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Effects of Cooking on Radiocesium in Fish from the Savannah River: Exposure Differences for the Public

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Abstract. Understanding the factors that contribute to the risk from fish consumption is an important public health concern because of potential adverse effects of radionuclides, organochlorines, other pesticides, and mercury. Risk from consumption is normally computed on the basis of contaminant levels in fish, meal frequency, and meal size, yet cooking practices may also affect risk. This study examines the effect of deep-frying on radiocesium (^{137}Cs) levels and risk to people fishing along the Savannah River. South Carolina and Georgia have issued consumption advisories for the Savannah River, based partly on ^{137}Cs. ^{137}Cs levels were significantly higher in the cooked fish compared to the raw fish on a wet weight basis. Mean ^{137}Cs levels were 0.61 pCi/g (wet weight basis) in raw fish, 0.81 pCi/g in cooked–breaded, and 0.99 pCi/g in cooked–unbreaded fish. Deep-frying with and without breading resulted in a weight loss of 25 and 39%, while ^{137}Cs levels increased by 32 and 62%, respectively. Therefore, the differences were due mainly to weight loss during cooking. However, the data suggest that risk assessments should be based on cooked portion size for contaminant analysis, or the risk from ^{137}Cs in fish will be underestimated. People are likely to estimate the amounts of fish they eat based on a meal size of the cooked portion, while risk assessors determine ^{137}Cs levels in raw fish. A conversion factor of at least two for ^{137}Cs increase during cooking is reasonable and conservative, given the variability in ^{137}Cs levels. The data also suggest that surveys determining consumption should specifically ask about portion size before or after cooking and state which was used in their methods.

Protecting human health involves assessing hazards and understanding how to avoid or mitigate harm. Scientists have devoted considerable time to assessing the hazards posed to organisms by metals, organochlorines, other pesticides, and radionuclides, often using bioindicators and biomarkers of exposure (Kolehmainen 1972; Sheehan *et al.* 1984; Whicker *et al.* 1990; Brisbin 1991; Burger 1993; Renzoni 1994; Hoffman *et al.* 1995; Linthurst *et al.* 1995) Fish are particularly useful as bioindicators of contamination because of their role in the food chain, for both humans and other organisms.

Fishing is an important aspect of culture and tradition in much of the United States, particularly in the Southeast (Fleming *et al.* 1995; Toth and Brown 1997; Burger *et al.* 1999a, b). Contaminants, such as mercury and polychlorinated biphenyls (PCBs), as well as radionuclides, are sufficiently high in some fish and seafood to pose a potential risk to human consumers (ATSDR 1996; IOM 1996; Ratcliffe *et al.* 1996; Kamrin and Fischer 1999; Burger *et al.* 2001). Concern about such health risks has led to the issuing of consumption advisories for some waters (EPA 2000). Fetuses, neonates, and young children are the group most at risk (Ratcliffe *et al.* 1996; Weiss and Elsner 1996; Weihe *et al.* 1996; Jacobson and Jacobson 1996). Risk reduction for fetuses and neonates often involves calculating the appropriate consumption for pregnant women, combined with appropriate risk communication (Knuth 1996; Ebert 1996).

Risk from fish consumption involves data on contaminant loads of fish, meal frequency, and meal size. Yet other factors may affect the risk from fish consumption, including cooking practices (Zabik and Zabik 1995; Zabik *et al.* 1995; Morgan *et al.* 1997; Wilson *et al.* 1998). Several studies have examined the effect of trimming fat, removing skin, and cooking on mercury, PCBs, and other fat-soluble contaminants (Morgan *et al.* 1997; Burger 1998) and on pesticides (Zabik and Zabik 1995; Zabik *et al.* 1995), but no attention has been devoted to ^{137}Cs. Trimming and cooking of fish by various means reduces the levels of fat-soluble contaminants but not mercury (Burger *et al.* 2003). The effect on ^{137}Cs is unclear.

This article examines the effect of deep-frying on radiocesium (^{137}Cs) levels in largemouth bass (*Micropterus salmoides*), a preferred fish of people in South Carolina and else-

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where in the South (Fleming *et al.* 1995; Burger 1998). It is important to understand the effects of cooking and the use of batter on ^{137}Cs levels in fish because over 80% of the people interviewed along the Savannah River deep-fried their fish regularly (Burger *et al.* 1999), and when asked, 90% said that they were basing it on how their fried fish looked. Additionally, in a survey of students at Rutgers University, nearly 98% said that they were basing consumption on broiled or cooked fish (Burger, unpublished data).

We test the hypothesis that the levels of ^{137}Cs in raw and deep-fried fish (with and without a batter) does not differ. If the levels of ^{137}Cs differ in cooked and raw fish, this has major implications for risk assessment because most consumption studies report consumption on the basis of cooked fish (Fleming *et al.* 1995; Kamrin and Fischer 1999; Burger *et al.* 1999), yet contaminant data are reported for raw fish (Morgan *et al.* 1997; Wilson *et al.* 1998; Burger *et al.* 2001a, b).

Our overall objective was to determine whether deep-frying affects the resultant risk assessment for fish consumption. There are consumption advisories for largemouth bass from the Savannah River (SCDHEC 1996; GDNR 2001), and the inclusion of cooking effects will help clarify risk associated with bass consumption in this region.

Materials and Methods

Fish ($N = 39$) were collected from L Lake on the Savannah River Site (SRS; 33.1°N, 81.3°W) (Fig. 1), a 780-km^2 nuclear weapons production and research facility operated by the U.S. government since the early 1950s. L Lake was constructed in 1985 to serve as a source of cooling water for the reactor but was used infrequently (Kennamer *et al.* 1998). Prior to the construction of the lake, there was some ecosystem contamination of streams and the floodplain (Ashley and Zeigler 1980; Whicker *et al.* 1990). Some contaminants came from industrial activities upstream from SRS, activities on-site also resulted in contamination by a wide range of heavy metals and radionuclides (Kvartek *et al.* 1994; Sugg *et al.* 1995), and atmospheric deposition also contributed contaminants to SRS.

The SRS produced plutonium and tritium and processed other nuclear materials for nuclear weapons and other governmental and private industrial purposes. Radiocesium was released to the environment during the operation of a high-level waste storage system, two radiochemical processing facilities, and five production reactors (Cummins *et al.* 1991). Carlton *et al.* (1994) estimated that 65% of the released Cs remained on site. Impoundments on SRS were used as thermal cooling reservoirs for nuclear production reactors (Asley and Zeigler 1980; Whicker *et al.* 1990.

Fish were collected from L Lake under appropriate state permits and with protocol approvals from the University of Georgia Institutional Animal Care and Use Committee (A960205) and Rutgers University Institutional Review Board (07–017). Fish were collected using a rod and reel, placed on ice, and immediately dissected upon return to the laboratory at the Savannah River Ecology Laboratory (SREL).

Dissected fish were immediately frozen (−4°C) and labeled by date and collection location. The fillet from one side of the fish was designated for frying, while that from the other side was designated as raw. The side that was chosen for cooking was then divided longitudinally for a breaded and nonbreaded treatment. The designation of the side for the raw and breading treatment was done at random.

Fillets were cooked either with or without batter. Batter was applied by dusting the wet fillet with dry breading mixture (Zatarain's Seasoned Fish Fry, New Orleans, LA). Cooking was done according to local customs using local deep-frying vats and using the same oil (Dukes Peanut Oil) as is the local custom. However, we cooked all the unbattered fish first to avoid cross-contamination. Fillets were weighed before and after cooking. Fillets were submerged in the hot oil until the fillet began to float, indicating that cooking was complete. It was then patted dry and frozen for later analysis.

We determined ^{137}Cs count rates of wet muscle tissue using a Gamma-X HPGe High-Purity Germanium Coaxial Photon Detector System with a 56.7 × 77.3-mm crystal. An EG&G Ortec 92 × Spectrum Master integrated spectroscopy system with associated Gamma Vision Software was used for data acquisition. A counting window of approximately 658–666 keV was used after a peak region of interest was acquired after calibration with a known ^{137}Cs standard to record total absorptions from the ^{137}Cs emission of 662-keV photons. Counting time per sample was 500 min. Simultaneous background counts were performed for each sample. Count rates of standards were determined weekly before or after every counting sequence. The minimal detectable activity (MDA) was calculated using a 2-σ detection limit where the peak count is equal to twice the sum of 1 plus the square root of the sum of 1 plus the background divided by the live time (Currie 1968). All values are pCi/g (wet weight basis).

We used the Kruskal-Wallis non-parametric one-way analysis of variance (Wilcoxon option in the Statistical Analysis System PROC NPARIWAY) to examine differences among treatments (SAS 1995). The level for significance was designated as < 0.05.

Results

The moisture content of fish ranged from 67 to 77%. Mean ^{137}Cs levels were 0.61 pCi/g in raw fish and 0.81 and 0.99 pCi/g in breaded and unbreaded cooked fish. There were significant differences in ^{137}Cs levels (wet weight basis) as a function of treatment (Table 1) ($\chi^2 = 53.5$, df = 2, $p < 0.0001$). ^{137}Cs levels were 32% (breaded) and 62% (nonbreaded) higher in cooked than raw fish.

Discussion

The source of the ^{137}Cs in the fish was industrial pollution, since L Lake was used as a source of cooling water for a nuclear reactor when it was functioning (Kennamer *et al.* 1998). Prior to the construction of the cooling ponds, there was some ecosystem contamination of streams and the floodplain, and small quantities of radionuclides were released subsequently (Ashley and Zeigler 1980; Whicker *et al.* 1990; Kennamer *et al.* 1998). There is no controversy about the source of ^{137}Cs contamination in L Lake, although there is some limited atmospheric deposition of ^{137}Cs on-site.

Contaminants and radionuclides in fish are usually calculated on a wet weight basis, rather than a dry weight basis. While drying fish for dry weight analysis results in complete moisture loss, cooking for human consumption removes only some of the moisture. For fish ($N = 11$ species) collected in the Savannah River, the dry weight ranged from 23 to 33% of the corresponding wet weight (i.e., water content of 67–77%). Thus for the same samples, levels expressed on a wet weight basis are 1/4 to 1/3 of the same content expressed on a dry weight basis, although in some fish the ratio may be as high as 1/5 (Burger *et al.* 2001a). As has been found previously, the differences between raw and cooked fish are largely due to

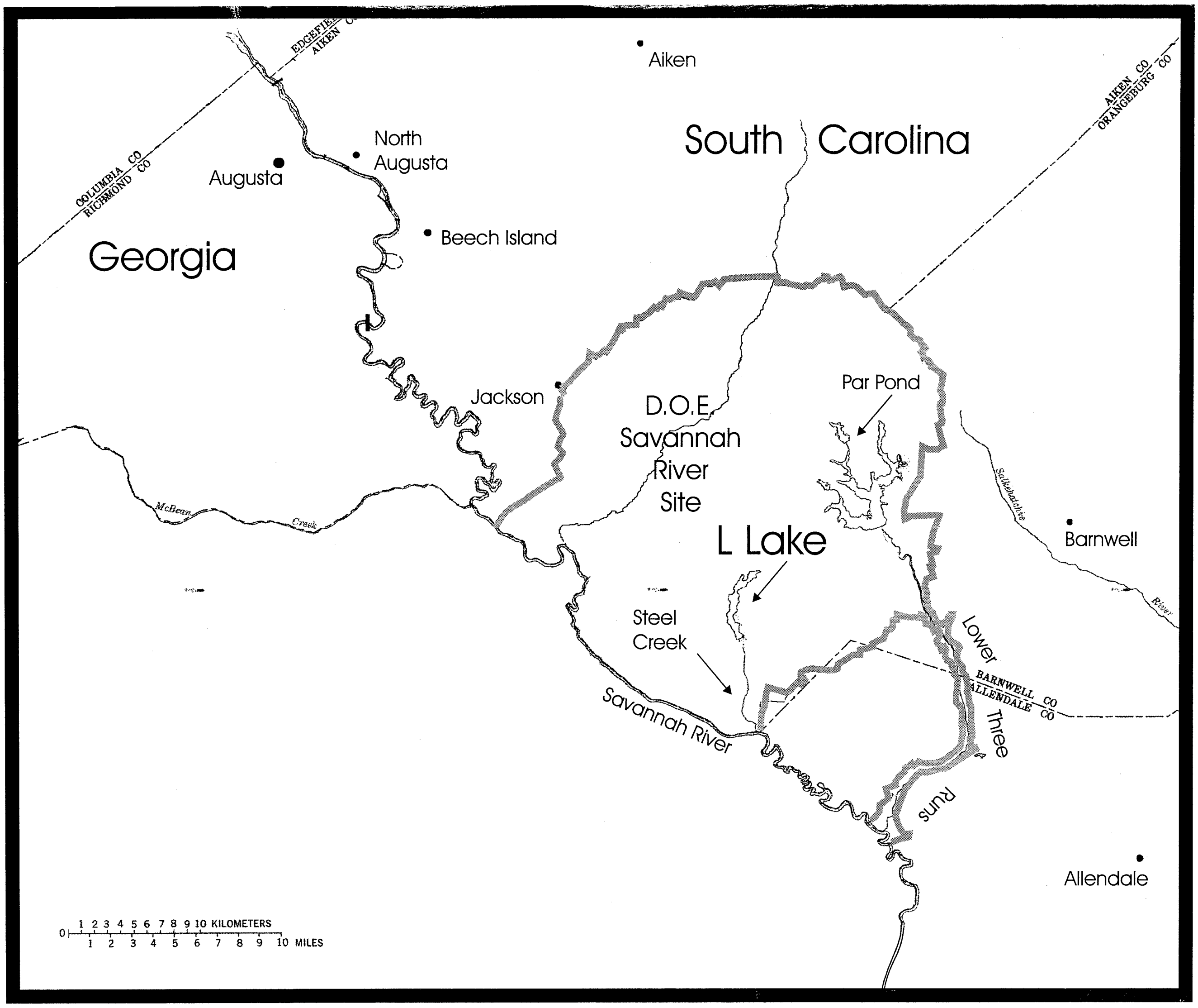

Fig. 1. Map showing the Savannah River Site and L Lake, where Largemouth Bass were collected.

Table 1. Concentrations of radiocesium (^{137}Cs) in raw and cooked largemouth bass with and without breading[a]

	Picocuries per gram		
	Arithmetic mean	SE	Range of values
Raw	0.61	0.02	0.38–0.97
Cooked–breaded	0.81	0.02	0.51–1.13
Cooked–unbreaded	0.99	0.10	0.62–4.50

[a] Fish ($N = 39$) were collected from the cesium-contaminated L Lake on the Savannah River Site in South Carolina. All means are statistically different ($p < 0.05$) from each other.

moisture loss (Zabik and Zabik 1995; Zabik *et al.* 1995; Burger *et al.* 2003).

Few studies have examined how cooking affects the amount of contaminants in fish. In largemouth bass, mercury levels were 45–75% higher in cooked fillets compared to uncooked fillets (on a wet weight basis [Burger *et al.* 2003]), which is slightly higher than the range reported by Morgan *et al.* (1997) for fish from Lake Superior. In some of the samples, mercury concentrations were twice as high in cooked as in uncooked fish. The primary objective of this study was to understand the effect of local cooking methods on ^{137}Cs in largemouth bass, one of the preferred local fish (Burger 1998). The data from this study clearly indicate that the concentration of ^{137}Cs (on a wet weight basis) in uncooked fish is less than in cooked fish (for the same portion size). The actual conversion factor will depend upon the species of fish and the cooking method. In this study, ^{137}Cs concentrations were up to 1.6 times higher in cooked compared to raw fish. However, when the maximum values are considered, the Cs concentrations were up to 115% higher in the cooked (nonbreaded) compared to the raw fish. This suggests that a conversion factor of at least 2 is required. While exposure to contaminants in fish will generally approach the mean values in fish for chronic consumers, high-end values are of interest for pregnant women because of sensitive periods in neurobehavioral development and our lack of knowledge of the specific effects of one or two meals with high levels during these sensitive periods. Clearly these data suggest that a conversion factor should be used in risk assessment. However, several issues should be examined before performing risk assessments and developing risk management plans, including (1) Are estimates of amount eaten based on cooked or uncooked portions of fish? (2) Are contaminant levels based on cooked or uncooked fish? (3) Are the conversion values for a specific fish and a specific cooking method known? (4) What are the ranges or uncertainties in the first three factors? and (5) What are the relative contributions of the different fish species and cooking methods to the total fish consumption of people eating wild-caught fish?

Morgan *et al.* (1997) suggested using food preparation factors in risk assessment, but these have generally not been applied because they are not generally known for specific fish. Preparation factors (mercury concentration in cooked fish/mercury concentration in raw fish) in their study generally ranged from 1.3 to 1.6 for fillets from Great Lakes fish, compared to 1.5 to 1.8 for largemouth bass in another study (Burger *et al.* 2003). These two studies suggest that a preparation conversion factor of 2 would be a suitable, protective default for mercury. However, there are no data for ^{137}Cs. ^{137}Cs data from this study suggest that the conversion factor should be at least 2 based on the maximum levels of ^{137}Cs in cooked and uncooked fish. The similarity of the conversion factor is based on the fact that the main difference is one of moisture loss in cooking.

Overall, the study suggests that risk assessors who do not take cooking method into account, but use contaminant data from raw fish, may be overestimating safe consumption levels. This factor should be considered by state agencies setting consumption levels for high risk populations. However, most consumption studies do not examine the species of fish eaten, making it difficult to use species-specific conversion factors. At the least, risk assessors should determine whether estimates of intake were made on a cooked or a raw fish basis.

Finally, it is clear that the mass of ^{137}Cs in the fillet itself has not changed; what has changed between raw and cooked fish is the perception of the quantity of fish consumed. The perceptual problem is faced by both the consumer (who often estimates intake based on cooked fish) and the risk assessor (who estimates risk based on contaminants levels in raw fish because contaminant levels are usually measured in raw fish). The human health risk is based on the dose (mass of ^{137}Cs). However, if people estimate their consumption based on cooked fish, but risk assessors compute risk on raw fish, the estimates are underestimates of the actual risk. Another implication of this research is that when people are asked about fish consumption, whether their answers are based on cooked or uncooked fish should be clearly stated.

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