaks. Samples were poached, baked, or baked in a nylon bag. The authors reported both small reductions and increases in average concentrations of Aroclor 1248 and Aroclor 1254 during cooking. Statistical analysis performed by the authors indicated that the reductions were not statistically significant. This lack of a clear trend could have been due to small numbers of samples, large variability in PCB content between individual samples, or low body-fat content of the fish.

Additional information for this study is contained in the thesis of Smith (1972), on which Smith *et al.* (1973) is based. The thesis and Smith *et al.* (1973) contained sufficient data to estimate an overall percentage of PCB loss on a mass basis during baking for the Chinook salmon (see discussion in the following section). The number of coho salmon samples was sparse and judged to be insufficient to warrant inclusion into this paper.

Trotter *et al.* (1989) studied the effects of baking on PCBs and lipophilic pesticides in 20 bluefish fillets. The authors initially reported increases in PCB levels on a wet weight basis. Estimates of PCB reduction on a total mass PCB basis were then calculated based upon information provided in the study relative to PCB concentrations and fillet weights before and after cooking. Expressed on a mass basis, the study found a reduction of 27% due to the baking process. Average fat content of the raw fillets in this study was 11.8%.

Zabik *et al.* (1979) assessed the changes in Aroclor 1254 levels in lake trout fillets which resulted from broiling, roasting, and microwave cooking the fish. Duplicate samples from head, middle, and tail portions of the fillets were analyzed for each

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cooking method. The total masses of PCBs were reduced by an average of 53% by broiling, 34% by roasting (baking), and 26% by microwave cooking. Mean fat content of the raw fillets was approximately 25% for samples used in the roasting experiment, 26% for fillets used in microwave cooking, and 29% for fillets that were broiled.

Zabik *et al.* (1982) reported the effects of several cooking methods on PCB and DDT levels in carp fillets from Saginaw Bay, Michigan. Mean fat content of the raw fillets was approximately 8%. These authors reported that PCB concentrations were reduced 25% by deep-fat frying, 27% by poaching, 25% by charbroiling, 33% by microwave cooking, and 20% by roasting, when data were expressed on a fat basis. However, when they expressed their results on a total mass basis, data for all cooking methods, except microwave cooking, indicated an increase in PCBs. Zabik *et al.* (1982) attributed these increases to more efficient extraction of phospholipid-associated PCBs during laboratory analyses of cooked tissue as compared with raw tissue.

Development of Quantitative Estimates of PCB Reduction

Of the nine studies identified, five studies contained sufficient data to allow the quantification of PCB loss during cooking on a mass basis. Other than Zabik *et al.* (1982), all of the 10 studies present evidence of loss of PCBs or similar lipophilic compounds during cooking. The subsequent paragraphs present a brief review of how the data in the five studies were used to quantitatively estimate cooking losses.

Zabik *et al.* (1979) reported changes in PCB content of fish fillets on a whole tissue (wet weight) basis (Zabik *et al.*, 1979, p. 139), a fat basis (Zabik *et al.*, 1979, p. 140), and a total mass of PCB basis (Zabik *et al.*, 1979, p. 141). Similarly, Skea *et al.* (1981) reported data for changes in PCB content during baking (Skea *et al.*, 1981, p. 17), broiling (Skea *et al.*, 1981, p. 16), or frying (Skea *et al.*, 1981, p. 18) on a whole tissue (wet weight) basis as well as a total mass of PCB basis. The total mass basis values from each of these studies were used without modification in this paper.

Puffer and Gossett (1983) initially reported changes in PCB content of white croaker samples on a wet weight basis. However, by employing a conversion factor ("weight loss factor") to account for weight loss from cooking, the authors subsequently determined PCB losses on a mass basis (Puffer and Gossett, 1983, p. 69). These estimates were used in this paper.

Trotter *et al.* (1989) initially reported changes in PCB content of bluefish fillets on a whole tissue (wet weight) basis (Trotter *et al.*, 1989, p. 502). Using data on PCB concentrations and weights of individual raw fillets versus cooked fillets, the authors calculated average changes in PCB content on a total mass basis (Trotter *et al.*, 1989, p. 502). The mass of PCBs in the individual raw fillets was calculated by multiplying the reported concentration of PCB in the fillet by its respective raw weight. Comparable calculations were conducted for these fillets in their cooked state. The percentage of change in the mass of PCBs for individual fillets in their raw state versus cooked state was determined, and an average of these percentages was calculated to estimate overall PCB loss during baking of the fillets.

Smith *et al.* (1973) reported the results on a mass per gram of fat basis (micrograms of PCB per gram of fat). As discussed in the previous section, Smith *et al.* (1973) then reported cooking loss by comparing PCB levels, expressed on a mean basis, in raw and cooked fillets. That is,

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Fraction of PCB remaining after cooking

$$= \frac{\text{Mean concentration } \mu g \text{ of PCB/gram of fat in cooked fillet}}{\text{Mean concentration } \mu g \text{ of PCB/gram of fat in raw fillet}}.$$

Because of the high variability of PCBs in individual samples and the relatively small differences between the cooked and raw fillets, cooking loss estimates by this method were not statistically significant.

Based on data provided in Smith (1972), PCB losses during cooking can be estimated by an alternative method. In Smith (1972) detailed information was provided on the levels of PCBs in the baked fillets and in the drippings collected in the pan below. Thus, it is possible to make a conservative estimate of the loss of PCBs by comparing the mass of PCBs in the drippings to the mass of the PCBs in the cooked fillets. The percentage of PCBs removed during cooking is estimated as follows:

Percentage of total PCB mass lost during cooking

$$= \frac{\text{Mass of PCBs in drippings}}{\text{Mass of PCB in cooked fillet} + \text{Mass of PCB in drippings}} \times 100.$$

The mass of the PCBs in the cooked fillet and the dripping from the fillet can be estimated as

$$M_{PCB} = C_{PCB} \times F \times M_f,$$

where M_{PCB} is the mass of PCBs in a fillet or dripping, C_{PCB} is the concentration of total PCBs in micrograms per gram of fat in a fillet or dripping, F is the percentage of fat in the fillet or dripping, and M_f is the mass of the fillet or dripping. Data on the concentration of PCBs (fat basis) and percentage of fat for the individual fillets and their drippings are given in Smith (1972). Data on the average mass of the fillets and drippings are given in Smith *et al.* (1973).

Based on this approach, it was estimated that the average cooking loss was 10% for baking. The calculated 10% loss during baking is a conservative estimate of total PCB loss because the estimate does not reflect the PCBs lost by volatilization during cooking. Had this component of cooking loss been included, the estimate of total loss during cooking would have been larger. This analytical approach was also applied to the results (Smith *et al.*, 1973) of poaching of chinook steaks. However, no meaningful estimates of the percentage of loss could be made due to the extremely low content of fat in the drippings resulting from the poaching process.

DISCUSSION OF REPORTED INCREASES OF PCBs AFTER COOKING

While most studies have reported declines in PCB levels after cooking (Table 2), some studies actually reported increases (Smith *et al.*, 1973; Skea *et al.*, 1981; Zabik *et al.*, 1982; Trotter *et al.*, 1989). The results of the studies that reported increases were generally expressed as a concentration on either a wet weight or fat basis (Smith *et al.*, 1973; Skea *et al.*, 1981; Trotter *et al.*, 1989). In these cases, the PCBs appeared to become concentrated due to a greater percentage of moisture loss than contaminant loss during the cooking process (Skea *et al.*, 1981). Trotter *et al.* (1989) specifically commented on this issue stating, "the relatively large loss of moisture during cooking compensated for the PCB and oil loss and resulted in similar ppm PCB and percent

TABLE 2

Changes in PCB Levels in Fish Samples Resulting from Various Cooking Methods

Method	Study	Fish species	Percentage of change on a PCB mass basis
Bake or roast	Smith *et al.*, 1973; Smith, 1972	Chinook salmon	−10
	Zabik *et al.*, 1979	Lake trout	−34
	Skea *et al.*, 1981	Smallmouth bass	−16
	Trotter *et al.*, 1989	Bluefish	−27
			Average −22
Broil	Zabik *et al.*, 1979	Lake trout	−53
	Skea *et al.*, 1981	Brown trout	0
			Average −27
Fry	Skea *et al.*, 1981	Smallmouth bass	−74
	Puffer and Gossett, 1983	White croaker (Santa Monica Bay)	−65
	Puffer and Gossett, 1983	White croaker (Orange County)	−28
			Average −56
Microwave or poach	Zabik *et al.*, 1979	Lake trout	−26
			Average −26

fat levels in the uncooked and cooked fillets." When the data from these studies are expressed on a mass basis instead of a concentration basis, they consistently show a reduction in PCBs after the cooking process. The data expressed on a mass basis are presented in Table 2.

The one exception to the decrease in PCB mass after cooking was reported by Zabik *et al.* (1982), who reported that PCB mass levels were increased by the cooking process. Zabik *et al.* (1982) suggested that the PCB mass increases could be due to more efficient extraction of phospholipid-associated PCBs during laboratory analyses of cooked fish tissue compared with raw tissue. The analytical method used to extract PCBs from fish tissue (Yadrick *et al.*, 1972) is not necessarily completely effective in extracting

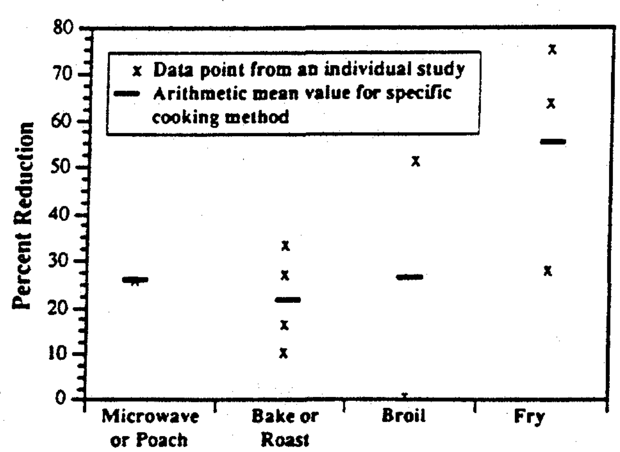

FIG. 1. Percentage of reduction of PCBs in fish fillets relative to cooking method.

TABLE 3

Average Lipid Content of Raw Fish Samples Used in Cooking Loss Studies

Method	Study	Fish species	Percentage of lipid content of raw fillets
Bake or roast	Smith *et al.*, 1973	Chinook salmon	2.7
	Zabik *et al.*, 1979	Lake trout	25.0
	Skea *et al.*, 1981	Smallmouth bass	2.8
	Trotter *et al.*, 1989	Bluefish	11.8
Broil	Zabik *et al.*, 1979	Lake trout	29.1
	Skea *et al.*, 1981	Brown trout	8.8
Fry	Skea *et al.*, 1981	Smallmouth bass	1.3
	Puffer and Gossett, 1983	White croaker (Santa Monica Bay)	1.2
	Puffer and Gossett, 1983	White croaker (Orange County)	0.9
Microwave or poach	Zabik *et al.*, 1979	Lake trout	26.4

intermuscular phospholipids in raw fish tissue. Thermal decomposition of the protein-lipid microstructures may facilitate a more complete extraction of these lipids and associated PCBs. Support for this conclusion is presented by Paul and Palmer (1972), as cited in Zabik *et al.* (1982), who reported, "cooking often causes an increase in the amount of ether extractable material in the lean portion of meat over that found in raw meat, even when the lipid extract is expressed on a dry basis."

The effect described by Paul and Palmer (1972) may occur in all cooking processes; however, the effect may be most conspicuous when total PCB losses are small. As discussed below, several authors have suggested that the degree of PCB removed will be higher in fish with high fat content. In fish with high fat content and high PCB removal rates the small increase in apparent PCB concentration caused by increased PCB extractability is overwhelmed by the larger reduction in PCB from volatilization and fat loss. In fish with low fat levels (carp used in Zabik *et al.* (1982) contained 8% fat) the effect is not overwhelmed by a large loss from fat rendering and is thus observed as an apparent increase.

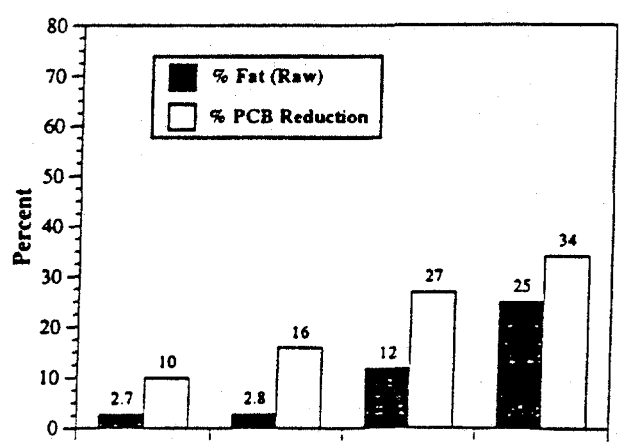

FIG. 2. Extent of PCB reduction relative to percentage of fat content by baking or roasting.

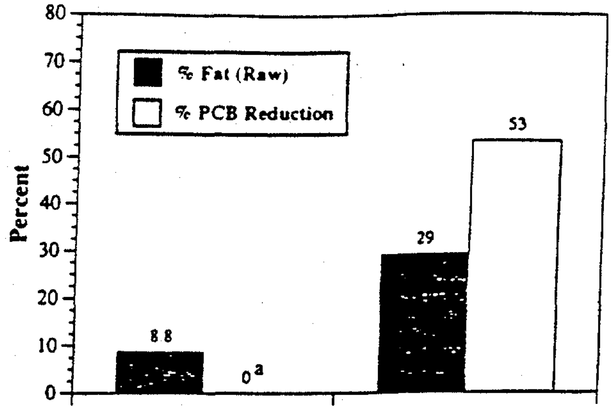

FIG. 3. Extent of PCB reduction relative to percentage of fat content by broiling. [a] Value of 0 is believed to be anomalous because significant reductions were reported for specific lipophilic pesticide residues.

If the Zabik hypothesis is correct, then all reported cooking loss measurements will tend to underestimate the true degree of removal. This will occur since the PCB levels in the raw fish will appear to be smaller due to the decreased extractability. This phenomenon may explain the apparent contradiction in Smith *et al.* (1973) where PCB levels in cooked fish appeared to be unchanged, while approximately 10% of the PCBs were measured in the drippings of the cooked fish.

The authors of this paper believe that it is highly unlikely that PCBs are actually formed during the cooking process. PCBs are commercially produced by the direct chlorination of biphenyl in nonpolar solvents (ATSDR, 1991). Such chemical processes are not likely to occur in fish tissue due to the absence of free chlorine, the presence of polar compounds (water, proteins, carbohydrates, etc.), and the unlikely occurrence of biphenyl or other suitable precursors. Thus, the generation of PCBs during the cooking process is highly implausible. Because of the absence of a plausible mechanism for the formation of PCBs, and the consistent measurements of reductions in PCB on a total mass basis in the majority of published studies, it can be concluded that PCBs are reduced to varying degrees by different cooking methods.

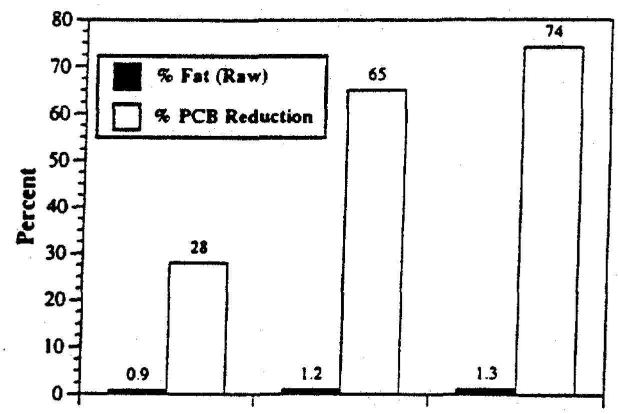

FIG. 4. Extent of PCB reduction relative to percentage of fat content by frying.

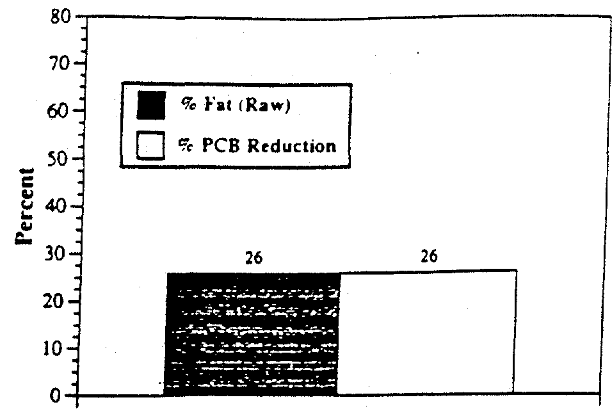

FIG. 5. Extent of PCB reduction relative to percentage of fat content by microwaving or poaching.

REDUCTION IN PCB MASS BY VARIOUS COOKING METHODS

The degree at which PCB mass is reduced during cooking varies with the cooking method. Certain cooking methods, such as microwave cooking or steaming, may be relatively ineffective in removing lipids from the fish due to the low cooking temperatures and/or short cooking times. Certain methodologies, such as stewing or using fish in casseroles, result in minimal reduction in PCB levels since volatilization is believed to be minimal, and the lipids lost during cooking are still consumed. Methods such as broiling or baking are more effective in reducing the amount of PCBs consumed because lipids containing these compounds are separated from the fish and not consumed, and because PCBs are also believed to be volatilized somewhat during these types of cooking processes. Finally, processes such as deep frying may also reduce the PCB concentration in the fish by an actual lipid extraction. In this process, it is hypothesized that PCBs may partition into the large volume of cooking oils and fats.

While the studies discussed in this paper clearly indicate that cooking reduces the PCB mass levels in edible fish tissues, an examination of the results (Table 2) indicates that there is a wide variation in the degree of reduction between the various cooking methods and also within the same method. The hypothesis that PCB loss is predominantly due to fat loss and volatilization suggests that PCB loss should increase for cooking methods that are more severe (i.e., higher temperatures and longer cooking times). To test this hypothesis, the cooking loss data for the various cooking methods

TABLE 4

Average Reduction of PCBs in Fish by Various Cooking Methods

Method	Percentage of reduction[a]
Bake or roast	22
Broil	27
Fry	56
Microwave or poach	26

[a] Mean percentage of reductions as reported in Table 2.

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were sorted according to normal cooking temperature. The ranking of method from least to the greatest temperature was microwave cooking, baking (or roasting), broiling, and frying. The percentage of reduction results are presented in Fig. 1. Reduction was greatest for frying; broiling and baking were lower; and data on poaching and microwave cooking were too limited to reach a definitive conclusion as to whether it would yield the lowest reduction. These results qualitatively support the hypothesis that the increased temperature and severity of the cooking method is correlated with the degree of PCB reduction.

It has also been suggested by several authors (Cordle *et al.*, 1982; Zabik *et al.*, 1982) that the degree of cooking losses for lipophilic chemicals should increase with the percentage of total fat content of the fish. Table 3 indicates the percentage of fat content of raw fillets used in specific studies, and Figs. 2 through 5 present the degree of PCB loss as a function of the percentage of fat for the different cooking methods. Based on this limited information, it appears that there may indeed be a correlation of reduction for baking and possibly frying but for other cooking methods the information is far too lacking to determine if a correlation between cooking loss and fat content occurs.

SUMMARY AND CONCLUSIONS

An examination of the literature indicates that cooking of fish fillets reduces the amount of PCBs in the fillet. The degree of reduction of PCBs can vary depending upon the specific cooking method employed and characteristics of the fillet being cooked. Because authors have presented their research data in various manners, a casual review of the literature suggests considerable variability in the results. When the degree of loss is expressed on a mass basis, however, the variability in the reported data is greatly reduced. Evaluation of the reported reductions resulting from each cooking method appear to demonstrate that PCBs are preferentially removed by cooking processes that involve higher cooking temperatures and longer cooking times, and which allow the separation of the rendered fat from the cooked fish.

Based on the available data, typical reduction rates as illustrated in Table 4 can be estimated for different cooking methods. These estimates are probably inaccurate for estimating PCB lost in individual meals, as actual losses in meals will be affected by fillet size, cooking time and temperature, and other factors. However, long-term exposure to PCBs is a function of exposures from many meals. Since the estimate of the average PCB loss by cooking method reflects the results of multiple fish tests in several studies, it provides reasonable guidance for general reductions that are likely to occur over long periods of time. It is, therefore, recommended that the average cooking-method-specific levels derived in this paper be used to evaluate actual exposure to PCBs found in fish.

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