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FOOD PRODUCTION AND CONSUMPTION NEAR THE SAVANNAH RIVER SITE

by

D.M. Hamby

Westinghouse Savannah River Company
Savannah River Laboratory
Aiken, South Carolina 29808

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ABSTRACT

Routine operations at the Savannah River Site (SRS) result in the release of radionuclides to the atmosphere and to the Savannah River. The resulting radiological doses to the off-site maximum individual and the 80-km population are estimated on a yearly basis. These estimates are generated using dose models prescribed in the NRC Reg. Guide 1.109 for the commercial nuclear power industry.

A study of land and water usage characteristics in the region of the Savannah River Site has been conducted to determine site-specific values of the NRC dose model parameters. The study's scope included local characteristics of meat, milk, vegetable production; Savannah River recreational activities and fish harvests; meat, milk, vegetable, and seafood consumption rates; and Savannah River drinking-water populations. Average and maximum consumption rates of beef, milk, vegetables, and fish have been determined for individuals residing in the southern United States. The study suggests that many of the consumption rates provided by the NRC may not be appropriate for residents of the South. Average consumption rates are slightly higher than the defaults provided by the NRC. Maximum consumption rates, however, are typically lower than NRC values. Agricultural productivity in the SRS region was found to be quite different than NRC recommendations.

Off-site doses have been predicted using both NRC and SRS parameter values to demonstrate the significance of site-specific data.

INTRODUCTION

The NRC provides numerical data to estimate committed doses to individuals and populations from routine releases of radioactive materials (US NRC 1977). These data are furnished in Appendix E of Regulatory Guide 1.109 for the various models presented therein. Approximately half of the NRC default values were derived through the utilization of the HERMES code developed by the Hanford Engineering and Development Laboratory (Fletcher 1971).

The majority of the usage and consumption data accessed by HERMES originated in a 1965 U.S. Department of Agriculture survey on the consumption habits of families in the north-central United States (Fletcher 1971). One-third of the defaults are judgements of the NRC staff (US NRC 1977). The remaining parameters (agricultural and garden productivity) are national averages obtained from the census bureau (US Census 1972). Estimates of parameter values specific to the Savannah River Site have been determined for the NRC dose models since most of the default values are obtained from usage data that are nearly 20 years old, specific to the north-central U.S., and/or not adequately documented.

METHODOLOGY AND RESULTS

This paper focuses on determining the parameters necessary for estimating radiological dose to humans via consumption of potentially contaminated foodstuffs and external gamma exposure from water immersion. The parameters include consumption rates of meat, milk, and vegetables contaminated by the deposition of radionuclides released to the atmosphere; the consumption of drinking water, fish, and invertebrates contaminated by liquid effluents reaching the Savannah River; and recreational river usage leading to
external irradiation of humans engaged in activities along or in the Savannah River. SRS-specific parameter values are compared to the NRC default values in Table 1.

The majority of the usage data was obtained from state and county agencies within the SRS 80-km dose assessment region and along the downstream portion of the Savannah River. Information on livestock grazing habits, source of forage, vegetation production, etc. was obtained directly from county agricultural extension agents within the 80-km region. Meat-packing and milk processing plants in Georgia and South Carolina provided details on the preparation of beef and milk products.

**Meat and Milk Production.** The diets of beef cattle in the south generally consist of about 75% pasture grass and 25% stored grass with total forage consumption averaging about 36 kg/day. Dairy cattle consume approximately 52 kg/day of which 56% is pasture grass, 25% is silage, and 19% is commercial grain. Southern farmers rely on year-round grazing of fresh, coastal bermudagrass (Mathis 1990). Bermudagrass that is not consumed is cut and baled every thirty days with storage times ranging from one month to one year, or at times up to two years. Silage may be stored for up to one year before consumption (Mathis 1990). Under these circumstances, the NRC stored-feed hold-up time of 90 days is considered conservative and appropriate for the Savannah River Site.

Most beef-cattle farmers in this region of the country operate on a cow-calf system; calves are raised locally until weaned (6 months) and then marketed to western feeder lots where their weights are increased before slaughter. These calves' average weight when sold is approximately 180 kg (400 lbs). Ideally, cows producing calves each year remain with the area farmer whereas cows not producing calves are slaughtered locally. Those cows slaughtered locally average about 360 kg (800 lbs). For the purposes of dose assessment, it is assumed that all calves are slaughtered at 180 kg and all calfless cows are slaughtered at 360 kg. All of this beef is assumed to be consumed locally. Approximately 41% of a beef cow is processed into retail cuts and sold for human consumption (Mathis 1990). Only about 1% of beef cattle in the Savannah River region are slaughtered and consumed on local farms.

Hogs and chickens are also raised on farms within 80 km of the SRS. Generally, however, commercially raised hogs do not graze; they are fed imported commercial feeds. Similarly, chickens raised for profit are housed in covered shelters and eat imported feed provided by the parent companies responsible for marketing the final product (Mathis 1990). Since the meat pathway models of Reg. Guide 1.109 consider feed consumption as the only pathway to meat then man, the local ingestion of pork and chicken is not considered in the determination of meat production or consumption.

The population of beef cattle within 80 km of the SRS is approximately seven times larger than the population of milk cattle with only half of the counties in the region having milk cattle herds. The average milk cow in the twenty-one-county region around the SRS produce an average of about 20 liters of milk per day, lactating three-quarters of the year.

**Transport Time.** The concentration of a given nuclide in beef or milk at the time of human consumption is dependent on several factors, the most significant of which is the concentration of the nuclide in the animal's feed. For the purposes of dose estimation, it is assumed that some fraction of the nuclides ingested by beef or milk cattle are instantaneously distributed in cattle flesh and/or milk. Thereafter, radioactive decay occurs before human consumption. Since cattle are assumed to feed continuously, the decay time is essentially the time required to process and deliver the final product to market. Slaughter-to-consumption and milking-to-consumption times were determined from practices at local beef and milk processing facilities. Transport times are considered to end when the product is available for consumption and, therefore, do not include distribution and storage.

The commercial slaughtering of beef cattle is generally a six-day process. Cattle are slaughtered the first day, processed and packed the next, and shipped on the sixth day. The beef is cured for the four days between packing and shipping (Mathis 1990). The NRC recommends using a 20-day time from slaughter to consumption.

Generally, milk in the Savannah River region is collected every other day from local dairies and shipped to one of several processing plants in South Carolina or Georgia. The process of homogenizing, pasteurizing,
and packing the milk can be completed in about 36 hours. Accordingly, it is assumed that milk is collected on day one, processed on day two, and shipped, ready for consumption, on day three (Bailes 1991).

Agricultural Production. Agricultural production is normally divided into two groups when considering ingestion dose as a result of radionuclide deposition on vegetation: leafy vegetables and other above-ground vegetables. Leafy-vegetables include cabbage, lettuce, and spinach; other above-ground vegetables considered include lima beans, broccoli, cauliflower, green peas, and sweet corn (Hoffman 1975). Literature from the Clemson University Extension Cooperative contains planting and growing times for a number of vegetables that are harvested in South Carolina (US Dept of Agriculture 1990). The average growing time for above-ground vegetables in South Carolina is approximately 70 days.

County-wide vegetable production was estimated from a survey of land usage distributed to twenty-one county extension agents in Georgia and South Carolina. Vegetable production in the southeast is difficult to determine since much of the area relies on vegetables grown in home gardens. Nearly half of the extension agents surveyed were, however, able to provide estimates of vegetable production. Vegetable production distributions were generated for both leafy and other above-ground vegetables. For those counties where the extension agent was unable to provide data, production was estimated using the average of those counties providing estimates.

Transport Time. The NRC recommends a holdup time for population dose calculations of fourteen days for all vegetables. The maximum individual is assumed to ingest leafy vegetables after a one-day holdup and produce after a sixty-day holdup (US NRC 1977). These transport times continue to be used at the SRS.

USE OF THE SAVANNAH RIVER

Drinking Water. Drinking water consumption rates remain unchanged from the NRC default so that a direct comparison can be made with the EPA drinking water standard. The effective population and transit time, however, are site-specific.

Two water treatment facilities draw water from the Savannah River for domestic supplies in Georgia and South Carolina. The Cherokee Hill Water Treatment Facility in Port Wentworth, Georgia processes between 150 and 170 million liters per day with a user population of 15,000 (Weil 1990). The population consists of employees of the twenty-nine industries in Port Wentworth's industrial park. Unlike Cherokee Hill, the domestic water treatment facility serving Beaufort and Jasper counties of South Carolina is committed almost entirely to household use. Beaufort-Jasper serves an effective population of 50,000, processing about 25 million liters per day (Curnutt 1990).

Conservatively, the time required for a radioactive effluent to reach the Savannah River after discharge is 24 hours. Travel times from Steel Creek down the Savannah River to the Beaufort-Jasper treatment facility average approximately 72 hours (Hayes 1990).

Aquatic Foods. Fish harvests from the Savannah River and its estuary have been divided into three categories: 1) sport fish harvest, 2) commercial fish harvest, and 3) sport & commercial invertebrate harvest (crabs, shrimp, oysters, and clams). The South Carolina Wildlife and Marine Resources Department (WMRD) and the Georgia Department of Natural Resources (GDNR) were instrumental in supplying data on local fish and invertebrate harvests. Data from the GDNR also included commercial harvests from the Wassaw River since it is fed by the Savannah River near Savannah, Georgia. It is conservatively assumed that all edible portions of fish and invertebrates taken from the Savannah River and its estuary are consumed by the 80-km population.

The annual fish harvest from the river by sport fishermen has been estimated from a 1988 Savannah River creel survey conducted by the GDNR (Schmidt 1989). For 1988, approximately 69,000 kg (152,000 lbs) of fish were harvested from the Savannah River and its estuary from sport fishing.

The South Carolina WMRD provided data on the commercial fish harvest in the Savannah River for 1989 (Applegate 1990). The GDNR provided similar data on the Savannah and Wassaw River areas for 1972 to
1989 (Tritaik 1991). The Georgia and South Carolina commercial fish catch of 5,480 kg consisted primarily of carp, sturgeon, and catfish. For dose assessment, it is assumed that 50% of the fish harvest is edible.

Annual summaries of state-wide seafood harvests for the fifteen year period from 1975 to 1989 have been obtained from the South Carolina WMRD. The GDNR has provided data on invertebrate harvests from 1972 to 1989 for the inshore areas of the Savannah and Wassaw Rivers.

Six thousand, eighty kilograms of blue crabs were harvested by South Carolina fishermen from the Savannah River estuary in 1989 (Applegate 1990). The 18-year annual harvest of crabs by Georgia fishermen is 560,000 kg (Tritaik 1991). With the edible portion of the average crab being 14% by weight (Applegate 1990), the annual edible portion of the crab harvest is 87,000 kg.

The average South Carolina annual shrimp (headless) and clam (meat only) harvests from the Savannah River estuary are estimated to be 34,000 kg and 2,500 kg, respectively (Applegate 1990). The annual average Georgia shrimp harvest (from 1978 to 1989) is approximately 280,000 kg (headless) (Tritaik 1991). Clam meat harvested by Georgia fishermen averages 1,900 kg annually (Tritaik 1991). Assuming that 90% of a headless shrimp is edible and 100% of clam meat is edible, the edible portions of shrimp and clams harvested from the Savannah River are estimated to be 284,000 kg and 4,500 kg, respectively.

South Carolina oyster catches have been estimated using a state-specific factor converting bushels of harvested oysters to pounds of edible meat. The conversion factor for oysters taken off the coast of South Carolina is 1.44 kg/bushel (Applegate 1990). Approximately 408,000 bushels of oysters are harvested annually by South Carolina commercial fishermen. The average oyster harvest by Georgia fishermen over the past 18 years is about 620 kg per year. Therefore, it is estimated that about 13,600 kg of oyster meat are harvested annually from the Savannah River estuary.

It is estimated that an additional 6,400 kg of miscellaneous shellfish would be harvested from the river. Assuming 10% of the harvest is edible, approximately 640 kg of miscellaneous Savannah River shellfish are harvested annually for ingestion.

Recreation on the Savannah River. Shoreline, swimming, and boating usage of the Savannah River has been estimated for residents of Georgia and South Carolina. A study conducted by the GDNR gives an assessment of outdoor recreation for 1989 (Ga DNR 1990). This assessment approximates, for a given recreational activity, the participating fraction of the population, the average frequency of participation, and average hours per outing. Data are available on, among others, water-skiing, canoeing/rafting, motorboating/sailing, swimming at beaches, and warm-water fishing (as opposed to cold-water, mountain-stream fishing).

Annual shoreline, swimming, and boating usage has been determined for the 80-km population and for the maximum individual. Population usage is the product of the 80-km population, the fraction participating, the annual frequency of participation, the average hours per outing, and a usage factor. The usage factor is the population fraction that is assumed to participate in water recreational activities on the Savannah River. Usage factors are typically less than 0.15 and are estimated for each activity.

Average usage for shoreline, swimming, and boating is estimated from the product of the average outings per capita and the average hours per outing. Maximum usage is estimated from average usage using the age-specific NRC defaults for shoreline activities as a guide (US NRC 1977). Maximum usage is divided by a population weighting factor to determine usage as a function of age.

CONSUMPTION RATES

The rates of consumption of meat, milk, vegetables, fish, and invertebrates have been determined for the average resident of the southern United States using data gathered by the U.S. Department of Agriculture (US Dept of Agriculture 1983). The default consumption rates for the NRC average adult are derived from nation-wide averages then age prorated and maximized using consumption-rate surveys of individuals living in the North-Central United States (US NRC 1977 and Fletcher 1971).
Estimates of average and maximum, adult consumption rates recommended by the NRC and for the Southern United States are given in Figures 1 and 2. Age-specific consumption rates for individuals in the South are determined from ratios of the NRC adult consumption default values to the NRC teen, child, and infant defaults. The NRC age-specific ingestion rates were determined primarily from studies of Hanford-area school children (Soldat 1968).

Average consumption rates were taken directly from the food consumption survey conducted by the U.S. Department of Agriculture during 1977 and 1978 (US Dept of Agriculture 1983). Consumption rates for the average adult living in the South are generally higher than those suggested by the NRC with the exception of meat consumption. The NRC includes beef, pork, and poultry in the default value for meat consumption (US NRC 1977). Because of feeding practices in the area around the SRS, the potential for contamination through the meat consumption pathway exists only for grazing beef cattle.

Consumption rate estimates for the maximum individual in the southern U.S. are generally lower than the NRC defaults. The NRC values were estimated by multiplying average consumption times maximum-to-average consumption ratios (Fletcher 1971). The validity of these ratios for use in other regions of the country is in question, however, since they were approximated from dietary surveys of Hanford workers (Wilson 1970). In some cases, the maximum rate provided by the NRC is the consumption rate of the individual with the highest intake of a given food item. Consumption rates for the maximum individual in the South were estimated from the 99.5th percentile of the average household consumption rates observed in weekly usage of meat, milk, vegetables, and seafood (US Dept of Agriculture 1983).

EFFECTS OF SITE SPECIFIC VALUES ON OFF-SITE DOSE

Annual effective dose equivalents have been estimated using NRC dosimetric models for atmospheric and aqueous releases from the SRS. A comparison has been made of off-site dose using the NRC defaults and the SRS-specific values for model parameter input. Comparisons of the maximum individual and population dose as a function of environmental pathway are given in Figures 3 through 6. Figures 3 and 4 show predictions of effective dose equivalent to the SRS hypothetical maximum individual from atmospheric and aqueous releases, respectively. Pathway doses to the 80-km population are compared in Figures 5 and 6. Only doses from significant pathways are given.

The site-specific usage factors developed from this study have no affect on dose from the following pathways: 1) plume shine, 2) ground shine, 3) inhalation, and 4) drinking water consumption. Inhalation, shine and water ingestion doses in Figures 4 through 7 are constant whether using NRC or SRS parameter values. Dose prediction variations shown for the meat, milk, vegetable, fish, and invertebrate consumption pathways generally correspond to differences in ingestion rates, however, other factors play significant roles.

Doses received through the atmospheric pathways are also affected by changes in the absolute humidity and the cow ingestion rate. Additionally, population doses from atmospheric releases depend on the production-weighted average concentration of nuclides in the food products. Nuclide concentration estimates are, in addition to humidity and cow ingestion, functions of crop exposure time and productivity. The maximum individual's dose received via the liquid pathway depends not only on fish and invertebrate consumption but also on an SRS-specific bioaccumulation factor for freshwater fish. Since population dose due to liquid effluents is estimated solely on harvest and not individual consumption, the freshwater-fish bioaccumulation factor is entirely responsible for the difference in population dose from the sport fish pathway.

CONCLUSIONS

A survey of land and water usage characteristics in the region of the Savannah River Site suggests that many of the consumption rates provided by the NRC (US NRC 1977) as defaults for the NRC Regulatory Guide 1.109 dose model parameters may not be appropriate for residents of the South. The holdup time for cows milk has been decreased by 25% and the processing time for beef has been decreased by 70% over the NRC default values. Pasture-grass productivity for the SRS region is more than 2.5 times higher and the
average vegetable growing/exposure time is increased by 17%. Agricultural productivity, on the other hand, is nearly 3 times lower than that recommended by the NRC.

The most significant difference between the SRS-specific and the NRC parameter values is seen in consumption rate estimates. The NRC selected consumption surveys from the North-Central and North-Western portions of the country form the basis of all but the average adult consumption rate default values (US NRC 1977). Consumption rates of individuals in the South, however, appear to be quite different than those of individuals in the North (US Dept of Agriculture 1983). Average consumption rates determined from this study are generally higher than the defaults suggested by the NRC. Maximum consumption rates, however, are typically lower than the NRC values. SRS-specific rates have been determined from consumption data obtained from southern households and are more appropriate for the Savannah River region. The consumption rates for drinking water remain equal to the NRC default values to maintain comparability of SRS dose estimates with the EPA drinking water standard (40 CFR 141 1989).

Predictions of offsite dose using SRS-specific parameter values are generally lower from atmospheric pathways and higher from liquid pathways when considering release scenarios from SRS heavy-water reactors and separations facilities. For releases typical of SRS operations (both atmospheric and liquid), the use of site-specific model parameter values result in a 15% decrease in maximum individual dose and a 3% decrease in population dose at the Savannah River Site.

Acknowledgement. The author sincerely appreciates the contributions by J.G. Black in contacting and obtaining data from various federal, state, and local agencies. The author also wishes to thank all those who contributed their time and expertise in providing data critical to this report, especially Mr. Terry Mathis of the Aiken County Extension Service.
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Curnutt, J., Beaufort-Jasper Water Treatment Facility, Beaufort, SC, November 1, 1990.


Weil, W., Savannah Industrial and Domestic Water Supply, Port Wentworth, Georgia, October 30, 1990.

TABLE 1. Usage constants and consumption rates recommended by the NRC and specific to the SRS.

<table>
<thead>
<tr>
<th>Description</th>
<th>Units</th>
<th>NRC*</th>
<th>SRS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cattle forage consumption (wet)</td>
<td>kg d⁻¹</td>
<td>50</td>
<td>44</td>
</tr>
<tr>
<td>Fraction of time cattle on pasture</td>
<td></td>
<td>0.75</td>
<td>0.75</td>
</tr>
<tr>
<td>Fraction of milk-cow intake from pasture</td>
<td></td>
<td>1</td>
<td>0.56</td>
</tr>
<tr>
<td>Fraction of beef-cow intake from pasture</td>
<td></td>
<td>1</td>
<td>0.75</td>
</tr>
<tr>
<td>Feed-milk-man transport time</td>
<td>d</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Time from slaughter to consumption</td>
<td></td>
<td>20</td>
<td>6</td>
</tr>
<tr>
<td>Crop exposure time</td>
<td></td>
<td>60</td>
<td>70</td>
</tr>
<tr>
<td>Pasture grass productivity</td>
<td>kg m⁻²</td>
<td>0.7</td>
<td>1.8</td>
</tr>
<tr>
<td>Agricultural productivity (veg/produce)</td>
<td>kg m⁻²</td>
<td>2</td>
<td>0.7</td>
</tr>
<tr>
<td>Sport fish harvest**</td>
<td>kg y⁻¹</td>
<td></td>
<td>3.5x10⁴</td>
</tr>
<tr>
<td>Commercial fish harvest**</td>
<td>kg y⁻¹</td>
<td></td>
<td>2.7x10³</td>
</tr>
<tr>
<td>Invertebrate harvest**†</td>
<td>kg y⁻¹</td>
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<td>3.9x10⁵</td>
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<td>Maximum shoreline usage</td>
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<td>23</td>
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<tr>
<td>Population shoreline usage</td>
<td>per-h</td>
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<td>9.6x10⁵</td>
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<tr>
<td>Maximum swimming usage</td>
<td>h y⁻¹</td>
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<td>8.9</td>
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<td>Population swimming usage</td>
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<td>1.6x10⁵</td>
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<tr>
<td>Maximum boating usage</td>
<td>h y⁻¹</td>
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<td>21</td>
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<tr>
<td>Population boating usage</td>
<td>per-h</td>
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<td>1.1x10⁶</td>
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<tr>
<td>Effective population - Beaufort/Jasper</td>
<td>persons</td>
<td></td>
<td>5.0x10⁴</td>
</tr>
<tr>
<td>Effective population - Port Wentworth</td>
<td>persons</td>
<td></td>
<td>1.5x10⁴</td>
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<tr>
<td>Annual average absolute humidity††</td>
<td>g m⁻³</td>
<td>8.0</td>
<td>11.4</td>
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<tr>
<td>Bioaccumulation factor for Cs in fish††</td>
<td>L kg⁻¹</td>
<td>2000</td>
<td>3000</td>
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Average Adult Consumption Rates

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<th>Vegetables</th>
<th>kg y⁻¹</th>
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</thead>
<tbody>
<tr>
<td>Leafy</td>
<td>30</td>
<td></td>
<td>21</td>
</tr>
<tr>
<td>Other</td>
<td>190</td>
<td></td>
<td>163</td>
</tr>
<tr>
<td>Meat</td>
<td>95</td>
<td></td>
<td>43</td>
</tr>
<tr>
<td>Milk</td>
<td>110</td>
<td></td>
<td>120</td>
</tr>
<tr>
<td>Fish</td>
<td>6.9</td>
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Maximum Adult Consumption Rates

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<th>kg y⁻¹</th>
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<th></th>
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</thead>
<tbody>
<tr>
<td>Leafy</td>
<td>64</td>
<td></td>
<td>43</td>
</tr>
<tr>
<td>Other</td>
<td>520</td>
<td></td>
<td>276</td>
</tr>
<tr>
<td>Meat</td>
<td>110</td>
<td></td>
<td>81</td>
</tr>
<tr>
<td>Milk</td>
<td>310</td>
<td></td>
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<td></td>
<td>19</td>
</tr>
<tr>
<td>Seafood</td>
<td>5</td>
<td></td>
<td>8</td>
</tr>
</tbody>
</table>

* from US NRC 1980.
** only edible portions considered.
† includes crabs, clams, oysters, and shrimp.
†† determined previously.
Figure 1. Consumption rates for an NRC and an SRS average individual.
Figure 2. Consumption rates for an NRC and an SRS maximum individual.
Figure 3. Predictions of maximum individual dose from 1987 atmospheric releases.
Figure 4. Predictions of maximum individual dose from 1987 aqueous releases.
Figure 5. Predictions of 80-km population dose from 1987 atmospheric releases.
Figure 6. Predictions of 80-km population dose from 1987 aqueous releases.

*(BJ) 50,000 users of Beaufort-Jasper facility, (PW) 15,000 users of Port Wentworth facility
END

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