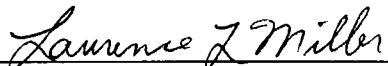
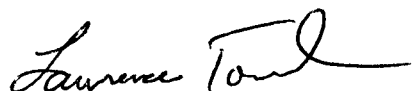


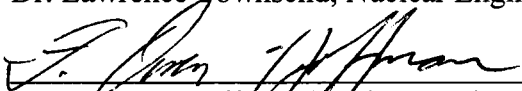
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I am submitting herewith a thesis written by Brian A. Thomas entitled "Radiation doses and health risks from radionuclides released into the Clinch River in support of the Oak Ridge dose Reconstruction Project." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Nuclear Engineering.

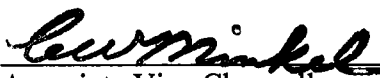

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**RADIATION DOSES AND HEALTH RISKS FROM RADIONUCLIDES
RELEASED INTO THE CLINCH RIVER IN SUPPORT OF THE OAK
RIDGE DOSE RECONSTRUCTION PROJECT**

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Brian A. Thomas

December 4, 1998

ACKNOWLEDGMENTS

The author wishes to express his sincere appreciation to his major advisor, Dr. L.F. Miller, for his advice and direction during the course of this study. Appreciation is also extended to Dr. F. O. Hoffman, President of SENES Oak Ridge, Inc., Dr. H. L. Dodds, Department Head, Nuclear Engineering, University of Tennessee, and Dr. L.W. Townsend, University of Tennessee, for their review and critique of the manuscript and for serving on the author's committee. The author would like to recognize the following individuals for their contribution to the Oak Ridge Dose Reconstruction Project and for their support of my efforts: Kathleen M. Thiessen, Jana H. Gouge, F. Owen Hoffman, A. Iulian Apostoaei, Cathy J. Lewis, B. Gordon Blaylock, Brian Caldwell, Thomas E. Widner, Susan Flack, Shyam K. Nair, and E. Willow Reed.

Sincere appreciation is expressed to my family and friends for their encouragement and support throughout this endeavor. The author would also like to thank the numerous people at SENES Oak Ridge, Inc. for supplying many useful and creative discussions and ideas.

This research was supported by subcontract with McLaren Hart Environmental Services, Inc. through their contract with the Tennessee Department of Health. Its contents are solely the responsibility of the author and do not necessarily represent official views of the Tennessee Department of Health.

ABSTRACT

The purpose of this work is to estimate off-site radiation doses and health risks (with uncertainties) associated with the release of radionuclides from the X-10 site (now called the Oak Ridge National Laboratory) on the Oak Ridge Reservation. The X-10 facility was originally designed to operate only one year as a pilot plant for the Hanford, Washington operation. The radioactive wastes generated from the plant were intended to be stored in large tanks. The original intent was changed, and in 1944 the first radioactive effluents were released to White Oak Creek and flowed into White Oak Lake. White Oak Lake acted as a final settling basin for the released contaminants. The radionuclides remaining in the water column were released over White Oak Dam, which is located one kilometer upstream from the Clinch River.

Following an initial screening analysis, the exposure pathways of interest included fish ingestion, drinking water ingestion, the ingestion of milk and meat, and external exposure from shoreline sediment. Four representative locations along the Clinch River, from the White Oak Creek Embayment to the city of Kingston, were chosen. Reference individuals were determined with respect to the pathways involved.

The doses and risks estimated in this study for individuals consuming fish exceeded dose and risk estimates for all other pathways. The category I consumer of fish (1-2.5 meals per week) at Clinch River Mile 20.5, received the highest doses. The central values of the cumulative doses for 1944 through 1991 for specific organs ranged from 0.31 cSv (skin) to

0.81 cSv (bone) for males. The excess lifetime risk of cancer incidence was estimated based on cancer incidence data from the Japanese Atomic bomb survivors and the background incidence of cancer for East Tennessee. For males, the highest risk is to the red bone marrow (central value of 3.7×10^{-5}); for females, the highest risks are for the breast and red bone marrow (central values of 5.5×10^{-5} and 2.8×10^{-5} , respectively). Although differences between the highest and lowest organ-specific doses at any one location was only a factor of 2 to 4, the difference between risks is about a factor of 70 to 80 for females and 40 for males.

For the Category I consumer of fish near Jones Island, the 95% uncertainty range of the total excess lifetime risk of cancer incidence for all radionuclides and organs was 3.6×10^{-5} to 3.5×10^{-3} (2.8×10^{-3} central value) for males and 2.9×10^{-5} to 2.8×10^{-3} (2.3×10^{-4} central value) for females. The variation in fish across genders primarily reflects the difference in ingestion rates. For both males and females, the largest contribution to the total risk was from ^{137}Cs (about 90%).

The doses and risks estimated in this study are not significant enough to cause a detectable increase in health effects in the population. In most cases, the organ doses are well below the limits of epidemiological detection (1 to 30 cSv) for radiation-induced health outcomes. Therefore, it is unlikely that exposure to radionuclides released from the X-10 site is responsible for an increased number of cancers to populations utilizing the Chinch River after 1944.

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1.0 INTRODUCTION

From 1944 to the present time the Oak Ridge National Laboratory has discharged liquid radioactive wastes into White Oak Creek, which empties into the Clinch River at mile 20.8. The radioactive wastes came from the direct operations of the graphite reactor and the chemical separation plant as well as other ORNL operations and other nuclear facilities throughout the southern region. Offsite releases of radioactive wastes continued until the mid-1960s when changes in ORNL operations and disposal techniques caused dramatic reductions.

Individual members of the public have been potentially exposed to radiation since the first releases to the river. The public has had access to the Clinch River from 1944 to the present time. The purpose of this study is to calculate the total lifetime risk of cancer incidence for individuals exposed to radioactivity released to the Clinch River from the X-10 site.

This study will use Analytica, an object-oriented modeling software package developed by Lumina Systems, Inc., as the main tool in performing an assessment which can be easily presented to the public and to peers. Doses and risks will be estimated to individuals exposed to radionuclides which were released into the Clinch River system from the Oak Ridge National Laboratory (Oak Ridge, TN) from 1944 to 1991. Uncertainties in all inputs will be considered and propagated through to the final result.

In addition, an analysis will be performed to estimate which inputs contribute the most uncertainty to the overall result.

Chapter 2 (Background) introduces the particular process for which the models in this report were designed. Although a specific problem is addressed in this work, the models themselves are designed in such a way to allow for easy modification and adaptation to many situations. Chapter 3 supplies details of the modeling approach. The fourth chapter discusses the approach for handling uncertainty in a risk assessment problem. Chapter 5 describes how the problem was handled using two different software options. Chapter 6 gives example results from the uncertainty analysis, sensitivity analysis, and model validation. The conclusions follow in Chapter 7.

2.0 BACKGROUND

2.1 Release of Radionuclides to the Clinch River (Oak Ridge, TN)

Beginning in 1944 and continuing until the present time, the Oak Ridge National Laboratory has released liquid radioactive wastes into White Oak Creek, which empties into the Clinch River. This section discusses the origins of the Oak Ridge National Laboratory, as well as the primary methods of waste disposal chosen by the laboratory.

2.1.1 Early History of the Oak Ridge National Laboratory

Construction of the Oak Ridge National Laboratory, originally the Clinton Laboratory, began on February 10, 1943. The Laboratory was intended as a pilot plant for demonstrating the production and separation of plutonium. Initially, the graphite reactor was to operate for a period of one year. All radioactive waste resulting from its operation was to be stored in a series of gunite tanks. However, the extent of work to be completed at ORNL was quickly expanded, and as a result, the planned holding tanks were not enough house the larger amounts of radioactive wastes which were produced. In early 1944, the decision was made to release low-level radioactive wastes to the environment by way of White Oak Creek. Significant off-site releases from the operation of the graphite reactor and the chemical separation plant continued through the mid-1960s, when major reductions in releases occurred due to changes in ORNL operations.

In 1943 White Oak Lake was formed by impounding White Oak Creek 0.6 miles upstream from its mouth. Radioactive waste from ORNL could be held in White Oak Lake for several days to allow time for short half-life radionuclides to decay and to permit suspended solids to settle. Until 1990, White Oak Creek flowed the final 0.6 miles unimpeded in the White Oak Creek embayment before joining the Clinch River. In 1990, a coffer cell dam was constructed at the mouth of the creek to prevent radioactive sediments that had been deposited in the embayment from eroding into the Clinch River (Blaylock et al., 1993).

2.1.2 History of Radioactive Waste Disposal at the Oak Ridge National Laboratory

Over the years, many approaches have been used to dispose of the radioactive waste created at the Oak Ridge National Laboratory. The initial method devised to handle the waste involved using storage tanks, holding ponds, and a settling basin. An evaporation technique was employed next. Pits and trenches were built and operated to house radioactive waste. A waste water treatment was built to reduce levels of radioactivity released to White Oak Creek. White Oak Lake was used as a final settling basin for radioactive liquid waste.

From 1944 to 1949, "highly" radioactive waste was placed in the underground gunite storage tanks. The fluids that did not settle were decanted and mixed with process water from ORNL. This radioactive process water went into one of two holding tanks, known

as the East and West Ponds. Water would remain in one tank to allow decay and settling to occur while the other tank was being filled. When the second tank was nearly full, the first tank was drained into White Oak Creek. Because of the inadequacy of the holding ponds, a 1,500,000 gallon settling basin was built and put into operation. The settling basin was to act as a collection, sampling, and settling pond for the gunite tank supernatants to permit radioactive solids to settle from the waste water before being discharged into White Oak Creek (Feige et al., 1960).

An important part of the disposal process was the identification of different categories of liquid waste. In 1949, liquid waste was classified into four types according to composition and radioactivity (Browder, 1949). Radioactive waste was classified as "highly" radioactive. Metal waste included plutonium-, uranium-, or thorium-bearing waste. Warm waste was moderately radioactive. Process water was theoretically non-radioactive and was derived from cooling water, laboratory sinks, and floor drains.

The precipitation and decanting procedure for treatment of "highly" radioactive waste was replaced in 1949 by an evaporation step that produced both a concentrate (stored in the gunite tanks) and a low-level condensate (released to White Oak Creek). The evaporator was eventually replaced by waste disposal pits.

Four open pits and three covered trenches were constructed in the White Oak drainage area between 1951 and 1966 for the disposal of radioactive liquid waste. The pits and

trenches disposed of radioactive waste by letting the liquid seep away while the radioactivity was retained by the surrounding soil. Approximately 1.2 million curies of high-energy beta emitters were disposed of using this method (Spalding and Boegly, 1985). At the time, this operation was considered to be a safe, simple, and economical solution to radioactive waste.

It was discovered, however, that ruthenium was not retained by the soil. Due to the short half-life of ^{106}Ru (about 1 year), the severity of these releases was not fully understood until 1959 when large quantities of ^{106}Ru were reported in ground water leaving the pits. In late 1959, an estimated 1320 curies of ^{106}Ru were released to White Oak Creek from seepage from one of the pits. At this time, the concentration of ^{106}Ru in the Clinch River began to increase, and radiation levels at the pit site became too high to send personnel into the area for sampling or other purposes.

A process water treatment plant was constructed and put into operation in 1957. This plant was designed to reduce the level of radioactive contamination in the low-activity process waste water being discharged to White Oak Creek. In 1959, an automatic diversion valve was installed which diverted the process waste water flow to the treatment plant when the level of radioactivity in the water exceeded a given level. Waste water containing low levels of radioactivity were sent directly to the settling basin and

into the river. Sludge waste from the process waste water treatment plant was taken to the pits and trenches.

2.2 Conservative Screening Analysis

The primary goal of a typical conservative screening assessments, in a risk assessment framework, is to produce estimates of risk which are not likely to underestimate the actual risk that a specified target individual would receive. The assessment endpoint (target individual), exposure assumptions, and parameter values are intentionally chosen with this purpose in mind. Risk assessments which initially include numerous contaminants, pathways, or assessment endpoints, benefit greatly from the incorporation of a screening assessment.

The particular assessment for which the models in this report were designed for was initially very complicated. Available evidence indicated that 24 radionuclides were released to the Clinch River. Evidence also suggested ten routes of potential exposure that represented opportunities for actual historical exposures of the public.

A decision criterion of 1 chance in 100,000 (10^{-5}) was used in this screening analysis. If the screening index for an individual pathway and radionuclide fell clearly below the decision criterion, further study of the contaminant for that pathway was given a low priority. If the screening index for a given radionuclide and pathway was at or above the

decision criterion, the radionuclide was evaluated in more detail for that pathway in the next phase of the assessment (Thiessen et al., 1998).

The importance of a screening assessment can be seen in this example. As a result of the screening exercise, the 24 radionuclides were reduced to only eight. In addition, the pathways of potential exposure were narrowed from ten to five. This assessment paved the way for intense efforts to be focussed on propagating uncertainties for the remaining pathways and radionuclides through the entire model process.

2.3 Locations of Interest

The demography of the lower Clinch River supplied information dealing with land use which aided in the determination of sites to focus efforts on. The locations which proved to be the most significant included Jones Island (Clinch River Mile, CRM 20.5), Grassy Creek and K-25 (CRM 14), Kingston Steam Plant (CRM 3.5), and the City of Kingston (CRM 0). These areas of interest have historically been and are still primarily agricultural and residential areas (USDOE, 1996). A map of the Oak Ridge Reservation with locations of interest is presented in Figure 2.1.

The Jones Island area is defined to include the island itself and the land adjacent to the banks of the Clinch River from CRM 21.0 to 17.0. Grassy Creek enters along the north bank of the Clinch River at CRM 14.; however, the Grassy Creek area encompasses the

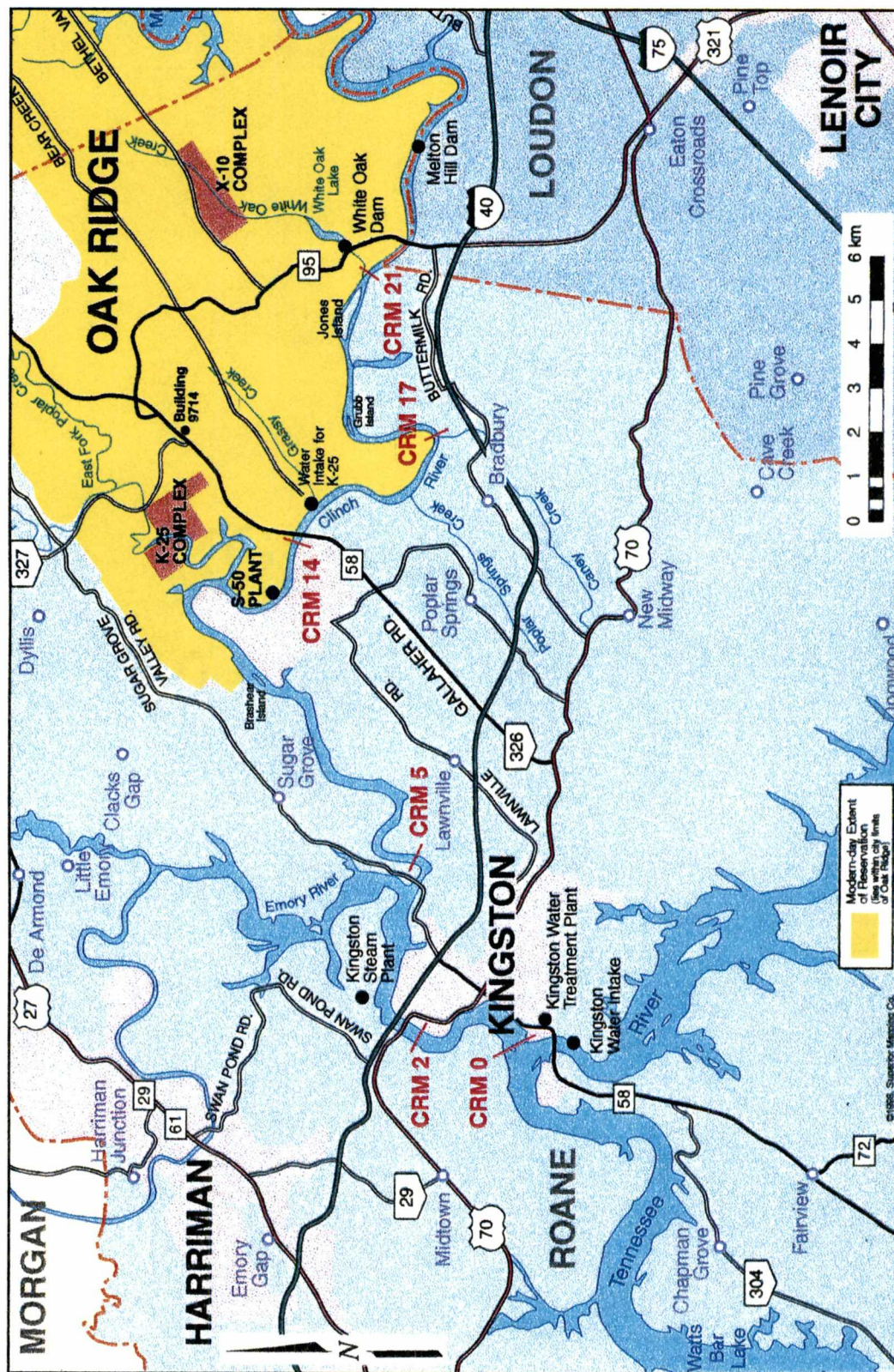


Figure 2.1 Area surrounding the Oak Ridge Reservation, with locations of interest for the dose reconstruction for radionuclides from White Oak Creek.

land adjacent to the banks from CRM 17.0 to 14.0. The K-25 area is comprised of the land adjacent to the banks of the Clinch River from CRM 14.0 to CRM 5.0. The Kingston Steam Plant is located on the north bank of the river at CRM 2.6, but the Kingston Steam Plant area includes the land from CRM 5.0 to 2.0. The final section of the Clinch River considered (CRM 2.0 to 0.0) is defined as the City of Kingston area.

2.4 Relevant Exposure Pathways

The relevant exposure pathways considered in this study were chosen through the use of demographic information, an initial conservative screening assessment, and a predetermined risk-based decision criterion. The pathways determined from the screening assessment for the Clinch River from Jones Island to the City of Kingston included the ingestion of fish, the ingestion of drinking water, the ingestion of milk and meat from cattle, external exposure from shoreline sediment, exposure from dredged sediment, and the ingestion of produce contaminated via dredged sediment. For each area of the river, demographic information was used to determine the individual pathways that actually existed.

For the Jones Island area, the exposure pathways modeled include fish ingestion, external exposure from shoreline sediment, and the ingestion of milk and meat from cows. The Grassy Creek and K-25 areas were considered to be the same for the fish, milk, and meat ingestion pathways; however, the external exposure was considered only for the Grassy

Creek area, due to the occurrence of fishing along the banks. The pathways of concern for the Kingston Steam Plant include external exposure to shoreline sediments and the ingestion of drinking water, fish, and milk and meat from cattle.

3.0 MODELING APPROACH

This section of the report describes the general methodology used in each component of the modeling process. The basic conceptual model used to estimate the risks from exposure to radiation is presented first. Section 3.2 provides an introduction to the methodology used to evaluate each component of the dose and risk estimation. The equations used to estimate intake from the various pathways of concern are given in Section 3.3. The approach for evaluating organ-specific doses and risks is given in sections 3.4 and 3.5, respectively. The method for calculating the total excess lifetime risk of cancer incidence is presented in Section 3.6.

3.1 Basic Conceptual Model

The excess lifetime risk (ELR) of cancer incidence from exposure to a radionuclide is defined as the probability that an individual exposed to a single dose D_i in a given year (i) will develop a radiation-induced cancer over their lifetime. The excess lifetime risk of cancer incidence during year " i " (ELR_i) was calculated using the following equation:

$$ELR_i = RF_i \cdot D_i \quad (3.1)$$

where,

$$RF_i = \text{Organ-specific Risk Factor, excess lifetime risk of cancer to an organ per unit dose from exposure during year "i" [Sv}^{-1}\text{].}$$

and D_i = Dose delivered to the organ from an exposure in year "i" [Sv].

If the individual was exposed for more than one year, the total excess lifetime organ-specific risk (TEL_{Rj}) of cancer was given by:

$$TEL_{R_j} = \sum_{i=1}^N RF_i \cdot D_i \quad (3.2)$$

where N is the number of years exposed.

A process-based approach was used to estimate the total excess lifetime risk (TEL_R).

The ELR from an annual exposure was calculated as a multiplicative chain of factors, each representing an independent compartment of the exposure pathway.

$$\begin{aligned} ELR = & \{ \text{source term} \} \times \{ \text{aquatic transport} \} \times \{ \text{food chain transfer} \} \\ & \times \{ \text{intake or exposure} \} \times \{ \text{dose per unit intake or exposure} \} \\ & \times \{ \text{risk per unit dose} \} \end{aligned} \quad (3.3)$$

3.2 Description of Model Components

This section presents the general methodology used in the determination of the components listed in Equation 3.3 in the previous section.

3.2.1 Source Term Estimation

The amounts of each radionuclide of interest released from the Oak Ridge National Laboratory that made their way into the Clinch River were quantified using source term estimation. The methodology involved using several uncertain correction and/or bias factors on the documented annual release estimates. The sources of uncertainty varied over time due to different sources of error resulting from changes in monitoring and analysis methods and due to various events and changes that occurred in the operations of the facilities.

3.2.2 Estimation of Radionuclide Concentration

The estimation of the actual radionuclide concentrations in the surface water and in shoreline sediments plays a vital role in the reconstruction of possible exposures. Some of the factors that must be taken into account in this process include: the radioactive half-life, the flow-rate of the river system, the effects of dilution or water volume, the form of particulate matter, the suspension of particulate matter, the resuspension of particulates, scouring events, and so on.

Estimates of Water Concentration

A modified version of an aquatic transport model called HEC-6 was used to estimate the concentration of contaminants in the water. Whenever available, measured data were used

in the place of the modeled estimates. One of the reasons that the measured data was preferred over the modeled data is that the measurements of water concentration are not affected by the uncertainty in the estimates of releases of radionuclides over White Oak Dam.

Estimates of Sediment Concentration

Shoreline sediment concentrations were also estimated using the modified HEC-6 model. This model was used to track the sediment inventory in various reaches of the Clinch River. Flood and scouring events were also included in the modeling effort. This estimation involved the use of known information about water concentration, particulate type, suspension of particulate matter, and distribution coefficient (K_d) values. Monitoring data obtained in the early 1960s were used to calibrate the model for shoreline sediment estimation. The calibration was based on sediment inventory during this time period. All estimated shoreline sediment concentrations used in the risk estimation were based on predicted results.

Estimation of Concentration in Aquatic and Terrestrial Biota

Aquatic and terrestrial biota living in and near the Clinch River were likely to accumulate radionuclides in their tissues. To estimate the concentration of contaminants present in fish as a result of radionuclides in the water, a bioconcentration factor (BCF) was used. An uncertain BCF was developed for each radionuclide of interest. These BCF values

were derived from available environmental data and from published information. To predict the transfer of radionuclides from water to cow's milk and meat, radionuclide-specific transfer coefficients were derived.

3.2.3 Estimation of Exposures to Target Individuals

The exposure pathways of concern at all locations were fish ingestion and the ingestion of cow's milk and meat; other pathways varied by location. For instance, for the Jones Island reach (CRM 21.0 to CRM 17.0), the exposure pathways considered in this study are fish ingestion, external exposure to shoreline sediments, and ingestion of milk and meat (Thiessen et al., 1998).

The target reference individual considered for this study is dependent on the pathway, the pathway's specific characteristics, and the size and type of population affected. For example, for the fish pathway, the target reference individuals were individuals who consumed varying amounts of fish (avid, typical, or casual rates). The milk ingestion pathway also had multiple target individuals: children, who could have consumed different fractions of milk depending on whether they were at school or at home, and adults. The meat ingestion and external exposure pathways considered the adult as the target individual. The water ingestion pathway took into account both a child and an adult reference individual.

Several special scenarios were considered for this study. These scenarios included an individual who could have consumed fish patties made up of whole fish (bones and fillets), a fisherman who may have caught and eaten a fish that migrated out of White Oak Lake, an individual consuming a contaminated deer, waterfowl, or turtle that migrated off the reservation.

3.3 Equations used to Estimate Intake

This section of the report describes an analysis of exposures to radionuclides released from X-10 facility through ingestion of fish, ingestion of water, ingestion of milk, ingestion of meat, and external exposure to shoreline sediments. The generic equations used to estimate the intake or exposure for each of these pathways are listed below.

Ingestion of Fish:

$$Intake = (C_{water} \cdot BCF) \cdot N_{fish} \cdot P_{fish} \cdot F_{cf} \cdot EF \cdot ED \cdot F_{R,fish} \quad (3.4)$$

where

<i>Intake</i>	=	Amount of radioactivity ingested (Bq)
<i>C_{water}</i>	=	Concentration in surface water (Bq L ⁻¹)
<i>BCF</i>	=	Bioconcentration factor (L kg ⁻¹)
<i>N_{fish}</i>	=	Number of meals (fish meals d ⁻¹)
<i>P_{fish}</i>	=	Size of portions (kg fish meal ⁻¹)
<i>F_{cf}</i>	=	Fraction of fish consumed that is contaminated (unitless)
<i>EF</i>	=	Exposure frequency (d y ⁻¹)

- ED = Exposure duration (y)
- $F_{R, fish}$ = Fraction of radionuclide remaining in fish after food processing (unitless).

Ingestion of Water (Drinking Water Pathway):

$$Intake = C_{water} \cdot U_{water} \cdot F_{cw} \cdot F_{filt} \cdot EF \cdot ED \cdot B_{RK} \quad (3.5)$$

where,

- $Intake$ = Amount of radioactivity ingested (Bq)
- C_{water} = Concentration of radionuclide in surface water (Bq L⁻¹)
- U_{water} = Average daily consumption of drinking water (L d⁻¹)
- F_{cw} = Fraction of water consumed that is contaminated (unitless)
- F_{filt} = Fraction of radioactivity in water remaining after filtering (unitless)
- EF = Exposure frequency (d y⁻¹)
- ED = Exposure duration (y)
- B_{RK} = Fraction of Clinch River water backflowing up the Tennessee River (unitless) [used only for CRM 0 at Kingston].

Ingestion of Milk:

$$Intake = C_{milk} \cdot U_{milk} \cdot F_{cm} \cdot EF \cdot ED \cdot e^{-(\lambda_R \cdot t_{delay})} \quad (3.6)$$

where

- $Intake$ = Amount of radioactivity ingested (Bq)
- C_{milk} = Concentration in milk at the time of milking (Bq L⁻¹)
- U_{milk} = Milk ingestion rate by humans (L d⁻¹)

- F_{cm} = Fraction of contaminated milk ingested by humans (unitless)
 EF = Exposure frequency (d y⁻¹)
 ED = Exposure duration (y)
 λ_R = Radioactive decay (d⁻¹)
 t_{delay} = time between milking and consumption (d)

and

$$C_{milk} = C_{water} \cdot WM \quad (3.7)$$

where

- C_{milk} = Concentration in milk (Bq L⁻¹)
 C_{water} = Concentration of contaminant in water (Bq L⁻¹)
 WM = Water to milk transfer factor (unitless)

$$WM = F_m \cdot Q_m \cdot P_m \quad (3.8)$$

where

- F_m = Transfer coefficient to milk (d L⁻¹)
 Q_m = Amount of water consumed by a dairy cow (L d⁻¹)
 P_m = Fraction of water consumed by a dairy cow that is contaminated (unitless)

Ingestion of Meat:

$$Intake = C_{meat} \cdot U_{meat} \cdot F_{cb} \cdot EF \cdot ED \cdot F_{r,meat} \quad (3.9)$$

where

- $Intake$ = Amount of radioactivity ingested (Bq)

- C_{meat} = Concentration of contaminant in meat at time of slaughter (Bq kg^{-1})
 U_{meat} = Ingestion of meat by humans (kg d^{-1})
 F_{cb} = Fraction of contaminated meat ingested by humans (unitless)
 EF = Exposure frequency (d y^{-1})
 ED = Exposure duration (y)
 $F_{r,meat}$ = Fraction of radionuclide remaining in meat after food preparation (unitless)

and

$$C_{meat} = C_{water} \cdot WF \quad (3.10)$$

where

- C_{meat} = Concentration in meat (Bq kg^{-1})
 C_{water} = Concentration of contaminant in water (Bq L^{-1})
 WF = Water to meat transfer factor (L kg^{-1})

and

$$WM = F_f \cdot Q_f \cdot P_f \quad (3.11)$$

where

- Q_f = Ingestion of water by beef cattle (L d^{-1})
 F_f = Transfer coefficient to meat (d kg^{-1})
 P_f = Fraction of water consumed by beef cattle that is contaminated (unitless)

External Exposure to Shoreline Sediments:

$$Exposure = C_{sed} \cdot EF_{ext} \cdot ED \quad (3.12)$$

where

$Exposure$ = Radiation absorbed from external exposure (Bq kg⁻¹ y)

C_{sed} = Concentration of contaminant in sediment (Bq kg⁻¹)

EF_{ext} = Exposure frequency (unitless)

ED = Exposure duration (y)

and

$$EF_{ext} = (ET_{ss} \cdot F_{t(up)}) + (ET_{fw} \cdot F_{t(down)}) \quad (3.13)$$

where

$F_{t(up)}$ = Fraction of time (days per every 365 days) using the shoreline when the water level is up (unitless)

ET_{ss} = Fraction of time (hours per every 24 hours) in a single trip for the summer and spring months (unitless)

$F_{t(down)}$ = Fraction of time (days per every 365 days) using the shoreline when the water level is down (unitless)

ET_{fw} = Fraction of time (hours per every 24 hours) in a single trip for the fall and winter months (unitless)

After the intake or exposure is obtained for a given pathway, the dose is determined by the following equation:

$$D = (Intake \text{ or } Exposure) \cdot DF \quad (3.14)$$

where

D = Dose delivered to an organ from an exposure (Sv)

$Intake$ = Amount of radioactivity ingested (Bq)

or *Exposure* = Radiation absorbed from external exposure (Bq m^{-2})

DF = Organ-specific dose factor per unit intake (energy deposited
divided by organ mass) (Sv Bq^{-1} for internal exposure or for
external, a dose rate factor with units of $\text{Sv y}^{-1} \text{Bq}^{-1} \text{kg}$).

3.4 **Organ-specific Doses**

It was determined that five radionuclides which were released into the Clinch River may have affected individuals consuming fish, drinking water, milk, or meat. They are: ^{137}Cs , ^{90}Sr , ^{60}Co , ^{106}Ru , and ^{131}I . The internal dosimetry methodology of the International Commission of Radiological Protection (ICRP) was employed to estimate doses to individuals consuming contaminated food items or drinking water. Ingestion dose factors (the committed dose from the ingestion of a unit of radioactivity - Sv Bq^{-1}), along with their uncertainties, were determined for various organs in the body, for each radionuclide, and for different target individuals (Thiessen et al., 1998). This allows for the estimation of the dose received by all primary organ sites as well as the remainder.

3.5 **Organ-specific Dose-response**

The excess lifetime risk (ELR) of cancer incidence was estimated for a unit radiation dose received by individuals who may have been exposed to radionuclides released to the Clinch River as a result of operations at the Oak Ridge National Laboratory. The ELR is defined as the risk of acquiring a radiation-induced cancer over a lifetime, in excess of the

background risk (expected risk in an unexposed population). The ELR per unit dose is also referred to as a risk factor.

The risk factor for cancer occurring as a result of irradiation of a given organ was estimated based on epidemiological investigations of the atomic bomb survivors from Hiroshima and Nagasaki. The dose-response relationship from this study, and from other epidemiological studies, can be expressed on either a relative or an absolute risk basis (ICRP, 1991; NRC, 1990).

The relative model is based on the assumption that, after a minimum latency period from the moment of first exposure, the risk of radiation-induced cancer will follow the same pattern as the background rate of cancer incidence. This model is preferred by the International Commission on Radiological Protection (ICRP, 1991) and the National Research Council Committee on Biological Effects of Ionizing Radiation (BEIR V; NRC, 1990).

The alternate approach is referred to as the absolute or additive risk projection model. It assumes that, after a given latency period, the excess risk of cancer will be independent of the background rate of cancer incidence. The relative and absolute models should give similar results when applied to the populations for which they were derived (NRC, 1990; Thompson et al., 1994). Differences between the two approaches are observed when risks are estimated for populations that have different background cancer incidence rates.

3.6 Total Excess Lifetime Risk of Cancer Incidence

The estimation of the total cancer incidence that would occur from the intake of multiple radionuclides can be very complex or even impossible due to the lack of complete information required to determine risk coefficients for every organ. One approach is to use a risk coefficient for the excess incidence of all solid tumors as the result of a uniform external dose to the whole body (which is available) and a weighted whole body internal dose to obtain the total risk of cancer incidence resulting from irradiation of all internal organs from radionuclides that are taken into the body with water or food. The dose is determined by summing the internal doses to individual organs weighted according to their relative importance to the total number of cancers. The methodology for the derivation of the weight given to each organ is discussed below.

The relationship between a given dose and the probability of that dose causing stochastic (random) effects is found to be dependent upon the tissue or organ irradiated (ICRP, 1991). Therefore, it is important to define a quantity which indicates the combination of different doses to several different tissues in a way which correlates well with the total of the stochastic effects. This factor is referred to as the **tissue weighting coefficient**, k_T . It is the factor by which the dose in tissue T is weighted and represents that organ's contribution to the total response to these effects resulting from a uniform irradiation of

the whole body. The total response is referred to as the **weighted dose**, D_w , with units of sieverts.

$$D_w = \sum_T k_T D_T \quad (3.15)$$

where,

D_w = weighted dose equivalent (Sv),

k_T = relative contribution of tissue T to the weighted dose, and

D_T = absorbed dose equivalent for tissue T (Sv).

It is important to note that the terminology used in this report was intentionally chosen to be different from the terminology used by the International Commission on Radiological Protection (ICRP). For example, tissue weighting factors, w_T , are given in the 1990 Recommendations of the ICRP (ICRP, 1991). These weighting factors are based on cancer mortality data. The methodology in this report has been developed to estimate a different set of tissue weighting coefficients that may be used when dealing with cancer incidence (k_T).

The total number of cancers in a population will be equal to the summation of individual cases of cancer found in each tissue/organ:

$$\sum_T N_T = N_{POP} \quad (3.16)$$

where,

N_T = number of solid tumors for tissue T in a given population, and

N_{POP} = total number of solid tumors in the same population.

By assuming a linear dose-response relationship (Thompson et al., 1994), the number of solid tumors originating in tissue T can be calculated as:

$$N_T = D_T \times ERR_{T(1sv)} \times B_T \times P \quad (3.17)$$

where,

$ERR_{T(1sv)}$ = excess relative risk per unit dose for tissue T,

B_T = background rate of cancer for tissue T, and

P = number of people in population.

Likewise, the total solid tumors (all types) can be calculated as:

$$N_{POP} = D_{eff} \times ERR_{1sv} \times B \times P \quad (3.18)$$

where,

ERR_{1sv} = excess relative risk per unit dose for all solid tumors,

B = background rate of cancer for all solid tumors, and

P = number of people in population.

The background rate of cancer incidence for tissue T (B_T) is defined as the number of new cancers in that tissue in the unexposed population over a given period of time divided by the number of people in the unexposed population. The background rate of cancer incidence for all solid tumors (B) is defined as the total number of new solid tumors in the unexposed population over a given period of time divided by the number of people in the unexposed population.

By applying Equations 3.17 and 3.18 to Equation 3.16, we get:

$$\sum_T (D_T \times ERR_{T(1sv)} \times B_T \times P) = D_w \times ERR_{1sv} \times B \times P \quad (3.19)$$

Solving for the effective dose, yields:

$$D_w = \sum_T \left(\frac{ERR_{T(1sv)} \times B_T}{ERR_{1sv} \times B} \right) \times D_T \quad (3.20)$$

By relating Equation (3.15) to Equation (3.20), we derive a definition for the tissue weighting factor:

$$k_T = \frac{ERR_{T(1sv)} \times B_T}{ERR_{1sv} \times B} \quad (3.21)$$

Thompson et al. (1994) has analyzed the follow-up data for the Japanese Atomic Bomb Survivor Study (the most complete information set dealing with the relationship between the dose and risk of cancer incidence). This published report estimates the excess relative risk per sievert for solid tumors for each of several tissue systems ($ERR_{T(1sv)}$). The excess relative risk per sievert for total solid tumors (ERR_{1sv}) is also estimated. Equation 3.21 uses the ratio of B_T to B , which is numerically equal to the ratio of the number of cancers originating in tissue T in the unexposed population (N_T) to the total number of solid tumors in the unexposed population (N). These numbers given in Table 3.1.

In this report, the remainder tissue category is defined as a sum of all tissues/organs that are not explicitly addressed. The tissue weighting coefficient for the remainder category is calculated as one minus the sum of the other tissue coefficients.

3.6.1 *Estimation of Total Risk*

The excess lifetime risk of cancer incidence from all solid tumors (ELR_{ST}) is estimated as follows:

$$ELR_{ST} = D_w \times ERR_{ST(1sv)} \times B \times 70 \quad (3.22)$$

where,

D_w = weighted dose equivalent for all solid tumors,

Table 3.1. Number of cases of reported cancers occurring in two unexposed populations.

Tissue or organ system	Japanese population ¹ (1958-87)	Tennessee population ² (1992)
Oral cavity and pharynx	68	515
Esophagus	101	193
Stomach	1353	368
Colon	234	1769
Rectum	172	693
Liver	302	103
Gallbladder	152	—
Pancreas	118	464
Nasal cavity	21	—
Larynx	43	—
Lung	423	3580
Skin (non-melanoma)	77	—
Female breast	240	2985
Uterus	375	852
Ovary	67	402
Prostate	79	3078
Bladder	95	799
Kidney	39	—
Renal pelvis and ureter	14	—
Nervous system	56	302
Thyroid	96	178
Remainder ³	161	2601
Total solid tumors	4286	18882

¹ Data from Thompson et al., 1994. Unexposed population consists of 39,213 people.

² Data from Tennessee Cancer Reporting System (TCRS), 1992. Population in 1992 was approximately 5,000,000 people.

³ The remainder tissue category is defined as a sum of all tissues/organs that are not explicitly addressed.

$ERR_{ST(1sv)}$ = excess relative risk per unit dose for all solid tumors, and

B = background rate of cancer incidence for all solid tumors.

The excess lifetime risk of cancer incidence from leukemia (ELR_L) is estimated as follows:

$$ELR_L = D_{RBM} \times ERR_{L(1sv)} \times B_L \times 70 \quad (3.23)$$

where,

D_{RBM} = dose to red bone marrow,

$ERR_{L(1sv)}$ = excess relative risk per unit dose for leukemia, and

B_L = background rate of cancer incidence for leukemia.

The total excess lifetime risk of cancer incidence (TEL_R) is estimated as follows:

$$TEL_R = ELR_{ST} + ELR_L \quad (3.24)$$

3.6.2 *Application for a US Population*

Tissue weighting coefficients have been calculated for a combination of both genders. However, these weighting coefficients are applicable only to the Japanese population. In order to obtain weighting coefficients which could be applied to another population (State of Tennessee), background incidence rates for that that population are needed. The ratio of cancer incidence in Tennessee to cancer incidence in Japan makes several interesting

points. Stomach cancer is much more prevalent in Japan (32% of all solid tumors) than in Tennessee (2% of all solid tumors). In contrast, lung, breast, and prostate cancers make up 51% of solid tumors in the state of Tennessee; the same three cancers represent only 18% of solid tumors in Japan. Therefore, it is clear that the tissue weighting coefficients derived for the Japanese population could not be applied to doses estimated for people living in Tennessee.

To obtain weighting coefficients applicable to a Tennessee population, the weighting coefficients for the Japanese population were multiplied by the ratios of background cancer incidence (TN vs. Japan).

$$k_{w(TN)} = k_{w(Japan)} \times \left(\frac{(B_T / B)_{TN}}{(B_T / B)_{Japan}} \right) \quad (3.25)$$

The weighting coefficients for the Tennessee population were then normalized so that their sum will be equal to 1.

The weighting coefficients calculated for both the Japan and Tennessee populations are given in Table 3.2. Although not completely comparable, the weighting factors suggested by ICRP 60 are given in Table 3.2 as a reference. However, it should be noted that the ICRP values are based on cancer mortality data while the values calculated in this report are based on cancer incidence data.

Table 3.2. Tissue weighting coefficients (k_T) for combined genders based on data from Thompson et al. (1994) for cancer incidence compared with the tissue weighting factors (w_T) defined by ICRP (1990) for the derivation of the effective dose.

Cancer site	Japan (k_T)	Tennessee (k_T)	ICRP-60 ¹ (w_T)
Oral cavity and pharynx	0.007	0.010	--
Esophagus	0.010	0.003	0.05
Stomach	0.160	0.008	0.12
Colon	0.062	0.082	0.12
Rectum	0.013	0.009	--
Liver	0.055	0.003	0.05
Gallbladder	0.007	--	--
Pancreas	0.008	0.005	--
Lung	0.149	0.220	0.12
Skin (Non-Melanoma)	0.029	--	0.01 ²
Female breast	0.141	0.306	0.05
Uterus ³	--	--	--
Ovary	0.025	0.026	0.2 ⁴
Prostate	0.008	0.058	--
Bladder	0.035	0.052	0.05
Nervous system	0.005	0.005	--
Thyroid	0.043	0.014	0.05
Remainder	0.242 ⁵	0.199 ⁵	0.05 ⁶

¹ Tissue weighting factors from ICRP-60 based on cases of weighted detriment for defining the "effective dose".

² Since ICRP-60 tissue weighting factors are based on cancer mortality, 'skin' is probably based on cases of melanoma.

³ Evidence suggests that the uterus has a negative dose response function.

⁴ Value given in ICRP-60 for gonads.

⁵ In this report, the remainder tissue category is defined as a sum of all tissues/organs that are not explicitly addressed.

⁶ ICRP-60 considers the remainder to be composed of the following tissues and organs: adrenals, brain, upper large intestine, small intestine, kidney, muscle, pancreas, spleen, thymus, and uterus.

One discrepancy between the calculated factors in this report (k_T) and the values reported in ICRP 60 (w_T) is the additional weight given in ICRP to genetic effects from irradiation of the gonads. ICRP 60 not only considers cancer mortality for the gonads, but also genetic effects produced by the irradiation of the gonads.

It should be noted that the weighting factors given in ICRP 60 are composed of four components: the probability of attributable fatal cancer, the weighted probability of attributable non-fatal cancer, the weighted probability of severe hereditary effects, and weighting for the relative length of life lost. In addition, the background rate of cancer mortality used by ICRP is an arithmetic average of incidence of cancer mortality from six individual populations from around the world. In contrast, the weighting coefficients developed in this report for the incidence of cancer morbidity are directly applicable to a Tennessee population.

The estimation of the total cancer incidence that would occur from the intake of multiple radionuclides can be estimated using a risk coefficient for the excess incidence of all solid tumors and a weighted whole body internal dose. A methodology is derived in this report to calculate tissue weighting coefficients which can be used to sum the doses to individual organs weighted according to their relative importance to the total number of cancers that would occur when the whole body is uniformly irradiated. Tissue weighting coefficients directly applicable to a Tennessee population are presented. Through the use of this

method and the availability of background cancer incidence rates specific for a given location, tissue weighting coefficients can be calculated for any population.

4.0 UNCERTAINTY ANALYSIS

An uncertainty analysis provides a quantitative estimate of the range of model outputs that results from uncertainties in the inputs to the model or the model structure. A properly executed uncertainty analysis will result in a range of values in which it will be highly probable that the true value that the model is trying to predict is included in the range. For these reasons, uncertainty analysis is an important and integral part of simulation modeling.

4.1 Goals of Uncertainty Analysis

There are many objectives when performing a quantitative uncertainty analysis. One goal of uncertainty analysis is to quantify the range of possible model outcomes. This range will aid in the avoidance of non-realistic estimates (either pessimistic or optimistic). An uncertainty analysis gives insight into the behavior and complexity of the model as well as information about the region in which the model is applicable. Computer models can be compared on a quantitative basis using uncertainty analysis. Finally, an uncertainty analysis can be used to determine which model inputs contribute most to the uncertainty in the model outcome, allowing future research to be directed toward decreasing the uncertainty in the model outcome which will aid in the creation of models to simulate the real world.

4.2 General Methodology for Uncertainty Analysis

Because of the various situations in which uncertainty analysis can be used, a detailed approach applicable to each and every situation is difficult to describe. Nevertheless, several important steps will be discussed as a guideline to quantifying uncertainty.

4.2.1 Determination of Assessment Endpoint

Defining the assessment endpoint is perhaps the most important step in an uncertainty analysis. This effort will lay the groundwork for the determination of uncertainty. Questions like "why is an uncertainty analysis being performed?", "what is the goal of the analysis?", or "how can the given information be best represented?" must be answered. For example, the ranges of the input quantities need to be defined, as do the techniques to be used. Due to the variety of possible applications of uncertainty analysis, the answers to these questions, and therefore the formulation of the problem, will differ from model to model.

4.2.2 Identification of All Sources of Uncertainty

For every model, several sources of uncertainty can be identified. First, uncertainties in the model structure are caused by attempting to simulate the "real world" with mathematical equations. In addition, the coefficients used to characterize the model behavior are not known exactly. This can be due to their natural variability or because the

parameter cannot be directly measured. Dependencies and correlations between model inputs will also lead to parameter uncertainty.

4.2.3 Quantification of Uncertainty

After identifying the possible uncertain sources, whose uncertainty will be propagated, the uncertainty must be quantified. This uncertainty is assumed to be treated as parameter uncertainty. This can be accomplished by assigning subjective probability distributions to each parameter. The range of values for each input needs to be specified. Next, the degree of belief or frequency needs to be specified for these values. This can be done through the use of data or by expert judgement. If adequate data are not available, experts familiar with the given parameter can be asked to state the possible range of values and their degree of belief in these values.

4.2.4 Propagation of Uncertainty

There are two main methods of propagating uncertainty through models: analytical methods and numerical methods (IAEA, 1989). The complexity of the situation will help determine which method to use. For relatively simple equations, statistical error may be propagated using algebraic equations. These analytical methods can be applied to rapidly provide the needed information without the use of a computer. Two of the most common

methods used in the analytical approach are variance propagation and moment matching (IAEA, 1989).

If the situation requires more than a simple model, as in the case at hand, numerical methods must be used. One such method involving random selection based on the specified subjective confidence interval is known as Monte Carlo simulation (Figure 4.1) (Hoffman and Gardner, 1983; IAEA, 1989). The methods of random selection most commonly used for parameter uncertainty analysis are simple random sampling (SRS) and Latin hypercube sampling (LHS) (IAEA, 1989).

Simple random sampling is conceptually straightforward. Basically, a random number is obtained from each distribution specified for an uncertain parameter, and is used to calculate an estimate of the desired endpoint. This process is repeated for a given number of iterations. The result is a subjective probability distribution representing the model endpoint. However, when the sample size is less than a few thousand, SRS tends to be less efficient than its counterpart, LHS.

In LHS, the input distribution representing each parameter is divided into sections of equal probability (Figure 4.2). Unlike for SRS, where it is entirely a matter of chance how evenly the selected values cover the range of a given parameter, LHS places restrictions upon possible unevenness. Only one number is selected from each section, and then that

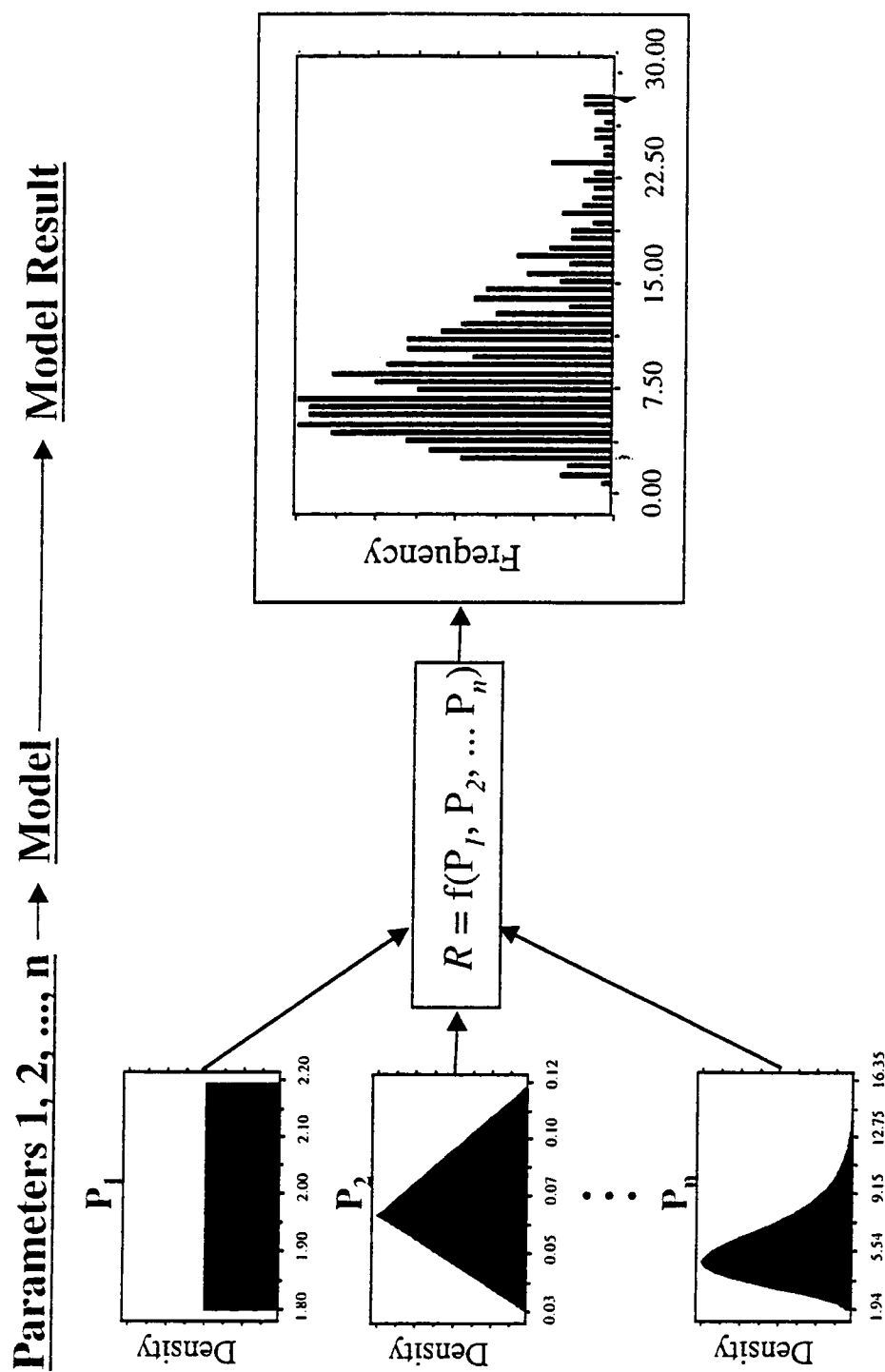


Figure 4.1 Probability density function resulting from a Monte Carlo simulation.

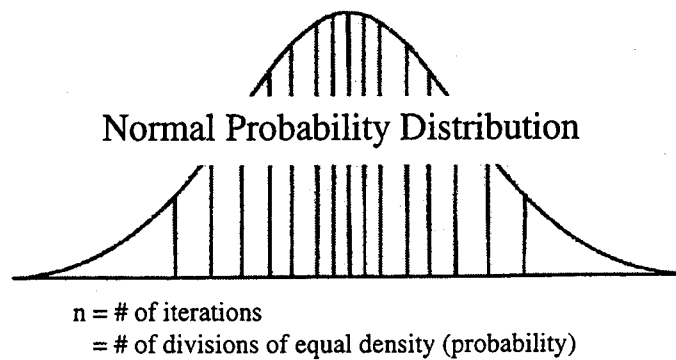


Figure 4.2 Schematic displaying the methodology used in Latin Hypercube Sampling.

section is excluded from the rest of the analysis. Estimates derived from a LHS sample are therefore expected to exhibit less variation from sample to sample and therefore to be more efficient than those derived from a simple random sample of equal size (IAEA, 1989). The models designed in this work utilize Monte Carlo simulation for error propagation and employ LHS as the method of random sampling.

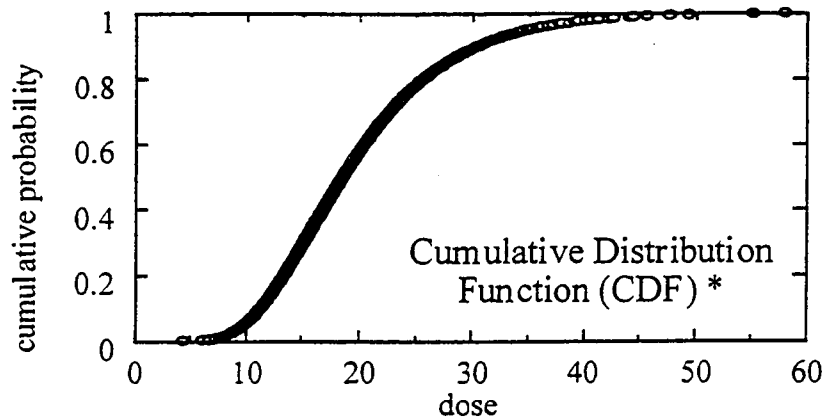
4.2.5 *Interpretation of Results*

There are several ways to present the results of a Monte Carlo analysis. Figure 4.1 shows a probability density function resulting from a Monte Carlo simulation of several uncertain input parameters. Other methods of representing the output of a Monte Carlo simulation include cumulative distribution functions, complementary cumulative distribution functions, and probability plots. These alternative ways of representing the

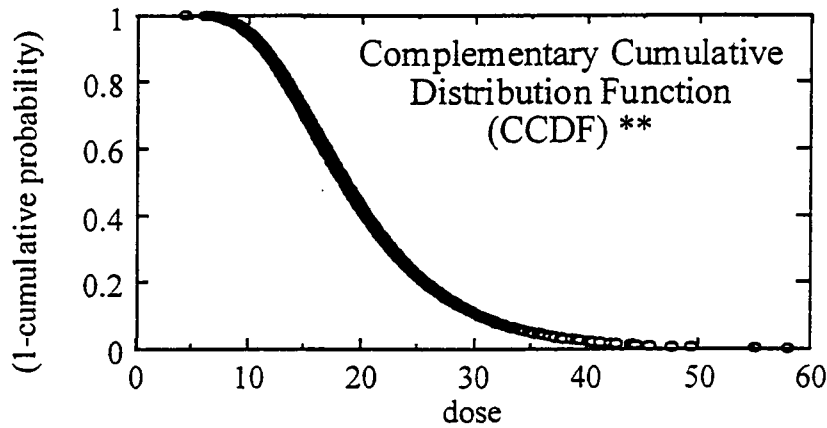
results of a Monte Carlo analysis are shown in Figure 4.3. The mode in a density function is clearly shown as a peak in the curve. It is easier to judge symmetry or skewness, and other features, on the density function. In general, the density function is a much more sensitive indicator of variations in probability density. Each approach has its advantages and there is no reason why only one approach should be used. Looking at all approaches together can help educate the public about the meaning of probability distributions.

4.3 Sensitivity Analysis

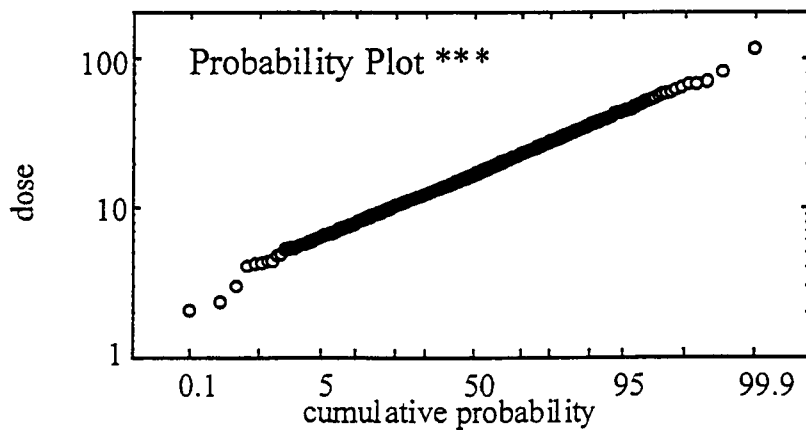
One application of uncertainty analysis is the ability to rank each of the model input parameters according to their contribution to the overall uncertainty in the model prediction. This ranking can aid in efficiently allocating further research efforts in order to reduce the overall uncertainty. Uncertainty analyses of environmental models often show that a few parameters contribute the majority of the variance to the model output. The most common method of ranking uncertain parameters using numerical propagation techniques (the method used in this example) involves the application of correlation and regression methods to the input parameter values and their corresponding model output (IAEA, 1989).



* the probability that any value in the distribution is equal to or less than a given value of dose



** the probability that any value in the distribution is greater than a given value of dose



*** a probability plot permits close examination of values in the tails of the distribution

Figure 4.3 Alternative ways of representing the results of a Monte Carlo analysis.

5.0 IMPLEMENTATION

The need for results from simple problems can often be satisfied using a spreadsheet format. As the problem becomes more complex, spreadsheet modeling can very quickly become cumbersome, making it difficult to assure quality. Programming languages, such as FORTRAN and C++, are excellent alternatives for solving complex tasks. Through the use of Visual Basic or Visual C++, models can be designed in a way to allow understanding. Modeling software packages are also available which combine the calculational power of programming languages and the demonstrational power of visual applications to permit problem solving in an object-oriented fashion.

This study will use Analytica, an object-oriented modeling software package developed by Lumina Systems, Inc., as the main tool in performing an assessment which can be easily presented to the public and to peers. Doses and risks will be estimated to individuals exposed to radionuclides which were released into the Clinch River system from the Oak Ridge National Laboratory (Oak Ridge, TN) from 1944 to 1991. Uncertainties in all inputs will be considered and propagated through to the final result. In addition, an analysis will be performed to determine which inputs contribute the most uncertainty to the overall result.

5.1 Programming Options

All calculations were programmed in the visual programming tool, Analytica, as well as in spreadsheet format, using Microsoft's Excel and the Crystal Ball forecasting add-in to Excel. Advantages and difficulties for each approach are discussed in this section. The model designed to estimate doses and risks to individuals who consumed fish from the Clinch River will be presented in detail for both approaches.

5.1.1 *Analytica*

Analytica is a visual software tool for creating, analyzing, and communicating quantitative models. Analytica provides an alternative to the spreadsheet, providing graphical influence diagrams to show qualitative structure of models, hierarchical models to organize complicated models into manageable modules, and intelligent arrays with the power to scale simple models up to handle large problems. Analytica is available for Windows 95/98/NT 4.0 and the Macintosh OS.

Analytica has the capability of handling multi-dimensional arrays of data, as opposed to the two-dimensional restriction in spreadsheets. What this means is that an equation need only be keyed in once. The operation will be performed for every entry in a given dimension of the array. This simplification of effort allows for a straight forward method for checking the equations used in the model.

A screen-shot of the initial start-up screen for the fish ingestion pathway is presented in Figure 5.1. The model allows the user to select the gender of interest (male, female, or both), the Clinch River Mile (CRM) location (CRM 20.5, 14, 3.5, and 0), and the consumption category (cat. I, II, or III; discussed in Section 3.2.3). Various results are readily accessible from this screen as well. Simply click on the "Calc" button to estimate radionuclide concentrations in water or fish, the organ-specific doses, or the total risk. In addition, the "Personal Risk Calculation" allows for the custom input of fish consumption habits and allows the user to specify the exact years they were exposed. The total personal risk is estimated from these inputs.

By double-clicking the "Fish Ingestion Model" button (module), the actual model can be viewed (Fig. 5.2). Each of the five modules is representative of a component needed for the calculation. For example, all calculations leading up to the estimation of the Bq intake from fish are located in the "Intake (fish)" module. Each of the modules, and their contents, will be discussed in this section.

The intake of radionuclides from the consumption of fish is estimated using Equation 3.4. This process is modeled in Analytica as seen in Figure 5.3. The actual formula is contained in The "Intake" module. The arrows connecting the individual components show which modules are dependant upon others. It can also be noted that the modules are of varying shapes.

Select Receptor

Male ▼

Select CRM Location

20.5 ▼

Select Consumption Category

All ▼



Fish Ingestion Model

Radionuclide Concentration in Water (Bq/L)

Calc mid

Radionuclide Concentration in Fish (Bq/kg)

Calc

Total Organ Dose (cSv)

Calc

Total Risk

Calc

Personal Risk Calculation

Fish meals per week (Meals/wk)

Edit Table

Risk per Selected Years

Edit Table

Total Personal Risk

Calc

Figure 5.1 Screen-shot of the initial start-up screen for the fish ingestion pathway.

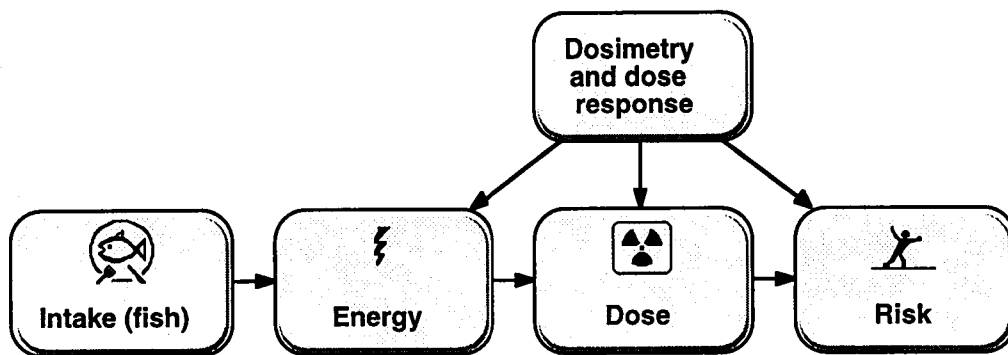


Figure 5.2 Schematic of the basic model structure.

The rectangle with the bold outline ("Radionuclide Concentration in Fish") indicates that there is another layer of calculations contained within. The "Fish meals per week" node represents a table containing various consumption rates. The ovals ("Portion size", "Fraction of fish contaminated", and "Food processing") symbolize uncertain inputs represented by distributions. The polygon shapes ("Exposure Frequency" and "Exposure Duration") signify fixed quantities.

By double-clicking on the "Radionuclide Concentration in Fish" module in Figure 5.3, the schematic shown in Figure 5.4 is revealed. This step basically multiplies the radionuclide concentration in water by bioconcentration factors to obtain radionuclide concentrations in fish. An adjustment factor is applied at the CRM 20.5 location to account for the fact that the river was not completely mixed yet, and that fish could swim in and out of the plume.

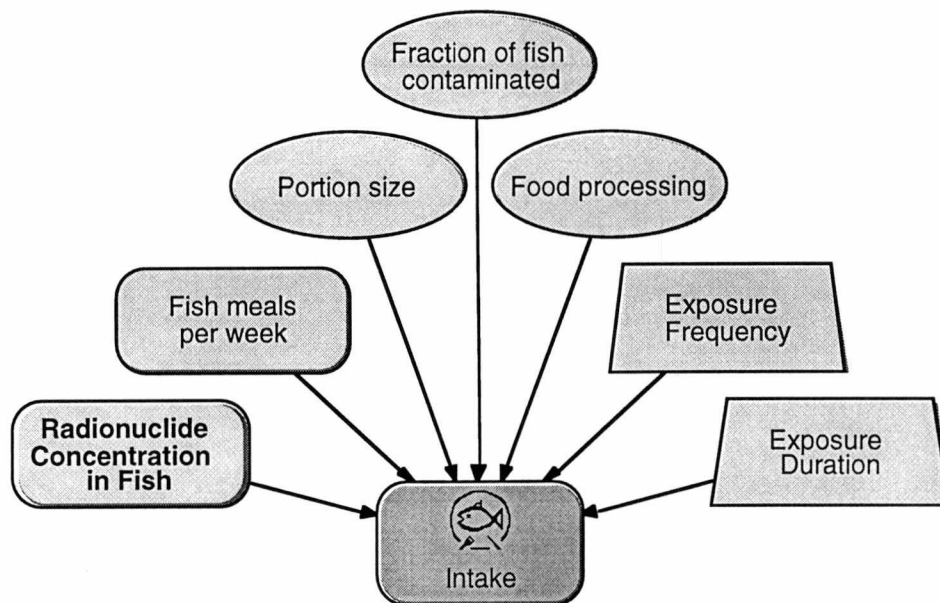


Figure 5.3 Diagram of the components needed to estimate radionuclide intake from fish consumption.

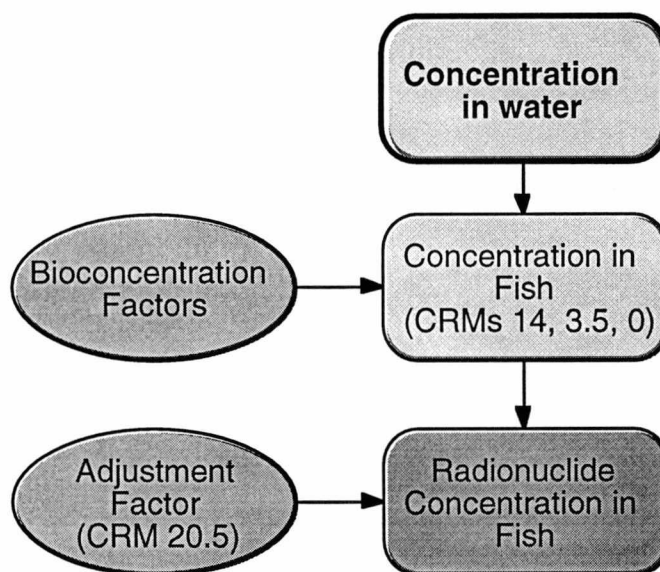


Figure 5.4 Diagram showing the estimation of radionuclide concentration in fish from the radionuclide concentration in water

Selecting the "Concentration in water" module gives the diagram in Figure 5.5. The "Water Concentration" node consists of an IF statement. If there are observed concentrations available through sampling techniques, they were used in the calculation. Otherwise, the modeled water concentrations were used. Figures 5.6 and 5.7 show how the predicted and observed water concentrations are composed, respectively. The steps performed in the nodes shown in Figure 5.6 include assigning a lognormal distribution to the outputs from the aquatic model (HEC-6R) and applying an additional uncertainty factor. Uncertain bias correction factors are applied to the original data (seen in Figure 5.7) to obtain the measured (observed) data to be used in the calculation.

Figure 5.8 shows the contents of the "Energy" module shown in Figure 5.2. Likewise, the details of the dose estimation are shown in Figure 5.9. Figure 5.10 is a visual representation of how the total risk calculation for the consumption of fish was performed.

Finally, the "Dosimetry and dose response" node of Figure 5.2 is made-up of the components shown in Figure 5.11. Included are the distributions of energy per unit intake for each radionuclide and organ, individual organ masses, and the risk factor.

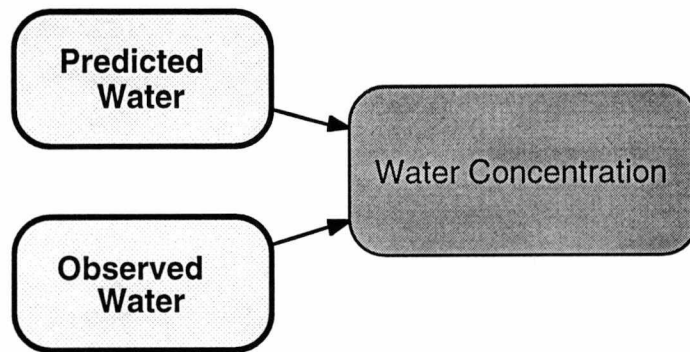


Figure 5.5 Representation of the water concentration used in the calculation.

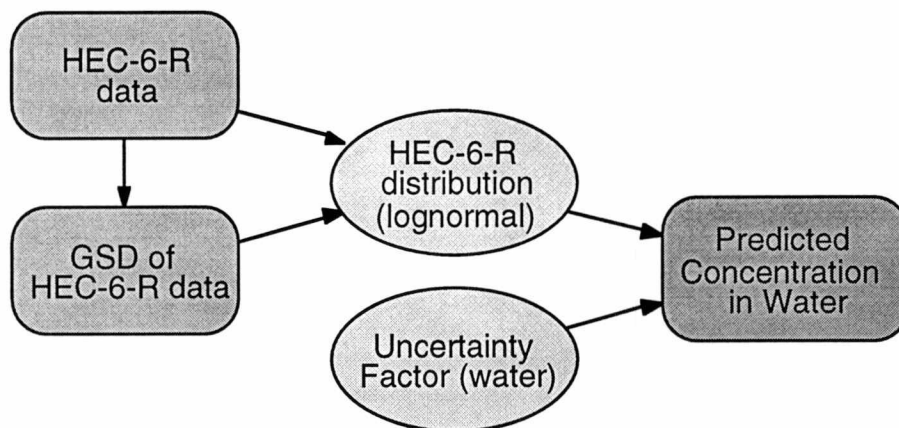


Figure 5.6 Schematic representing the modeled (predicted) radionuclide concentrations in water.

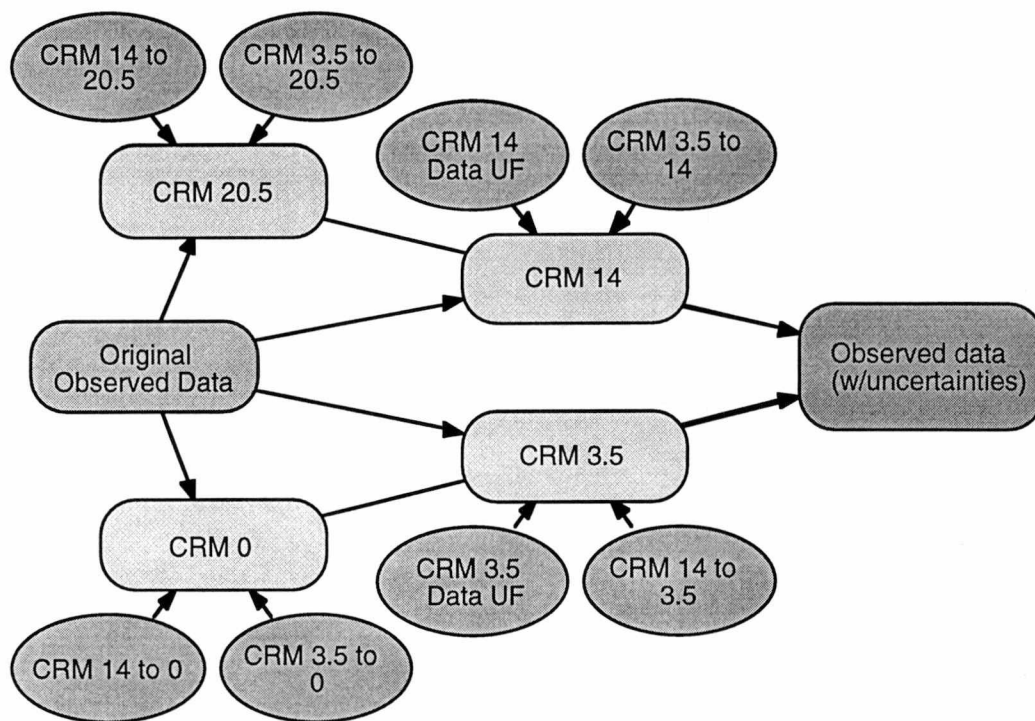


Figure 5.7 Representation of the application of uncertain bias correction factors to obtain the measured data (with uncertainties).

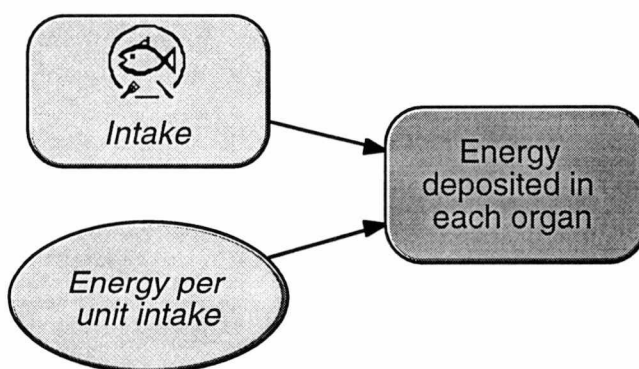


Figure 5.8 Diagram of the energy calculation.

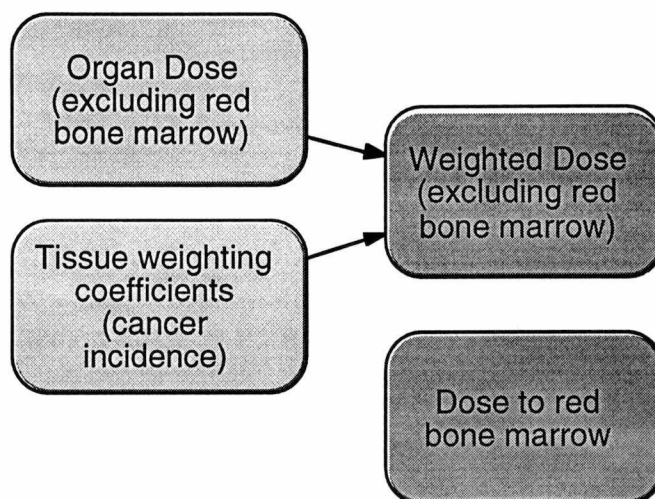


Figure 5.9 Diagram of the dose calculation.

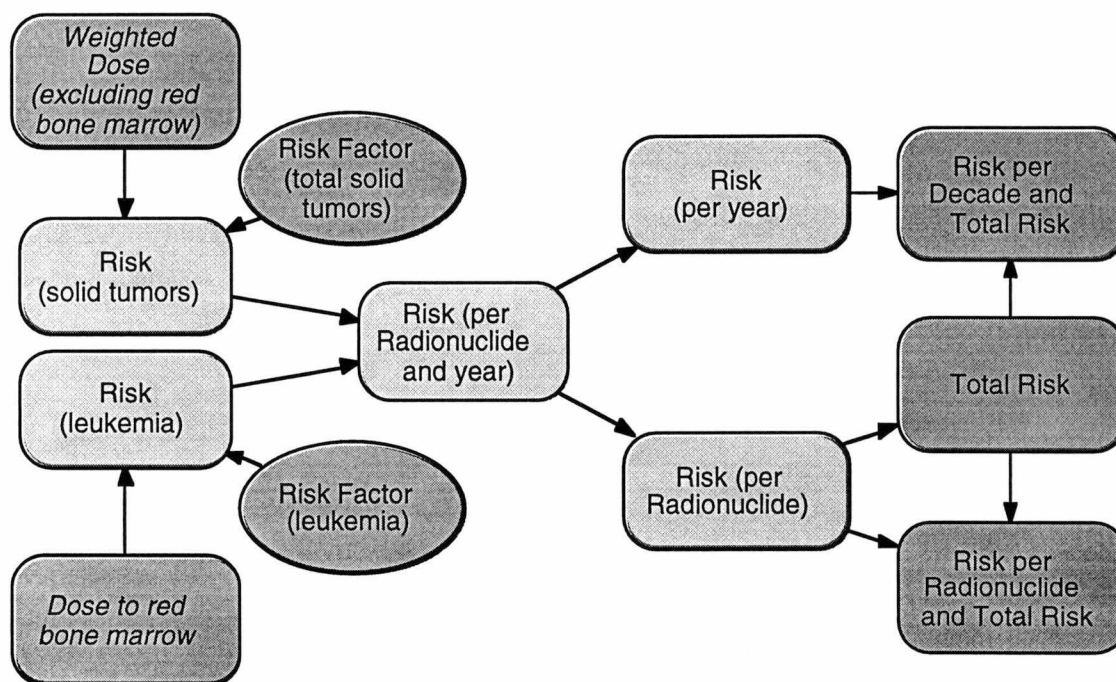


Figure 5.10 Diagram of the risk calculation.

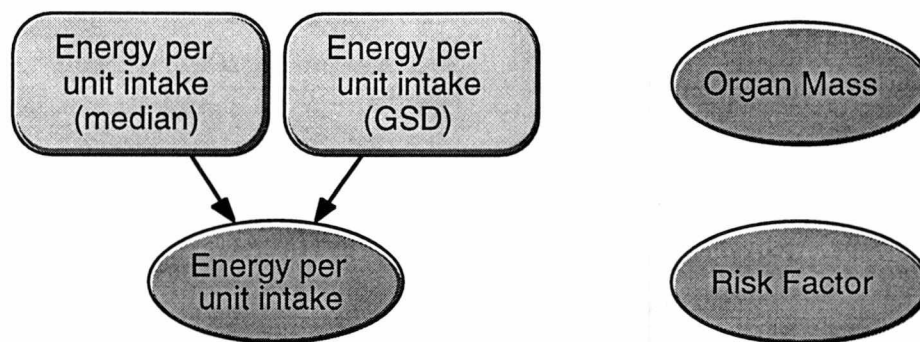


Figure 5.11 Schematic of dosimetry and dose response module.

5.6.2 Microsoft Excel/Crystal Ball

Crystal Ball is a Monte Carlo software tool that is used as an add-in for Microsoft Excel. Crystal Ball allows the user to change data in more than one cell at a time. When performing a “what if” analysis, it provides a reliable way to determine the likelihood of any specific result.

Assumptions are made about the uncertain values in a spreadsheet and the cells that contain the answers are identified. Using the Monte Carlo method, Crystal Ball repeatedly selects random numbers that conform to your assumptions, recalculates your spreadsheet, and gathers results from the forecast (results) cells.

6.0 RESULTS

This section contains example results obtained from the models designed for this report, by combining the following components:

- estimated concentrations of radionuclides in Clinch River water and shoreline sediments;
- the transfer of radionuclide contamination to aquatic and terrestrial biota;
- internal and external exposure parameters for pathways of concern;
- the radiation doses per unit exposure; and
- the risk of cancer incidence per unit dose.

The results presented in this work were generated using the previously discussed models for use in the Tennessee Dose Reconstruction project. Various results from that report (Theissen et al, 1998) have been used and the text paraphrased.

Reference individuals for each of four locations along the Clinch River were described in terms of the exposure pathways that could have occurred at that location. Estimates of doses and risks to these reference individuals were based on the assumption of continued exposure at the indicated location from 1944 to 1991. In addition, because the X-10 (Oak Ridge National Laboratory) operations and releases varied over time, selected analyses of doses and risks were also performed for shorter periods of exposure. The reference

individuals for which dose and risk estimates were made are described according to the pathways that could have occurred for each of four sections of the river.

Risk of cancer incidence is the overall endpoint of the study; therefore, most of the discussion is devoted to the description of results in terms of risk. The most important sources of uncertainty in the estimates of dose and risk are identified through a series of sensitivity analyses (Section 6.2). The results from this analysis are compared to results obtained using the recently published Federal Guidance 13, which provides government consensus of regulatory values of risk per unit intake (Section 6.3).

The primary radionuclides of interest released from the X-10 facility into the Clinch River via White Oak Creek were identified in the initial screening analysis as ^{137}Cs , ^{90}Sr , ^{60}Co , ^{106}Ru , ^{144}Ce , ^{131}I , ^{95}Zr , and ^{95}Nb . Of these radionuclides, ^{137}Cs , ^{60}Co , ^{106}Ru , ^{90}Sr , and ^{131}I were evaluated for their contribution to internal exposure pathways, while ^{137}Cs , ^{60}Co , ^{106}Ru , ^{90}Sr , ^{144}Ce , ^{95}Zr , and ^{95}Nb were evaluated for their contribution to the external exposure pathway.

Of seven potential exposure pathways evaluated in the initial screening analysis, five were determined to have occurred historically: ingestion of Clinch River fish, ingestion of drinking water from the Clinch River, external exposure from shoreline sediments, ingestion of milk from cows having access to river water, and ingestion of beef from cattle having access to river water. Reference individuals, for whom dose and risk calculations

have been made, were described for each of four locations along the Clinch River: near Jones Island (CRM 20.5); near the K-25 site or Grassy Creek (CRM 14); near the Kingston Steam Plant (CRM 3.5); and near the city of Kingston (CRM 0). For each location, the reference individuals were specified in terms of the exposure pathways that occurred near that site (Tables 6.1 and 6.2). Reference individuals were described as adults (males and females) for all situations except internal exposure to ^{131}I . Dose and risk factors for ^{131}I are age-specific, with only children below age 15 having a significant risk of radiation-induced thyroid cancer from ingestion of ^{131}I . Dose and risk factors for the other radionuclides in this analysis are not age-specific. Therefore, the reference individuals for the drinking water and milk ingestion pathways included both children (for ^{131}I) and adults (for ^{137}Cs , ^{90}Sr , ^{106}Ru , and ^{60}Co).

Because the consumption of fish could have occurred from any section of the river, the fish ingestion pathway was included at all sites. Reference individuals were specified in terms of the amount of fish consumed:

- Category I, 1 to 2.5 meals per week
- Category II, 1 meal per month to 1 meal per week
- Category III, 1 meal per 6 months to 1 meal per 3 weeks

Table 6.1 Summary of exposure pathways by location.

Clinch River Reach	Exposure Pathways	Exposure Period ^a
Jones Island area, CRM 20.5 (CRM 21.0-CRM 17.0)	Fish ingestion	1944-1991
	External exposure	1963-1991 ^b
	Ingestion of meat and milk	1963-1991 ^b
K-25/Grassy Creek areas, CRM 14 (CRM 17.0 to CRM 5.0)	Drinking water	1944-1991
	Fish ingestion	1944-1991
	External exposure	1944-1991
	Ingestion of meat and milk	1944-1991
Kingston Steam Plant, CRM 3.5 (CRM 5.0 to CRM 2.0)	Drinking water	1954-1989 ^c
	Fish ingestion	1944-1991
	External exposure	1944-1991
	Ingestion of meat and milk	1944-1991
City of Kingston, CRM 0 (CRM 2.0 to CRM 0)	Drinking water	1955-1991 ^d
	Fish ingestion	1944-1991
	External exposure	1944-1991
	Ingestion of meat and milk	1944-1991

^a Unless otherwise indicated, the reference individual was assumed to have been exposed for the entire study period, 1944-1991.

^b Public exposure to contaminated water or sediment near Jones Island occurred only on the far bank (south bank); negligible contamination occurred on that bank prior to operation of Melton Hill Dam (beginning in 1963) because the contaminated plume was not mixed until further downstream.

^c The Kingston Steam Plant obtained drinking water from an intake on the Clinch River only from 1954-1989.

^d The City of Kingston began to obtain drinking water from an intake on the Tennessee River (near the confluence of the Clinch River) in 1955.

Table 6.2 Summary of reference individuals by exposure pathway.

Exposure Pathway	Reference individuals
Drinking water	Adult visitors to K-25
	Adult visitors to the Kingston Steam Plant
	Adults and children living, working, or in school in the city of Kingston
Fish ingestion	Adults consuming fish from the Clinch River
External exposure	Adults using the shoreline for recreational purposes
Ingestion of meat and milk	Adults consuming meat from farm-raised cattle
	Adults and children consuming milk from a backyard cow

Meal size was defined as 0.10 to 0.30 kg per meal for males and 0.08 to 0.25 kg per meal for females. Thus in terms of total fish consumption per year, the categories can be summarized as follows: Category I, 5.5 to 37 kg y⁻¹ for males and 4.6 to 32 kg y⁻¹ for females; Category II, 1.5 to 20 kg y⁻¹ for males and 1.5 to 16 kg y⁻¹ for females; and Category III, 0.3 to 4.9 kg y⁻¹ for males and 0.2 to 4.2 kg y⁻¹ for females. These values represent the 95% subjective confidence intervals of the subjective probability distributions for intake obtained by propagation (using Monte Carlo techniques) of the distributions for number of meals and amount of fish per meal; the extreme values (e.g., 1 meal per week $\times$ 0.10 kg per meal = 5.2 kg y⁻¹ and 2.5 meals per week $\times$ 0.30 kg per meal = 39 kg y⁻¹) are outside the 95% subjective confidence interval. For each category, 20-100% of the fish consumed was assumed to have come from the Clinch River near the stated location, and 80-90% of the radioactivity in the fish was assumed to remain after processing.

6.1 Example Results from Uncertainty Analysis

The models were designed to estimate doses and risks to the reference individuals from each of five major exposure pathways. This section includes the major findings of the study made possible by the models discussed in this report. The estimated doses and risks for the fish ingestion pathway are summarized in Sections 6.1.2 and 6.1.3, respectively.

6.1.1 *Organ-specific Doses*

The highest organ doses estimated for any pathway in this study were for ingestion of fish from CRM 20.5 by Category I and II consumers. The 95% subjective confidence intervals for the organ doses received by Category I consumers near CRM 20.5 range from about 0.02 to 8 cSv (0.02 to 8 rem), with central values varying from 0.3 to 0.8 cSv for males and from 0.2 to 0.6 cSv for females (shown for selected organs in Table 6.3). Doses to Category II consumers are about a factor of 2 less than for Category I at any given location, and for Category III about a factor of 4 less than for Category II (Table 6.3). The differences in doses between males and females or between categories of consumption reflect the differences in the consumption rates defined for each category and gender. Doses from fish obtained near CRM 20.5 are about a factor of 6 higher than for CRM 14 for similar reference individuals; doses for CRM 14 are about a factor of 1.5 higher than for CRM 3.5 and CRM 0, which are about the same. Differences in doses with location reflect differences in the estimated radionuclide concentrations in water and fish by location.

The structure of the model allows for the determination of which organs receive the highest doses. The highest values were obtained for the bone and red bone marrow, and the lowest for the breast, brain, ovaries, and skin, although the greatest differences in organ doses (central values) were only a factor of 2-3 for males and 3-4 for females. The similarity of doses among organs probably reflects the importance of ^{137}Cs to the organ

Table 6.3 Selected organ-specific doses (cSv^a) for consumption of fish from the Clinch River near Jones Island or Kingston^b.

Organ	Jones Island (CRM 20.5)			Kingston (CRM 0)		
	Category I	Category II	Category III	Category I	Category II	Category III
Males						
Bone	0.067-7.4 ^c (0.81) ^d	0.023-3.2 (0.33)	0.0046-0.78 (0.081)	0.011-0.58 (0.096)	0.0050-0.26 (0.041)	0.00086-0.066 (0.0097)
Lower large intestine	0.053-5.2 (0.57)	0.022-2.0 (0.23)	0.0043-0.49 (0.057)	0.010-0.40 (0.064)	0.0036-0.18 (0.029)	0.00069-0.045 (0.0062)
Red bone marrow	0.052-4.8 (0.60)	0.018-2.0 (0.24)	0.0043-0.49 (0.055)	0.0095-0.40 (0.065)	0.0029-0.18 (0.027)	0.00068-0.047 (0.0065)
Skin	0.027-2.9 (0.31)	0.0088-1.1 (0.13)	0.0018-0.28 (0.031)	0.0054-0.24 (0.035)	0.0017-0.097 (0.016)	0.00032-0.024 (0.0036)
Females						
Bone	0.058-7.9 (0.60)	0.019-2.7 (0.28)	0.0038-0.81 (0.059)	0.011-0.54 (0.074)	0.0041-0.21 (0.034)	0.00091-0.053 (0.0079)
Breast	0.024-3.6 (0.24)	0.0089-0.96 (0.11)	0.0018-0.40 (0.025)	0.0049-0.19 (0.030)	0.0015-0.091 (0.013)	0.00032-0.025 (0.0028)
Lower large intestine	0.046-4.5 (0.43)	0.018-1.7 (0.19)	0.0039-0.52 (0.043)	0.0091-0.29 (0.054)	0.0029-0.15 (0.023)	0.00060-0.038 (0.0050)
Red bone marrow	0.039-4.8 (0.42)	0.015-1.6 (0.20)	0.0036-0.61 (0.043)	0.0095-0.30 (0.050)	0.0024-0.15 (0.022)	0.00071-0.041 (0.0055)
Skin	0.022-2.8 (0.23)	0.0072-0.87 (0.11)	0.0018-0.40 (0.025)	0.0044-0.19 (0.028)	0.0014-0.080 (0.013)	0.00031-0.024 (0.0027)

^a 1 cSv = 1 rem.

^b Consumption rates are as follows: Category I, 1-2.5 meals per week, or 5.5 - 37 kg y⁻¹ for males and 4.6 - 32 kg y⁻¹ for females.

Category II, 1 meal per month to 1 meal per week, or 1.5 - 20 kg y⁻¹ for males and 1.5 - 16 kg y⁻¹ for females.

Category III, 1 meal per 6 months to 1 meal per 3 weeks, or 0.3 - 4.9 kg y⁻¹ for males and 0.2 - 4.2 kg y⁻¹ for females.

For all categories, it was assumed that 20 to 100% of the fish was contaminated, and 80 to 90% of the radioactivity in the fish was retained after processing.

^c 95% subjective confidence interval

^d central value (50th percentile)

doses from fish ingestion, as ^{137}Cs is accumulated in the flesh of fish and then rather evenly distributed throughout the body of an individual consuming the fish. The higher doses to bone reflect the additional contribution of ^{90}Sr from the fish.

6.1.2 *Organ-specific Risks*

The organ-specific dose estimates summarized in Section 6.1.2 were used as the basis for organ-specific estimates of excess lifetime risk of cancer incidence. The methods used for risk estimation are described in Section 3.5. In general, the dose-response functions were based on cancer incidence data for the A-bomb survivors and on the background incidence rates of cancer for East Tennessee. The dose-response data for exposure to ^{131}I were based on numerous additional sources, including epidemiological investigations of children exposed to x-rays and children exposed to ^{131}I in the aftermath of the Chernobyl accident. Because children are more sensitive to ^{131}I exposure, doses and risks from this exposure were estimated for children instead of adults.

Although radiation doses were estimated for every organ for which information could be obtained, dose-response functions could not be developed for the entire set. For several organs (adrenals, bone, small intestine, upper large intestine, skin, spleen, testes, thymus, and uterus), either the A-bomb survivor data or the background cancer incidence in East Tennessee was not available; in addition, risks were not calculated for organs such as the prostate for which doses were not estimated (due to absence of sufficient dosimetric

information). The total risks described in this section were calculated from a tissue-weighted effective dose, using dose-response and background incidence information for total solid tumors and leukemia (Section 3.6).

Estimated organ-specific risks of cancer incidence for Category I fish consumers (1-2.5 meals per week) in the Jones Island area (CRM 20.5) ranged from 3.5×10^{-8} to 9.3×10^{-4} , with central values from 9.4×10^{-7} to 3.7×10^{-5} for males and from 6.8×10^{-7} to 5.5×10^{-5} for females (shown for selected organs in Table 6.4). For the Kingston area (CRM 0), risk values ranged from 5.2×10^{-9} to 7.1×10^{-5} , with central values from 9.5×10^{-8} to 4.3×10^{-6} for males and from 8.4×10^{-8} to 6.5×10^{-6} for females (Table 6.4, Figure 6.1). As with the doses (Section 6.1.2), the risks from consumption of fish from the Jones Island area are about a factor 8-9 higher than the risks for fish from the Kingston area, reflecting the differences in radionuclide concentrations between the two areas. Risks for Categories II and III (Table 6.4) are lower than those for Category I in proportion to the lower intake rates assumed for these individuals.

Although the bone marrow received among the highest doses and the breast among the lowest doses, the breast has the higher risk by almost a factor of 2 (Table 6.4). For females, the highest risks are for breast and red bone marrow; for males, the highest risk is for the red bone marrow. The lowest risks for males or females were for the pancreas. The difference between the highest and lowest risks for any one location and consumption rate is about a factor of 70-80 for females and 40 for males, although the

differences in doses are only a factor of 2-4. This situation illustrates the great difference in organ sensitivities to radiation-induced cancer and underlines the importance of calculating risks as well as doses.

For Category I consumers near Jones Island (CRM 20.5), the 95% subjective confidence intervals for the total excess lifetime risk of cancer incidence for all radionuclides and organs included in this analysis was 3.6×10^{-5} to 3.5×10^{-3} (50th percentile, 2.8×10^{-4}) for males and 2.9×10^{-5} to 2.8×10^{-3} (50th percentile, 2.3×10^{-4}) for females (Table 6.5). The slightly higher total risk for males is due primarily to the difference in ingestion rates. For both males and females, the largest contribution to the total risk (about 90%) is from ^{137}Cs (Table 6.5), which is concentrated in fish to a much larger extent than are the other radionuclides. The total risks to Category I consumers at Kingston (CRM 0) are about a factor of 7-9 lower than at Jones Island (Table 6.5), once again reflecting the differences in radionuclide concentrations in fish at the two locations. However, even at Kingston, the upper bound risk for Category I consumers is still above 1×10^{-4} for both males and females (Table 6.5; Figure 6.2).

6.2 Example Results from Sensitivity Analysis

An initial sensitivity analysis was performed to assess the contributions to the uncertainty in the estimates of total excess lifetime risk for each exposure pathway from

Table 6.4 Selected organ-specific risks^a of cancer incidence from all radionuclides for consumption of fish from the Clinch River near Jones Island or Kingston^b.

Organ	Category I	Category II	Category III
<u>Jones Island (CRM 20.5)</u>			
<u>Males</u>			
Lower large intestine	$2.5 \times 10^{-6} - 2.8 \times 10^{-4}$ (2.7×10^{-5})	$7.0 \times 10^{-7} - 1.4 \times 10^{-4}$ (1.1×10^{-5})	$1.7 \times 10^{-7} - 3.4 \times 10^{-5}$ (2.5×10^{-6})
Red bone marrow	$2.5 \times 10^{-6} - 3.4 \times 10^{-4}$ (3.7×10^{-5})	$8.6 \times 10^{-7} - 1.3 \times 10^{-4}$ (1.6×10^{-5})	$1.8 \times 10^{-7} - 3.7 \times 10^{-5}$ (3.8×10^{-6})
<u>Females</u>			
Breast	$4.3 \times 10^{-6} - 9.3 \times 10^{-4}$ (5.5×10^{-5})	$1.9 \times 10^{-6} - 4.1 \times 10^{-4}$ (2.3×10^{-5})	$3.7 \times 10^{-7} - 1.0 \times 10^{-4}$ (5.6×10^{-6})
Lower large intestine	$1.6 \times 10^{-6} - 2.6 \times 10^{-4}$ (2.2×10^{-5})	$5.8 \times 10^{-7} - 1.4 \times 10^{-4}$ (9.3×10^{-6})	$1.4 \times 10^{-7} - 3.2 \times 10^{-5}$ (2.0×10^{-6})
Red bone marrow	$2.5 \times 10^{-6} - 4.0 \times 10^{-4}$ (2.8×10^{-5})	$8.6 \times 10^{-7} - 1.8 \times 10^{-4}$ (1.2×10^{-5})	$1.6 \times 10^{-7} - 4.9 \times 10^{-5}$ (2.7×10^{-6})
<u>Kingston (CRM 0)</u>			
<u>Males</u>			
Lower large intestine	$3.4 \times 10^{-7} - 3.1 \times 10^{-5}$ (3.2×10^{-6})	$1.0 \times 10^{-7} - 1.2 \times 10^{-5}$ (1.4×10^{-6})	$2.9 \times 10^{-8} - 3.3 \times 10^{-6}$ (3.2×10^{-7})
Red bone marrow	$5.4 \times 10^{-7} - 2.8 \times 10^{-5}$ (4.3×10^{-6})	$1.5 \times 10^{-7} - 1.2 \times 10^{-5}$ (1.9×10^{-6})	$3.5 \times 10^{-8} - 3.3 \times 10^{-6}$ (4.4×10^{-7})
<u>Females</u>			
Breast	$9.1 \times 10^{-7} - 7.1 \times 10^{-5}$ (6.5×10^{-6})	$2.9 \times 10^{-7} - 3.3 \times 10^{-5}$ (2.8×10^{-6})	$5.2 \times 10^{-8} - 8.4 \times 10^{-6}$ (6.6×10^{-7})
Lower large intestine	$3.4 \times 10^{-7} - 2.3 \times 10^{-5}$ (2.8×10^{-6})	$8.9 \times 10^{-8} - 1.1 \times 10^{-5}$ (1.2×10^{-6})	$2.5 \times 10^{-8} - 2.9 \times 10^{-6}$ (2.6×10^{-7})
Red bone marrow	$4.3 \times 10^{-7} - 2.3 \times 10^{-5}$ (3.5×10^{-6})	$1.5 \times 10^{-7} - 1.1 \times 10^{-5}$ (1.5×10^{-6})	$3.5 \times 10^{-8} - 3.2 \times 10^{-6}$ (3.3×10^{-7})

Footnotes to Table 6.4

^a Ranges indicate the 95% subjective confidence intervals. Values in parentheses are the 50th percentiles.

^b Consumption rates are as follows:

Category I, 1-2.5 meals per week, or 5.5 – 37 kg y⁻¹ for males and 4.6 – 32 kg y⁻¹ for females.

Category II, 1 meal per month to 1 meal per week, or 1.5 – 20 kg y⁻¹ for males and 1.5 – 16 kg y⁻¹ for females.

Category III, 1 meal per 6 months to 1 meal per 3 weeks, or 0.3 – 4.9 kg y⁻¹ for males and 0.2 – 4.2 kg y⁻¹ for females.

For all categories, it was assumed that 20 to 100% of the fish was contaminated, and 80 to 90% of the radioactivity in the fish was retained after processing.

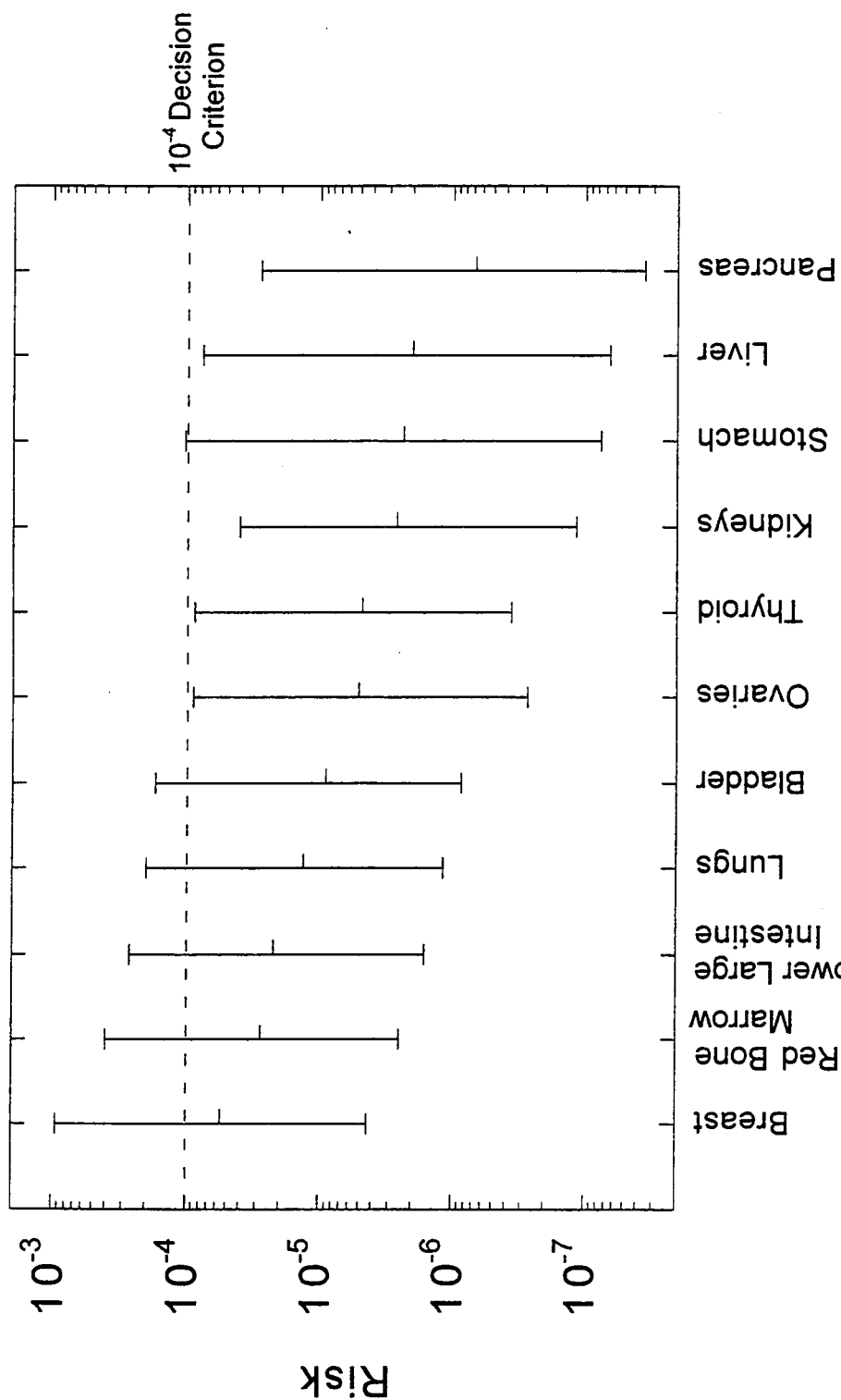


Figure 6.1 Organ-specific risks for females from ingestion of fish at CRM 20.5 (Category I consumers, 1-2.5 meals per week). The vertical lines indicate the 95% subjective confidence intervals on the estimated risks; the central values (50th percentiles) are indicated by dashes.

Table 6.5 Estimates of total excess lifetime risk of cancer incidence by radionuclide for Category I consumers^a of fish at CRM 20.5 and CRM 0 (fish ingestion only).

Radionuclide	95% Subjective Confidence Interval		
	Lower Limit	Central Value	Upper Limit
<u>CRM 20.5, male</u>			
¹³⁷ Cs	3.0×10^{-5}	2.6×10^{-4}	3.4×10^{-3}
¹⁰⁶ Ru	9.8×10^{-8}	1.7×10^{-6}	3.0×10^{-5}
⁹⁰ Sr	6.8×10^{-7}	1.1×10^{-5}	1.2×10^{-4}
⁶⁰ Co	6.6×10^{-8}	9.8×10^{-7}	1.4×10^{-5}
Total Risk ^b	3.6×10^{-5}	2.8×10^{-4}	3.5×10^{-3}
<u>CRM 20.5, female</u>			
¹³⁷ Cs	2.4×10^{-5}	2.2×10^{-4}	2.8×10^{-3}
¹⁰⁶ Ru	8.1×10^{-8}	1.4×10^{-6}	2.5×10^{-5}
⁹⁰ Sr	5.5×10^{-7}	9.0×10^{-6}	1.0×10^{-4}
⁶⁰ Co	5.5×10^{-8}	8.1×10^{-7}	1.1×10^{-5}
Total Risk ^b	2.9×10^{-5}	2.3×10^{-4}	2.8×10^{-3}
<u>CRM 0, male</u>			
¹³⁷ Cs	4.4×10^{-6}	3.4×10^{-5}	2.6×10^{-4}
¹⁰⁶ Ru	1.8×10^{-8}	2.8×10^{-7}	3.3×10^{-6}
⁹⁰ Sr	1.1×10^{-7}	1.4×10^{-6}	1.3×10^{-5}
⁶⁰ Co	1.4×10^{-8}	1.4×10^{-7}	1.4×10^{-6}
Total Risk ^b	5.6×10^{-6}	3.7×10^{-5}	2.6×10^{-4}
<u>CRM 0, female</u>			
¹³⁷ Cs	3.6×10^{-6}	2.8×10^{-5}	2.1×10^{-4}
¹⁰⁶ Ru	1.5×10^{-8}	2.3×10^{-7}	2.7×10^{-6}
⁹⁰ Sr	9.4×10^{-8}	1.1×10^{-6}	1.1×10^{-5}
⁶⁰ Co	1.1×10^{-8}	1.1×10^{-7}	1.2×10^{-6}
Total Risk ^b	4.6×10^{-6}	3.0×10^{-5}	2.1×10^{-4}

^a 1-2.5 meals per week (Sections 7, 13.1)

^b The calculations were performed using Monte Carlo techniques to add the distributions. Therefore, the total risks may not equal the arithmetic sums of the components.

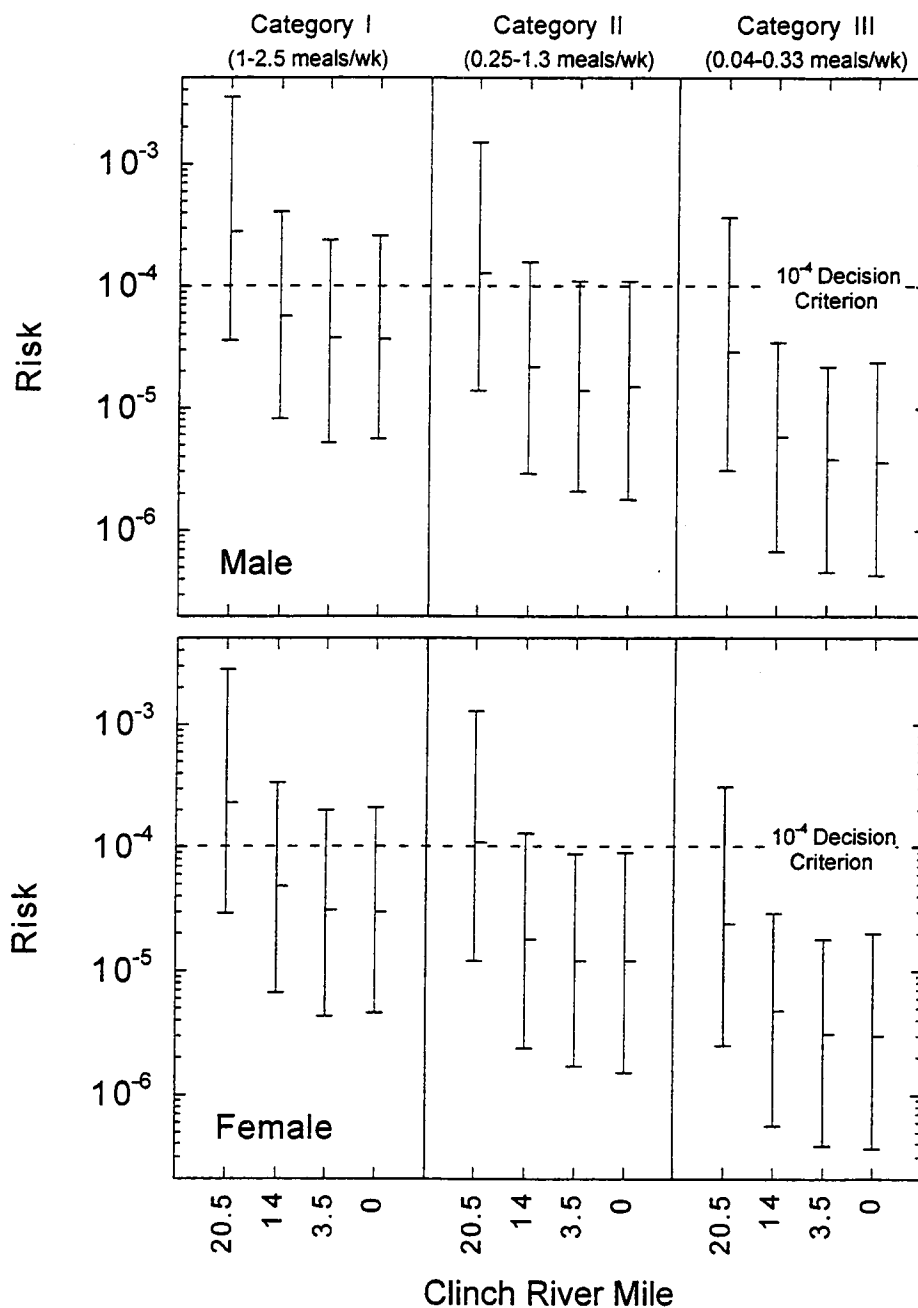


Figure 6.2 Excess lifetime risk of cancer incidence for male (top) and female (bottom) reference individuals consuming fish at each location of interest along the Clinch River. The vertical lines indicate the 95% subjective confidence intervals on the estimated risks; the central values (50th percentiles) are indicated by dashes.

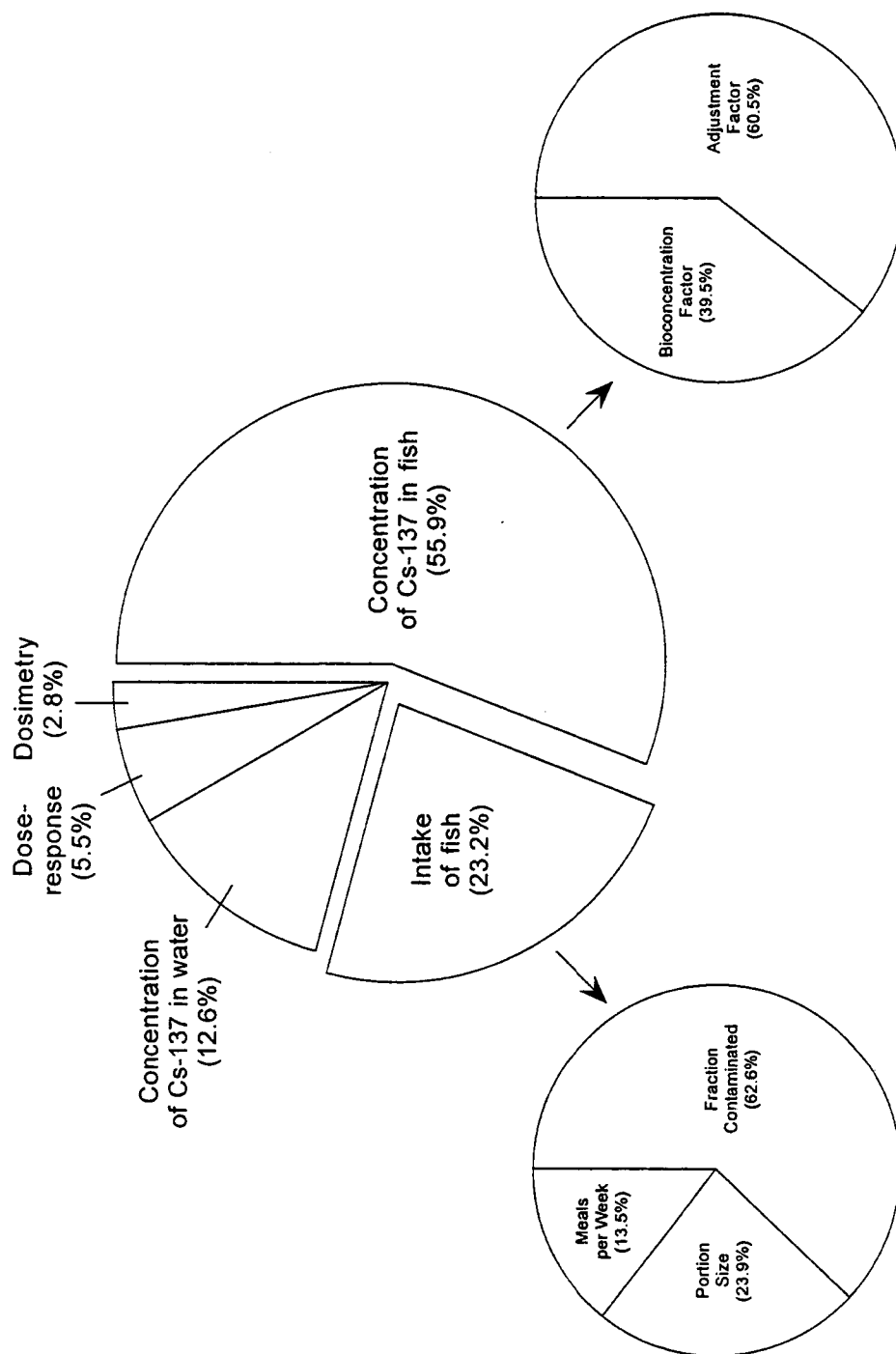


Figure 6.3 Results of a sensitivity analysis for the risk from ^{137}Cs to male Category I consumers of fish (1-2.5 meals per week) at CRM 20.5. The graphs show the contribution of each uncertain input to the total uncertainty in the estimate of excess lifetime risk.

each major component of the assessment. Sensitivity analyses were carried out for male Category I consumers of fish at CRM 20.5 and CRM 14, for male Category III consumers at CRM 14, and for external exposure and ingestion of drinking water at CRM 14. The male Category I consumer of fish at CRM 20.5 is presented in this section.

Because ^{137}Cs was the dominant contributor to dose and risk from fish ingestion at all consumption rates, the sensitivity analyses for fish ingestion were carried out only for the risk from ^{137}Cs . For all ingestion rates and locations examined, the radionuclide concentration in fish and the amount of fish consumed were the dominant contributors to the uncertainty in risk (Figure 6.3). Lesser contributors included the radionuclide concentration in water, the dose-response, and the dosimetry. For the Category I consumer at CRM 20.5, more than 50% of the uncertainty is attributed to the radionuclide concentration in fish; this in turn is due both to the uncertainty in the bioconcentration factor and to the additional adjustment factor used for CRM 20.5 to account for fish swimming in and out of White Oak Creek Embayment or the plume from White Oak Creek. Uncertainty in the amount of fish consumed accounted for about one-fourth of the uncertainty in risk for the Category I consumer at CRM 20.

6.3 Comparison to Federal Guidance 13

Risks per unit intake for ^{137}Cs , ^{106}Ru , ^{90}Sr , and ^{60}Co estimated in this analysis were compared with the standard risk factors presented in Federal Guidance 13 (Figure 6.4; Eckerman et al., 1998). In general, the central values obtained in this analysis were similar to or slightly lower than the values obtained with Federal Guidance 13; for ^{60}Co , the Federal Guidance 13 value was substantially higher. The exact reasons for this difference are unknown at present, but part of the bias is probably due to the higher GI tract absorption assumed in the Federal Guidance 13 model than was assumed in the present analysis. Thus, the Federal Guidance 13 estimates, although intended to produce best-estimate results, may still contain some amount of conservative bias (especially for ^{60}Co). The results produced in this analysis have included the uncertainties in both the dosimetry and the dose-to-risk estimation. Federal Guidance 13 currently does not include the results of an uncertainty analysis.

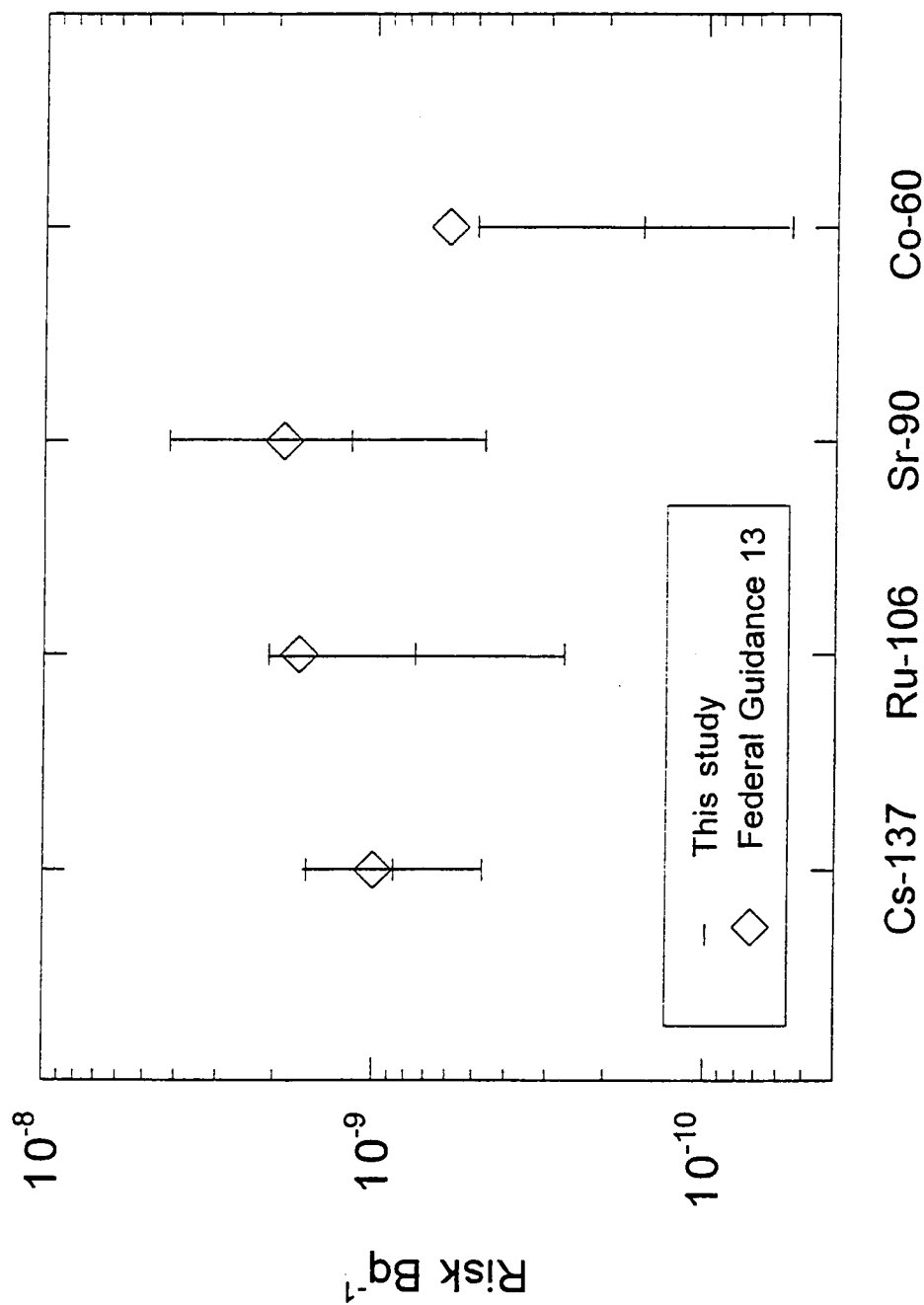


Figure 6.4

Comparison of risk per unit intake from this analysis with published risk factors in Federal Guidance 13 (Eckerman et al., 1998). The vertical lines indicate the 95% subjective confidence intervals on the risk per unit intake used in the present study; central values (50th percentiles) are indicated by the diamonds. Open diamonds indicate the values from Federal Guidance 13.

6.0 CONCLUSIONS

An initial screening analysis was performed to aid in the allocation of resources. The exposure pathways of interest included fish ingestion, drinking water ingestion, the ingestion of milk and meat, and external exposure from shoreline sediment. Doses and risks were estimated at four representative locations along the Clinch River (Clinch River Miles 20.5, 14, 3.5, and 0). Reference individuals were determined with respect to the pathways involved.

The doses and risks estimated in this study for individuals exposed to radionuclides released from the Oak Ridge National Laboratory to the Clinch River are not significant enough to cause a detectable increase in health effects in the population. In most cases, the organ doses are well below the limits of epidemiological detection (1 to 30 cSv) for radiation-induced health outcomes. Therefore, exposure to radionuclides released from the X-10 site is not likely to be responsible for an increased number of cancers to populations utilizing the Clinch River after 1944.

REFERENCES

REFERENCES

- Blaylock, B.G., Frank, M.L., Hook, L.A., Hoffman, F.O., and Ford, C.J. 1993. White Oak Creek Embayment Site Characterization and Contaminant Screening Analysis. Report ORNL/ER-81.
- Browder, F.N. 1949. Liquid Waste Disposal at Oak Ridge National Laboratory. Report ORNL-328.
- Eckerman, K.F. 1994. Dosimetric Methodology of the ICRP. Chapter 13 in Internal Radiation Dosimetry, Health Physics Society Summer School 1994. Medical Physics Publishing, Madison. pp. 239-270.
- Feige, Y., Parker, F.L., and Struxness, E.G. 1960. Analysis of Waste Disposal Practice and Control at ORNL. Report CFN 60-8-72.
- Hoffman, F. O. and Gardner, R. H. 1983. Evaluation of Uncertainties in Radiological Assessment Models. Chapter 11 of Radiological Assessment: A Textbook on Environmental Dose Analysis. Edited by Till, J. E. and Meyer, H. R. NRC Office of Nuclear Reactor Regulation, Washington, D.C.
- IAEA (International Atomic Energy Agency). 1989. Evaluating the Reliability of Predictions Made Using Environmental Transfer Models. IAEA Safety Series 100. Vienna, Austria.
- ICRP (International Commission on Radiological Protection). 1991. Recommendations of the International Commission on Radiological Protection. ICRP Publication No. 60. Vol. 21, No. 1-3. Pergamon Press, Inc. New York, New York.
- Morgan, M. G. and Henrion, M. 1990. UNCERTAINTY: A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis. Cambridge University Press. New York, New York.
- NRC (National Research Council). 1990. Health Effects of Exposure to Low Levels of Ionizing Radiation, BEIR V. National academy Press. Washington, DC.
- Spalding, B.P., and Boegly Jr., W.J. 1985. ORNL Radioactive Liquid Waste Disposal Pits and Trenches: History, Status, and Closure Characterization Needs. Report ORNL/CF-85/70.
- TCRS (Tennessee Cancer Reporting System). 1992. Tennessee Department of Health, Nashville, TN.

APPENDICES

APPENDIX A

Table A.1 Organ doses (cSv) from all radionuclides resulting from the consumption of fish for category I males exposed during the entire study period (45 years)a.

Organs	CRM 20.5			CRM 14			CRM 3.5			CRM 0		
	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	97.5%
Adrenals	3.6 E-02	4.2 E-01	4.1 E+00	1.0 E-02	7.1 E-02	5.6 E-01	7.5 E-03	4.9 E-02	3.3 E-01	7.4 E-03	4.7 E-02	3.4 E-01
Bladder	4.0 E-02	4.1 E-01	3.8 E+00	1.1 E-02	6.5 E-02	5.2 E-01	6.4 E-03	4.5 E-02	3.4 E-01	6.7 E-03	4.4 E-02	3.4 E-01
Bone	6.7 E-02	8.1 E-01	7.4 E+00	1.4 E-02	1.3 E-01	9.0 E-01	1.1 E-02	9.2 E-02	6.0 E-01	1.1 E-02	9.6 E-02	5.8 E-01
Brain	3.1 E-02	3.5 E-01	3.2 E+00	8.6 E-03	5.9 E-02	3.5 E-01	4.6 E-03	3.8 E-02	2.3 E-01	5.5 E-03	3.8 E-02	2.3 E-01
Stomach	4.1 E-02	4.0 E-01	4.0 E+00	1.1 E-02	6.9 E-02	4.6 E-01	6.4 E-03	4.7 E-02	2.9 E-01	7.2 E-03	4.6 E-02	3.1 E-01
Small Intestine	4.1 E-02	3.9 E-01	3.8 E+00	1.1 E-02	6.6 E-02	4.0 E-01	6.7 E-03	4.5 E-02	2.6 E-01	6.2 E-03	4.4 E-02	2.6 E-01
Upper Large Intestine	4.3 E-02	4.8 E-01	4.1 E+00	1.3 E-02	7.4 E-02	4.6 E-01	8.5 E-03	4.9 E-02	3.2 E-01	8.2 E-03	5.2 E-02	3.1 E-01
Lower Large Intestine	5.3 E-02	5.7 E-01	5.2 E+00	1.7 E-02	9.5 E-02	6.4 E-01	1.1 E-02	6.6 E-02	4.2 E-01	1.0 E-02	6.4 E-02	4.0 E-01
Kidneys	3.5 E-02	4.2 E-01	3.6 E+00	1.1 E-02	6.9 E-02	4.4 E-01	6.1 E-03	4.7 E-02	2.8 E-01	5.8 E-03	4.7 E-02	2.8 E-01
Liver	3.7 E-02	4.2 E-01	3.3 E+00	1.1 E-02	7.0 E-02	5.0 E-01	6.0 E-03	4.7 E-02	3.3 E-01	6.1 E-03	4.8 E-02	3.3 E-01
Lungs	3.1 E-02	3.6 E-01	3.2 E+00	8.9 E-03	6.2 E-02	4.4 E-01	5.7 E-03	4.1 E-02	2.5 E-01	5.8 E-03	4.0 E-02	2.7 E-01
Pancreas	4.2 E-02	4.4 E-01	3.6 E+00	1.0 E-02	7.1 E-02	5.1 E-01	6.3 E-03	4.7 E-02	3.3 E-01	5.8 E-03	4.6 E-02	3.2 E-01
Red Bone Marrow	5.2 E-02	6.0 E-01	4.8 E+00	1.5 E-02	9.6 E-02	6.4 E-01	9.5 E-03	6.6 E-02	4.1 E-01	9.5 E-03	6.5 E-02	4.0 E-01
Skin	2.7 E-02	3.1 E-01	2.8 E+00	7.9 E-03	5.4 E-02	3.5 E-01	4.9 E-03	3.7 E-02	2.3 E-01	5.4 E-03	3.5 E-02	2.4 E-01
Spleen	3.8 E-02	4.0 E-01	3.8 E+00	1.1 E-02	6.8 E-02	4.7 E-01	6.9 E-03	4.5 E-02	2.7 E-01	7.4 E-03	4.5 E-02	3.0 E-01
Tastes	3.5 E-02	4.2 E-01	5.5 E+00	9.7 E-03	6.9 E-02	5.8 E-01	6.0 E-03	4.4 E-02	3.6 E-01	5.9 E-03	4.7 E-02	3.7 E-01
Thymus	3.5 E-02	4.0 E-01	4.3 E+00	9.3 E-03	6.5 E-02	6.0 E-01	6.4 E-03	4.5 E-02	4.3 E-01	5.9 E-03	4.4 E-02	4.0 E-01
Thyroid	4.3 E-02	5.2 E-01	5.3 E+00	1.1 E-02	9.3 E-02	8.1 E-01	5.7 E-03	6.3 E-02	5.7 E-01	6.6 E-03	6.1 E-02	6.5 E-01

a. Consumption rate varies from 5.5 to 36.5 kg y⁻¹. It was assumed that 60% (range of 20 to 100%) of the fish was contaminated, and 85% (range of 80 to 90%) of the radioactivity in the fish was retained after processing (sections 7, 13.1).

Table A.2 Organ doses (cSv) from all radionuclides resulting from the consumption of fish for category II males exposed during the entire study period (40 years)a.

Organs	CRM 20.5				CRM 14				CRM 3.5				CRM 0			
	2.5%	50%	87.5%	97.5%	2.5%	50%	87.5%	97.5%	2.5%	50%	87.5%	97.5%	2.5%	50%	87.5%	97.5%
Adrenals	1.3 E-02	1.7 E-01	1.7 E+00	2.3 E-01	3.9 E-03	3.2 E-02	2.3 E-01	2.2 E-03	2.2 E-03	2.0 E-02	1.5 E-01	2.2 E-03	2.2 E-03	2.0 E-02	1.5 E-01	2.2 E-03
Bladder	1.4 E-02	1.8 E-01	1.8 E+00	2.3 E-01	3.9 E-03	3.0 E-02	2.2 E-01	2.3 E-03	2.3 E-03	2.0 E-02	1.3 E-01	2.2 E-03	2.2 E-03	2.0 E-02	1.4 E-01	2.2 E-03
Bone	2.3 E-02	3.3 E-01	3.2 E+00	3.5 E-01	6.8 E-03	5.7 E-02	3.5 E-01	4.6 E-03	4.6 E-03	4.0 E-02	2.5 E-01	5.0 E-03	5.0 E-03	4.1 E-02	2.5 E-01	5.0 E-03
Brain	1.2 E-02	1.5 E-01	1.2 E+00	1.9 E-01	2.8 E-03	2.7 E-02	1.9 E-01	1.8 E-03	1.8 E-03	1.7 E-02	1.1 E-01	1.8 E-03	1.8 E-03	1.7 E-02	1.1 E-01	1.8 E-03
Stomach	1.4 E-02	1.6 E-01	1.5 E+00	2.0 E-01	4.0 E-03	3.1 E-02	2.0 E-01	2.1 E-03	2.1 E-03	2.2 E-02	1.3 E-01	2.1 E-03	2.1 E-03	2.1 E-02	1.3 E-01	2.1 E-03
Small Intestine	1.2 E-02	1.7 E-01	1.5 E+00	1.8 E-01	3.4 E-03	2.9 E-02	1.8 E-01	2.2 E-03	2.2 E-03	1.9 E-02	1.4 E-01	2.0 E-03	2.0 E-03	1.9 E-02	1.2 E-01	2.0 E-03
Upper Large Intestine	1.7 E-02	1.9 E-01	1.6 E+00	2.0 E-01	4.4 E-03	3.3 E-02	2.0 E-01	2.7 E-03	2.7 E-03	2.2 E-02	1.4 E-01	3.0 E-03	3.0 E-03	2.2 E-02	1.5 E-01	3.0 E-03
Lower Large Intestine	2.2 E-02	2.3 E-01	2.0 E+00	2.8 E-01	5.7 E-03	4.1 E-02	2.8 E-01	3.7 E-03	3.7 E-03	2.8 E-02	1.6 E-01	3.6 E-03	3.6 E-03	2.8 E-02	1.8 E-01	3.6 E-03
Kidneys	1.1 E-02	1.7 E-01	1.4 E+00	1.9 E-01	3.6 E-03	3.0 E-02	1.9 E-01	2.4 E-03	2.4 E-03	2.1 E-02	1.2 E-01	2.2 E-03	2.2 E-03	2.0 E-02	1.1 E-01	2.2 E-03
Liver	1.1 E-02	1.8 E-01	1.5 E+00	2.3 E-01	3.1 E-03	3.2 E-02	2.3 E-01	1.9 E-03	1.9 E-03	2.1 E-02	1.5 E-01	1.8 E-03	1.8 E-03	2.1 E-02	1.6 E-01	1.8 E-03
Lungs	1.1 E-02	1.4 E-01	1.2 E+00	1.7 E-01	2.8 E-03	2.7 E-02	1.7 E-01	1.8 E-03	1.8 E-03	1.8 E-02	1.1 E-01	1.5 E-03	1.5 E-03	1.8 E-02	1.1 E-01	1.5 E-03
Pancreas	1.4 E-02	1.8 E-01	1.5 E+00	2.2 E-01	3.3 E-03	3.2 E-02	2.2 E-01	2.2 E-03	2.2 E-03	2.0 E-02	1.4 E-01	2.1 E-03	2.1 E-03	2.1 E-02	1.5 E-01	2.1 E-03
Red Bone Marrow	1.8 E-02	2.4 E-01	2.0 E+00	2.6 E-01	4.7 E-03	4.1 E-02	2.6 E-01	3.1 E-03	3.1 E-03	2.7 E-02	1.6 E-01	2.9 E-03	2.9 E-03	2.7 E-02	1.8 E-01	2.9 E-03
Skin	8.8 E-03	1.3 E-01	1.1 E+00	1.6 E-01	2.7 E-03	2.2 E-02	1.6 E-01	1.7 E-03	1.7 E-03	1.5 E-02	9.1 E-02	1.7 E-03	1.7 E-03	1.6 E-02	9.7 E-02	1.7 E-03
Spleen	1.5 E-02	1.8 E-01	1.5 E+00	2.0 E-01	3.5 E-03	3.1 E-02	2.0 E-01	2.1 E-03	2.1 E-03	2.0 E-02	1.2 E-01	2.2 E-03	2.2 E-03	2.0 E-02	1.3 E-01	2.2 E-03
Testes	1.2 E-02	1.9 E-01	2.4 E+00	2.6 E-01	3.1 E-03	3.0 E-02	2.6 E-01	1.9 E-03	1.9 E-03	2.0 E-02	1.8 E-01	2.0 E-03	2.0 E-03	1.9 E-02	1.5 E-01	2.0 E-03
Thymus	1.4 E-02	1.7 E-01	1.8 E+00	2.5 E-01	3.6 E-03	2.8 E-02	2.5 E-01	2.0 E-03	2.0 E-03	1.9 E-02	1.8 E-01	2.2 E-03	2.2 E-03	1.9 E-02	1.7 E-01	2.2 E-03
Thyroid	1.3 E-02	2.3 E-01	2.3 E+00	3.2 E-01	3.6 E-03	4.0 E-02	3.2 E-01	2.6 E-03	2.6 E-03	2.7 E-02	1.8 E-01	2.5 E-03	2.5 E-03	2.7 E-02	1.8 E-01	2.5 E-03

a. Consumption rate varies from 1.5 to 19.7 kg y⁻¹. It was assumed that 60% (range of 20 to 100%) of the fish was contaminated, and 85% (range of 80 to 90%) of the radioactivity in the fish was retained after processing (sections 7, 13.1).

Table A.3 Organ doses (cSv) from all radionuclides resulting from the consumption of fish for category III males exposed during the entire study period (48 years)a.

Organs	CRM 20.5			CRM 14			CRM 3.5			CRM 0		
	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	97.5%
Adrenals	2.7 E-03	4.0 E-02	4.3 E-01	8.1 E-04	6.8 E-03	5.8 E-02	5.0 E-04	4.5 E-03	3.2 E-02	4.9 E-04	4.6 E-03	3.3 E-02
Bladder	1.9 E-03	4.1 E-02	4.0 E-01	8.1 E-04	6.7 E-03	5.5 E-02	5.6 E-04	4.5 E-03	3.2 E-02	4.5 E-04	4.5 E-03	3.2 E-02
Bone	4.6 E-03	8.1 E-02	7.8 E-01	1.2 E-03	1.4 E-02	9.5 E-02	8.1 E-04	9.2 E-03	6.2 E-02	8.6 E-04	9.7 E-03	6.6 E-02
Brain	2.4 E-03	3.2 E-02	3.2 E-01	6.7 E-04	5.8 E-03	4.5 E-02	4.1 E-04	3.7 E-03	2.5 E-02	4.1 E-04	3.9 E-03	2.6 E-02
Stomach	2.8 E-03	3.8 E-02	3.9 E-01	6.8 E-04	7.3 E-03	5.4 E-02	4.6 E-04	4.5 E-03	3.3 E-02	4.6 E-04	4.7 E-03	2.9 E-02
Small Intestine	2.5 E-03	3.8 E-02	3.5 E-01	7.1 E-04	7.0 E-03	4.9 E-02	4.9 E-04	4.7 E-03	2.9 E-02	4.2 E-04	4.8 E-03	2.9 E-02
Upper Large Intestine	2.9 E-03	4.3 E-02	4.4 E-01	9.0 E-04	7.5 E-03	5.9 E-02	6.9 E-04	5.1 E-03	3.4 E-02	5.6 E-04	4.9 E-03	3.7 E-02
Lower Large Intestine	4.3 E-03	5.7 E-02	4.9 E-01	1.1 E-03	9.7 E-03	7.0 E-02	7.9 E-04	6.4 E-03	4.2 E-02	6.9 E-04	6.2 E-03	4.5 E-02
Kidneys	2.7 E-03	3.8 E-02	3.3 E-01	8.2 E-04	6.8 E-03	5.0 E-02	5.1 E-04	4.5 E-03	3.2 E-02	4.8 E-04	4.5 E-03	3.1 E-02
Liver	2.8 E-03	4.3 E-02	4.0 E-01	5.9 E-04	7.2 E-03	6.3 E-02	4.3 E-04	4.6 E-03	3.9 E-02	4.1 E-04	4.7 E-03	3.8 E-02
Lungs	2.4 E-03	3.5 E-02	3.1 E-01	6.7 E-04	6.4 E-03	4.8 E-02	4.6 E-04	4.0 E-03	2.6 E-02	3.9 E-04	4.2 E-03	2.9 E-02
Pancreas	2.9 E-03	4.3 E-02	3.7 E-01	6.8 E-04	7.2 E-03	4.9 E-02	4.7 E-04	4.5 E-03	3.2 E-02	4.5 E-04	4.7 E-03	3.3 E-02
Red Bone Marrow	4.3 E-03	5.5 E-02	4.9 E-01	1.1 E-03	1.0 E-02	6.8 E-02	7.2 E-04	6.4 E-03	4.6 E-02	6.8 E-04	6.5 E-03	4.7 E-02
Skin	1.8 E-03	3.1 E-02	2.8 E-01	4.9 E-04	5.5 E-03	4.1 E-02	3.7 E-04	3.5 E-03	2.3 E-02	3.1 E-04	3.6 E-03	2.4 E-02
Spleen	2.5 E-03	4.1 E-02	4.1 E-01	8.6 E-04	7.4 E-03	4.8 E-02	5.7 E-04	4.7 E-03	3.1 E-02	5.3 E-04	4.8 E-03	3.2 E-02
Testes	2.5 E-03	4.1 E-02	5.0 E-01	6.6 E-04	7.3 E-03	6.4 E-02	4.7 E-04	4.8 E-03	3.9 E-02	4.8 E-04	4.9 E-03	3.7 E-02
Thymus	2.7 E-03	3.7 E-02	3.8 E-01	6.3 E-04	6.8 E-03	5.2 E-02	3.5 E-04	4.4 E-03	3.6 E-02	4.2 E-04	4.6 E-03	3.7 E-02
Thyroid	2.9 E-03	5.0 E-02	6.0 E-01	9.5 E-04	9.5 E-03	8.2 E-02	5.9 E-04	6.1 E-03	5.1 E-02	5.3 E-04	6.4 E-03	5.2 E-02

a. Consumption rate varies from 0.3 to 4.9 kg y⁻¹. It was assumed that 60% (range of 20 to 100%) of the fish was contaminated, and 85% (range of 80 to 90%) of the radioactivity in the fish was retained after processing (sections 7, 13.1).

Table A.4 Organ doses (cSv) from all radionuclides resulting from the consumption of fish for category I females exposed during the entire study period (48 years).

Organs	CRM 20.5			CRM 14			CRM 3.5			CRM 0		
	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	97.5%
Adrenals	2.7 E-02	3.4 E-01	3.5 E+00	7.6 E-03	6.0 E-02	4.0 E-01	6.1 E-03	4.0 E-02	2.6 E-01	5.3 E-03	3.8 E-02	9.7 E-01
Bladder	3.1 E-02	3.2 E-01	4.2 E+00	8.8 E-03	5.6 E-02	4.5 E-01	6.1 E-03	3.7 E-02	2.3 E-01	5.9 E-03	3.7 E-02	2.4 E-01
Bone	5.8 E-02	6.0 E-01	7.9 E+00	1.6 E-02	1.1 E-01	8.1 E-01	1.1 E-02	7.6 E-02	5.3 E-01	1.1 E-02	7.4 E-02	5.4 E-01
Brain	2.7 E-02	2.5 E-01	2.6 E+00	7.5 E-03	4.8 E-02	2.9 E-01	5.4 E-03	3.2 E-02	1.8 E-01	5.0 E-03	3.1 E-02	1.8 E-01
Breast	2.4 E-02	2.4 E-01	3.5 E+00	6.8 E-03	4.6 E-02	3.5 E-01	4.7 E-03	3.0 E-02	1.9 E-01	4.9 E-03	3.0 E-02	1.9 E-01
Stomach	3.3 E-02	3.1 E-01	4.0 E+00	8.9 E-03	5.8 E-02	4.2 E-01	6.4 E-03	4.0 E-02	2.6 E-01	6.4 E-03	3.8 E-02	2.5 E-01
Small Intestine	2.6 E-02	2.8 E-01	3.5 E+00	8.7 E-03	5.6 E-02	4.0 E-01	5.7 E-03	3.7 E-02	2.1 E-01	5.5 E-03	3.6 E-02	2.2 E-01
Upper Large Intestine	3.6 E-02	3.5 E-01	3.6 E+00	1.0 E-02	6.3 E-02	4.4 E-01	7.3 E-03	4.2 E-02	2.9 E-01	6.7 E-03	4.0 E-02	2.7 E-01
Lower Large Intestine	4.6 E-02	4.3 E-01	4.5 E+00	1.4 E-02	7.9 E-02	4.6 E-01	9.6 E-03	5.3 E-02	2.8 E-01	9.1 E-03	5.4 E-02	2.9 E-01
Kidneys	2.9 E-02	3.2 E-01	3.2 E+00	7.0 E-03	6.0 E-02	3.8 E-01	5.5 E-03	3.9 E-02	2.3 E-01	5.3 E-03	3.8 E-02	2.1 E-01
Liver	2.9 E-02	3.3 E-01	3.0 E+00	7.9 E-03	5.9 E-02	3.8 E-01	5.8 E-03	3.9 E-02	2.7 E-01	5.4 E-03	3.8 E-02	2.5 E-01
Lungs	2.4 E-02	2.7 E-01	3.0 E+00	6.3 E-03	5.2 E-02	3.6 E-01	4.9 E-03	3.3 E-02	2.2 E-01	4.3 E-03	3.3 E-02	2.1 E-01
Ovaries	1.7 E-02	1.8 E-01	2.1 E+00	4.8 E-03	3.4 E-02	2.3 E-01	3.3 E-03	2.1 E-02	1.2 E-01	3.3 E-03	2.1 E-02	1.3 E-01
Pancreas	2.7 E-02	3.0 E-01	3.2 E+00	9.0 E-03	6.0 E-02	3.7 E-01	5.8 E-03	3.8 E-02	2.7 E-01	6.0 E-03	3.7 E-02	2.1 E-01
Red Bone Marrow	3.9 E-02	4.2 E-01	4.8 E+00	1.5 E-02	7.5 E-02	4.9 E-01	1.0 E-02	5.2 E-02	3.3 E-01	9.5 E-03	5.0 E-02	3.0 E-01
Skin	2.2 E-02	2.3 E-01	2.8 E+00	6.5 E-03	4.5 E-02	2.9 E-01	4.7 E-03	2.9 E-02	2.0 E-01	4.4 E-03	2.8 E-02	1.9 E-01
Spleen	3.3 E-02	3.1 E-01	3.5 E+00	8.5 E-03	5.9 E-02	3.6 E-01	6.0 E-03	3.8 E-02	2.1 E-01	6.1 E-03	3.7 E-02	2.3 E-01
Thymus	3.2 E-02	3.1 E-01	3.8 E+00	8.1 E-03	5.4 E-02	4.7 E-01	5.7 E-03	3.5 E-02	3.1 E-01	6.1 E-03	3.5 E-02	3.3 E-01
Thyroid	2.85E-02	4.23E-01	5.07E+00	8.74E-03	7.79E-02	6.01E-01	5.72E-03	5.15E-02	3.87E-01	5.33E-03	5.36E-02	3.74E-01
Uterus	3.09E-02	3.18E-01	3.00E+00	8.32E-03	5.75E-02	3.65E-01	6.94E-03	3.80E-02	2.16E-01	6.11E-03	3.85E-02	2.18E-01

* Consumption rate varies from 4.6 to 31.7 kg y⁻¹. It was assumed that 60% (range of 20 to 100%) of the fish was contaminated, and 85% (range of 80 to 90%) of the radioactivity in the fish was retained after processing (sections 7, 13.1).

Table A.5 Organ doses (cSv) from all radionuclides resulting from the consumption of fish for category II females exposed during the entire study period (48 years)a.

Organs	CRM 20.5			CRM 14			CRM 3.5			CRM 0		
	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	97.5%
Adrenals	1.1 E-02	1.4 E-01	1.4 E+00	3.2 E-03	2.6 E-02	1.9 E-01	1.9 E-03	1.6 E-02	1.3 E-01	1.8 E-03	1.6 E-02	1.3 E-01
Bladder	1.1 E-02	1.5 E-01	1.5 E+00	3.2 E-03	2.5 E-02	1.8 E-01	1.9 E-03	1.6 E-02	1.1 E-01	1.8 E-03	1.7 E-02	1.2 E-01
Bone	1.9 E-02	2.8 E-01	2.7 E+00	5.5 E-03	4.7 E-02	2.9 E-01	3.7 E-03	3.3 E-02	2.1 E-01	4.1 E-03	3.4 E-02	2.1 E-01
Brain	1.0 E-02	1.2 E-01	1.0 E+00	2.3 E-03	2.2 E-02	1.5 E-01	1.5 E-03	1.4 E-02	8.8 E-02	1.5 E-03	1.4 E-02	9.3 E-02
Breast	8.9 E-03	1.1 E-01	9.6 E-01	2.4 E-03	2.0 E-02	1.4 E-01	1.4 E-03	1.3 E-02	9.6 E-02	1.5 E-03	1.3 E-02	9.1 E-02
Stomach	1.1 E-02	1.4 E-01	1.2 E+00	3.2 E-03	2.6 E-02	1.6 E-01	1.7 E-03	1.8 E-02	1.0 E-01	1.8 E-03	1.8 E-02	1.1 E-01
Small Intestine	1.0 E-02	1.4 E-01	1.3 E+00	2.8 E-03	2.4 E-02	1.5 E-01	1.9 E-03	1.8 E-02	1.1 E-01	1.7 E-03	1.6 E-02	1.0 E-01
Upper Large Intestine	1.4 E-02	1.6 E-01	1.3 E+00	3.6 E-03	2.7 E-02	1.7 E-01	2.3 E-03	1.8 E-02	1.2 E-01	2.4 E-03	1.8 E-02	1.2 E-01
Lower Large Intestine	1.8 E-02	1.9 E-01	1.7 E+00	4.8 E-03	3.4 E-02	2.3 E-01	3.1 E-03	2.3 E-02	1.4 E-01	2.9 E-03	2.3 E-02	1.5 E-01
Kidneys	9.4 E-03	1.4 E-01	1.2 E+00	2.9 E-03	2.5 E-02	1.6 E-01	1.9 E-03	1.7 E-02	9.8 E-02	1.8 E-03	1.6 E-02	8.9 E-02
Liver	8.7 E-03	1.5 E-01	1.2 E+00	2.5 E-03	2.6 E-02	1.9 E-01	1.6 E-03	1.7 E-02	1.3 E-01	1.5 E-03	1.7 E-02	1.3 E-01
Lungs	8.7 E-03	1.2 E-01	9.8 E-01	2.3 E-03	2.3 E-02	1.4 E-01	1.5 E-03	1.5 E-02	8.9 E-02	1.3 E-03	1.5 E-02	9.5 E-02
Ovaries	6.9 E-03	7.7 E-02	6.8 E-01	1.7 E-03	1.5 E-02	8.5 E-02	9.9 E-04	9.6 E-03	5.9 E-02	9.6 E-04	9.8 E-03	6.1 E-02
Pancreas	1.1 E-02	1.5 E-01	1.3 E+00	2.7 E-03	2.6 E-02	1.8 E-01	1.8 E-03	1.7 E-02	1.2 E-01	1.7 E-03	1.7 E-02	1.2 E-01
Red Bone Marrow	1.5 E-02	2.0 E-01	1.6 E+00	3.9 E-03	3.4 E-02	2.2 E-01	2.6 E-03	2.2 E-02	1.4 E-01	2.4 E-03	2.2 E-02	1.5 E-01
Skin	7.2 E-03	1.1 E-01	8.7 E-01	2.2 E-03	1.8 E-02	1.3 E-01	1.4 E-03	1.2 E-02	7.6 E-02	1.4 E-03	1.3 E-02	8.0 E-02
Spleen	1.2 E-02	1.4 E-01	1.2 E+00	2.8 E-03	2.5 E-02	1.6 E-01	1.8 E-03	1.7 E-02	1.0 E-01	1.8 E-03	1.6 E-02	1.0 E-01
Thymus	1.1 E-02	1.4 E-01	1.5 E+00	2.9 E-03	2.3 E-02	2.1 E-01	1.7 E-03	1.5 E-02	1.5 E-01	1.8 E-03	1.5 E-02	1.4 E-01
Thyroid	1.10E-02	1.85E-01	1.90E+00	2.99E-03	3.31E-02	2.69E-01	2.14E-03	2.26E-02	1.50E-01	2.06E-03	2.25E-02	1.52E-01
Uterus	9.91E-03	1.39E-01	1.13E+00	2.49E-03	2.46E-02	1.69E-01	1.48E-03	1.61E-02	1.14E-01	1.53E-03	1.62E-02	1.06E-01

a. Consumption rate varies from 1.5 to 15.6 kg y⁻¹. It was assumed that 60% (range of 20 to 100%) of the fish was contaminated, and 85% (range of 80 to 90%) of the radioactivity in the fish was retained after processing (sections 7, 13.1).

Table A.6 Organ doses (cSv) from all radionuclides resulting from the consumption of fish for category III females exposed during the entire study period (48 years)a.

Organs	CRM 20.5			CRM 14			CRM 3.5			CRM 0		
	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	97.5%
Adrenals	2.2 E-03	3.3 E-02	4.2 E-01	7.0 E-04	5.9 E-03	4.7 E-02	4.1 E-04	3.9 E-03	3.4 E-02	4.0 E-04	3.8 E-03	3.3 E-02
Bladder	2.3 E-03	3.4 E-02	4.2 E-01	6.4 E-04	5.3 E-03	6.6 E-02	4.3 E-04	3.6 E-03	3.2 E-02	4.6 E-04	3.6 E-03	3.5 E-02
Bone	3.8 E-03	5.9 E-02	8.1 E-01	1.2 E-03	1.2 E-02	7.4 E-02	7.0 E-04	7.9 E-03	5.3 E-02	9.1 E-04	7.8 E-03	5.3 E-02
Brain	1.8 E-03	2.6 E-02	3.1 E-01	5.9 E-04	4.4 E-03	4.5 E-02	3.5 E-04	3.1 E-03	2.6 E-02	3.2 E-04	2.9 E-03	2.9 E-02
Breast	1.8 E-03	2.5 E-02	4.0 E-01	5.2 E-04	4.3 E-03	5.2 E-02	3.3 E-04	2.8 E-03	2.6 E-02	3.2 E-04	2.8 E-03	2.5 E-02
Stomach	2.4 E-03	3.1 E-02	5.1 E-01	7.6 E-04	5.5 E-03	5.7 E-02	4.9 E-04	3.7 E-03	3.4 E-02	4.1 E-04	3.6 E-03	3.2 E-02
Small Intestine	2.5 E-03	3.2 E-02	4.2 E-01	6.3 E-04	5.2 E-03	4.5 E-02	4.1 E-04	3.5 E-03	3.0 E-02	3.5 E-04	3.4 E-03	3.0 E-02
Upper Large Intestine	2.8 E-03	3.5 E-02	4.3 E-01	7.8 E-04	5.9 E-03	6.0 E-02	4.8 E-04	4.0 E-03	3.8 E-02	4.4 E-04	4.0 E-03	3.6 E-02
Lower Large Intestine	3.9 E-03	4.2 E-02	5.2 E-01	8.7 E-04	7.3 E-03	6.0 E-02	6.2 E-04	5.0 E-03	3.8 E-02	6.0 E-04	5.0 E-03	3.8 E-02
Kidneys	2.2 E-03	3.3 E-02	4.4 E-01	6.4 E-04	5.8 E-03	5.1 E-02	3.7 E-04	3.9 E-03	3.0 E-02	4.2 E-04	3.7 E-03	3.1 E-02
Liver	2.5 E-03	3.5 E-02	3.7 E-01	6.7 E-04	5.5 E-03	5.4 E-02	3.9 E-04	3.7 E-03	3.4 E-02	3.7 E-04	3.8 E-03	3.4 E-02
Lungs	2.0 E-03	2.7 E-02	4.0 E-01	6.2 E-04	4.7 E-03	4.8 E-02	3.9 E-04	3.2 E-03	3.0 E-02	3.7 E-04	3.1 E-03	2.9 E-02
Ovaries	1.3 E-03	1.8 E-02	2.4 E-01	4.2 E-04	3.1 E-03	3.1 E-02	2.8 E-04	2.1 E-03	1.9 E-02	2.3 E-04	2.1 E-03	1.9 E-02
Pancreas	2.3 E-03	3.2 E-02	3.9 E-01	6.3 E-04	5.5 E-03	5.2 E-02	3.7 E-04	3.7 E-03	3.3 E-02	3.9 E-04	3.8 E-03	3.1 E-02
Red Bone Marrow	3.6 E-03	4.3 E-02	6.1 E-01	1.0 E-03	8.0 E-03	6.5 E-02	6.8 E-04	5.3 E-03	3.9 E-02	7.1 E-04	5.5 E-03	4.1 E-02
Skin	1.8 E-03	2.5 E-02	4.0 E-01	5.2 E-04	4.1 E-03	4.0 E-02	3.7 E-04	2.8 E-03	2.4 E-02	3.1 E-04	2.7 E-03	2.4 E-02
Spleen	2.3 E-03	3.2 E-02	4.7 E-01	7.3 E-04	5.4 E-03	4.9 E-02	4.7 E-04	3.7 E-03	3.0 E-02	4.7 E-04	3.8 E-03	3.3 E-02
Thymus	2.5 E-03	3.3 E-02	5.0 E-01	5.3 E-04	5.0 E-03	6.2 E-02	4.2 E-04	3.5 E-03	3.9 E-02	3.9 E-04	3.6 E-03	4.2 E-02
Thyroid	2.80E-03	4.28E-02	4.97E-01	7.89E-04	7.83E-03	7.05E-02	5.31E-04	5.11E-03	5.01E-02	4.38E-04	5.09E-03	4.00E-02
Uterus	2.62E-03	3.14E-02	4.92E-01	6.56E-04	5.38E-03	4.88E-02	4.20E-04	3.70E-03	3.09E-02	3.88E-04	3.67E-03	3.03E-02

a. Consumption rate varies from 0.2 to 4.2 kg y⁻¹. It was assumed that 60% (range of 20 to 100%) of the fish was contaminated, and 85% (range of 80 to 90%) of the radioactivity in the fish was retained after processing (sections 7, 13.1).

Table A.7 Organ doses (cSv) from all radionuclides for external exposure to shoreline sediments for individuals exposed during the entire study period (48 years).

Organs	CRM 20.5			CRM 14			CRM 3.5			CRM 0		
	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	97.5%
Adrenals	1.5 E-03	7.3 E-03	3.4 E-02	5.4 E-03	2.6 E-02	1.2 E-01	6.5 E-03	2.9 E-02	1.2 E-01	6.4 E-03	3.2 E-02	1.3 E-01
Bladder	1.6 E-03	7.6 E-03	3.1 E-02	5.2 E-03	2.9 E-02	1.4 E-01	5.5 E-03	2.9 E-02	1.3 E-01	6.4 E-03	3.2 E-02	1.5 E-01
Bone	2.6 E-03	1.2 E-02	5.9 E-02	8.1 E-03	4.7 E-02	2.2 E-01	8.0 E-03	4.5 E-02	2.2 E-01	8.9 E-03	5.0 E-02	2.4 E-01
Brain	1.7 E-03	8.0 E-03	3.1 E-02	6.7 E-03	3.0 E-02	1.2 E-01	6.8 E-03	3.2 E-02	1.2 E-01	7.7 E-03	3.4 E-02	1.4 E-01
Breast	1.8 E-03	9.0 E-03	3.9 E-02	7.0 E-03	3.4 E-02	1.5 E-01	7.1 E-03	3.6 E-02	1.4 E-01	7.6 E-03	3.7 E-02	1.6 E-01
Oral Cavity	1.7 E-03	8.1 E-03	3.2 E-02	6.8 E-03	3.1 E-02	1.2 E-01	6.9 E-03	3.2 E-02	1.2 E-01	7.8 E-03	3.4 E-02	1.4 E-01
Esophagus	1.4 E-03	6.7 E-03	2.6 E-02	5.7 E-03	2.6 E-02	1.0 E-01	5.8 E-03	2.7 E-02	1.0 E-01	6.5 E-03	2.9 E-02	1.2 E-01
Stomach	1.7 E-03	7.9 E-03	3.3 E-02	6.2 E-03	3.0 E-02	1.3 E-01	6.4 E-03	3.0 E-02	1.3 E-01	6.8 E-03	3.3 E-02	1.4 E-01
Small Intestine	1.4 E-03	6.5 E-03	2.8 E-02	4.7 E-03	2.4 E-02	1.1 E-01	5.8 E-03	2.5 E-02	1.1 E-01	5.8 E-03	2.7 E-02	1.2 E-01
Upper Large Intestine	1.5 E-03	7.0 E-03	3.2 E-02	5.3 E-03	2.8 E-02	1.2 E-01	5.7 E-03	2.9 E-02	1.2 E-01	6.6 E-03	3.3 E-02	1.3 E-01
Colon	1.3 E-03	7.1 E-03	3.0 E-02	5.6 E-03	2.7 E-02	1.4 E-01	5.8 E-03	2.7 E-02	1.3 E-01	6.5 E-03	2.9 E-02	1.3 E-01
Rectum	1.5 E-03	7.0 E-03	2.7 E-02	6.0 E-03	2.7 E-02	1.1 E-01	6.0 E-03	2.8 E-02	1.1 E-01	6.9 E-03	3.0 E-02	1.2 E-01
Gallbladder	1.5 E-03	6.9 E-03	2.7 E-02	5.8 E-03	2.6 E-02	1.1 E-01	6.0 E-03	2.8 E-02	1.1 E-01	6.7 E-03	3.0 E-02	1.2 E-01
Kidneys	1.4 E-03	7.3 E-03	3.5 E-02	6.0 E-03	2.9 E-02	1.2 E-01	6.3 E-03	3.0 E-02	1.1 E-01	7.3 E-03	3.3 E-02	1.3 E-01
Liver	1.4 E-03	7.5 E-03	3.2 E-02	5.3 E-03	2.8 E-02	1.2 E-01	6.1 E-03	2.9 E-02	1.2 E-01	6.5 E-03	3.1 E-02	1.3 E-01
Lungs	1.5 E-03	8.0 E-03	3.2 E-02	6.1 E-03	2.9 E-02	1.1 E-01	6.3 E-03	3.0 E-02	1.2 E-01	7.9 E-03	3.3 E-02	1.3 E-01
Ovaries	7.9 E-04	3.8 E-03	1.6 E-02	3.0 E-03	1.5 E-02	6.6 E-02	3.5 E-03	1.6 E-02	6.5 E-02	3.7 E-03	1.7 E-02	6.9 E-02
Pancreas	1.4 E-03	6.6 E-03	3.1 E-02	5.1 E-03	2.6 E-02	1.2 E-01	5.8 E-03	2.7 E-02	1.2 E-01	6.1 E-03	2.9 E-02	1.2 E-01
Prostate	1.74E-03	8.09E-03	3.16E-02	6.82E-03	3.10E-02	1.25E-01	6.90E-03	3.21E-02	1.22E-01	7.80E-03	3.45E-02	1.39E-01
Red Bone Marrow	1.59E-03	7.72E-03	3.78E-02	5.24E-03	2.86E-02	1.28E-01	6.06E-03	2.98E-02	1.26E-01	6.46E-03	3.16E-02	1.48E-01
Skin	2.17E-03	1.00E-02	3.92E-02	8.81E-03	3.99E-02	1.57E-01	9.78E-03	4.41E-02	1.63E-01	1.12E-02	4.65E-02	1.86E-01
Spleen	1.60E-03	7.43E-03	2.90E-02	6.28E-03	2.85E-02	1.14E-01	6.35E-03	2.96E-02	1.12E-01	7.19E-03	3.17E-02	1.28E-01
Testes	2.02E-03	9.97E-03	4.27E-02	7.07E-03	3.58E-02	2.11E-01	7.53E-03	3.61E-02	2.07E-01	8.97E-03	4.01E-02	2.25E-01
Thymus	1.44E-03	7.87E-03	4.15E-02	4.95E-03	3.22E-02	1.80E-01	5.33E-03	3.26E-02	1.69E-01	5.90E-03	3.84E-02	1.94E-01
Thyroid	1.90E-03	1.08E-02	5.19E-02	6.45E-03	3.85E-02	1.81E-01	7.72E-03	3.96E-02	1.86E-01	8.48E-03	4.40E-02	1.86E-01
Uterus	1.47E-03	6.80E-03	2.65E-02	5.78E-03	2.61E-02	1.05E-01	5.85E-03	2.72E-02	1.03E-01	6.66E-03	2.92E-02	1.17E-01
Remainder	1.82E-03	8.25E-03	3.70E-02	5.82E-03	3.32E-02	1.44E-01	6.48E-03	3.30E-02	1.40E-01	7.09E-03	3.67E-02	1.56E-01

Table A.8 Organ doses (cSv) from all radionuclides for the ingestion of drinking water for individuals exposed during the entire study period (48 years)a.

Organs	CRM 14				CRM 3.5				CRM 0, stationary ^b				CRM 0, mobile			
	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%
Adrenals	3.7 E-04	2.3 E-03	1.6 E-02	2.3 E-04	1.4 E-03	1.2 E-02	1.3 E-05	1.5 E-04	1.3 E-05	1.5 E-04	2.5 E-03	1.1 E-05	1.3 E-04	1.6 E-03	1.1 E-05	1.3 E-04
Bladder	4.1 E-04	2.3 E-03	1.6 E-02	2.3 E-04	1.5 E-03	1.6 E-02	1.3 E-05	1.5 E-04	1.3 E-05	1.5 E-04	2.1 E-03	1.2 E-05	1.2 E-04	1.5 E-03	1.2 E-05	1.2 E-04
Bone	2.5 E-02	1.1 E-01	5.5 E-01	1.1 E-02	5.1 E-02	2.0 E-01	5.3 E-04	3.5 E-03	5.3 E-04	3.5 E-03	1.8 E-02	4.4 E-04	2.8 E-03	1.5 E-02	4.4 E-04	2.8 E-03
Brain	3.8 E-04	2.1 E-03	1.7 E-02	2.1 E-04	1.4 E-03	1.4 E-02	1.3 E-05	1.2 E-04	1.3 E-05	1.2 E-04	1.7 E-03	1.3 E-05	9.8 E-05	1.1 E-03	1.3 E-05	9.8 E-05
Breast	3.4 E-04	2.1 E-03	1.6 E-02	2.1 E-04	1.3 E-03	1.2 E-02	1.4 E-05	1.2 E-04	1.4 E-05	1.2 E-04	1.4 E-03	1.1 E-05	1.1 E-04	1.2 E-03	1.1 E-05	1.1 E-04
Stomach	9.1 E-04	5.1 E-03	3.2 E-02	6.6 E-04	3.6 E-03	2.7 E-02	4.2 E-05	3.6 E-04	4.2 E-05	3.6 E-04	4.2 E-03	3.3 E-05	2.8 E-04	3.9 E-03	3.3 E-05	2.8 E-04
Small Intestine	1.7 E-03	6.3 E-03	2.7 E-02	1.3 E-03	5.1 E-03	2.2 E-02	6.6 E-05	5.1 E-04	6.6 E-05	5.1 E-04	3.2 E-03	6.2 E-05	4.5 E-04	2.7 E-03	6.2 E-05	4.5 E-04
Upper Large Intestine	7.7 E-03	3.4 E-02	1.4 E-01	6.2 E-03	2.6 E-02	9.2 E-02	3.8 E-04	2.7 E-03	3.8 E-04	2.7 E-03	1.8 E-02	2.6 E-04	2.1 E-03	1.2 E-02	2.6 E-04	2.1 E-03
Lower Large Intestine	1.9 E-02	8.1 E-02	3.7 E-01	1.5 E-02	5.8 E-02	2.4 E-01	9.8 E-04	6.2 E-03	9.8 E-04	6.2 E-03	3.9 E-02	7.5 E-04	5.1 E-03	3.0 E-02	7.5 E-04	5.1 E-03
Kidneys	4.9 E-04	2.4 E-03	1.7 E-02	2.7 E-04	1.7 E-03	1.4 E-02	1.8 E-05	1.5 E-04	1.8 E-05	1.5 E-04	1.8 E-03	1.2 E-05	1.4 E-04	1.5 E-03	1.2 E-05	1.4 E-04
Liver	4.5 E-04	2.4 E-03	1.9 E-02	2.7 E-04	1.6 E-03	1.6 E-02	1.6 E-05	1.5 E-04	1.6 E-05	1.5 E-04	2.1 E-03	1.3 E-05	1.4 E-04	1.8 E-03	1.3 E-05	1.4 E-04
Lungs	3.6 E-04	2.2 E-03	1.7 E-02	2.1 E-04	1.4 E-03	1.6 E-02	1.6 E-05	1.5 E-04	1.6 E-05	1.5 E-04	1.4 E-03	1.2 E-05	1.2 E-04	1.3 E-03	1.2 E-05	1.2 E-04
Ovaries	2.5 E-04	1.4 E-03	1.2 E-02	1.4 E-04	9.8 E-04	1.1 E-02	9.6 E-06	1.1 E-04	9.6 E-06	1.1 E-04	1.3 E-03	8.7 E-06	8.2 E-05	9.4 E-04	8.7 E-06	8.2 E-05
Pancreas	3.9 E-04	2.4 E-03	1.9 E-02	2.1 E-04	1.6 E-03	1.5 E-02	1.5 E-05	1.5 E-04	1.5 E-05	1.5 E-04	2.3 E-03	1.2 E-05	1.2 E-04	1.4 E-03	1.2 E-05	1.2 E-04
Red Bone Marrow	1.2 E-02	4.6 E-02	1.9 E-01	5.8 E-03	2.2 E-02	9.9 E-02	2.2 E-04	1.7 E-03	2.2 E-04	1.7 E-03	9.7 E-03	1.9 E-04	1.4 E-03	7.2 E-03	1.9 E-04	1.4 E-03
Skin	3.6 E-04	2.4 E-03	1.4 E-02	2.0 E-04	1.5 E-03	1.1 E-02	1.7 E-05	1.4 E-04	1.7 E-05	1.4 E-04	1.6 E-03	1.2 E-05	1.2 E-04	1.1 E-03	1.2 E-05	1.2 E-04
Spleen	4.5 E-04	2.5 E-03	1.8 E-02	2.2 E-04	1.6 E-03	1.3 E-02	1.4 E-05	1.6 E-04	1.4 E-05	1.6 E-04	2.1 E-03	9.5 E-06	1.3 E-04	1.4 E-03	9.5 E-06	1.3 E-04
Testes	4.2 E-04	2.6 E-03	2.9 E-02	2.3 E-04	1.7 E-03	2.0 E-02	1.2 E-05	1.6 E-04	1.2 E-05	1.6 E-04	3.3 E-03	1.3 E-05	1.3 E-04	2.5 E-03	1.3 E-05	1.3 E-04
Thymus	3.72E-04	2.44E-03	2.53E-02	2.37E-04	1.47E-03	2.32E-02	1.72E-05	1.53E-04	1.72E-05	1.53E-04	1.68E-03	1.32E-05	1.42E-04	1.77E-03	1.32E-05	1.42E-04
Thyroid	5.44E-04	3.40E-03	2.14E-02	2.86E-04	2.18E-03	1.97E-02	2.26E-05	1.93E-04	2.26E-05	1.93E-04	3.07E-03	2.04E-05	1.57E-04	1.89E-03	2.04E-05	1.57E-04
Uterus	4.33E-04	2.55E-03	2.12E-02	2.38E-04	1.70E-03	1.64E-02	1.87E-05	1.60E-04	1.87E-05	1.60E-04	1.91E-03	1.38E-05	1.45E-04	1.74E-03	1.38E-05	1.45E-04

a Unless otherwise noted, an ingestion of 20 to 60% of filtered, treated water from the Clinch River is assumed.

b An ingestion of 20 to 80% of filtered, treated water from the Clinch River is assumed for an individual who resides and works near CRM 0.

Table A.9 Organ doses (cSv) from all radionuclides for the ingestion of meat for individuals exposed during the entire study period (46 years).

Organs	CRM 20.5 ^a			CRM 14 ^a			CRM 3.5 ^b			CRM 0 ^b		
	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	97.5%
Adrenals	3.3 E-06	3.3 E-05	2.0 E-04	4.8 E-05	3.7 E-04	2.1 E-03	1.8 E-05	1.7 E-04	8.3 E-04	1.7 E-05	1.6 E-04	9.5 E-04
Bladder	3.6 E-06	3.2 E-05	2.1 E-04	4.5 E-05	3.7 E-04	2.5 E-03	1.3 E-05	1.6 E-04	1.1 E-03	1.6 E-05	1.6 E-04	1.2 E-03
Bone	1.0 E-05	1.2 E-04	2.8 E-03	1.2 E-04	1.4 E-03	3.0 E-02	4.8 E-05	5.7 E-04	1.6 E-02	4.4 E-05	5.8 E-04	1.8 E-02
Brain	3.5 E-06	2.9 E-05	1.8 E-04	4.0 E-05	3.2 E-04	2.2 E-03	1.5 E-05	1.4 E-04	9.6 E-04	1.4 E-05	1.4 E-04	8.1 E-04
Breast	3.1 E-06	2.6 E-05	1.9 E-04	3.7 E-05	3.1 E-04	1.7 E-03	1.2 E-05	1.3 E-04	1.0 E-03	1.4 E-05	1.2 E-04	8.7 E-04
Stomach	4.8 E-06	4.2 E-05	4.0 E-04	6.0 E-05	4.8 E-04	2.9 E-03	2.0 E-05	2.0 E-04	1.6 E-03	2.0 E-05	2.0 E-04	1.5 E-03
Small Intestine	4.8 E-06	4.5 E-05	3.3 E-04	5.8 E-05	5.0 E-04	3.4 E-03	1.9 E-05	2.1 E-04	1.7 E-03	2.3 E-05	2.2 E-04	1.6 E-03
Upper Large Intestine	8.9 E-06	1.2 E-04	1.3 E-03	8.8 E-05	1.2 E-03	1.0 E-02	4.3 E-05	5.4 E-04	5.8 E-03	4.1 E-05	5.5 E-04	6.7 E-03
Lower Large Intestine	1.3 E-05	2.3 E-04	3.4 E-03	1.5 E-04	2.1 E-03	2.9 E-02	6.8 E-05	1.1 E-03	1.4 E-02	6.6 E-05	1.1 E-03	1.3 E-02
Kidneys	4.1 E-06	3.2 E-05	2.3 E-04	4.9 E-05	3.8 E-04	2.4 E-03	1.9 E-05	1.6 E-04	1.2 E-03	1.6 E-05	1.6 E-04	1.3 E-03
Liver	4.7 E-06	3.3 E-05	2.4 E-04	4.9 E-05	4.0 E-04	2.2 E-03	1.8 E-05	1.6 E-04	1.0 E-03	1.7 E-05	1.7 E-04	1.3 E-03
Lungs	3.5 E-06	3.1 E-05	2.2 E-04	4.5 E-05	3.3 E-04	2.3 E-03	1.5 E-05	1.4 E-04	8.9 E-04	1.5 E-05	1.4 E-04	1.0 E-03
Ovaries	2.2 E-06	2.0 E-05	1.4 E-04	2.5 E-05	2.1 E-04	1.3 E-03	9.6 E-06	9.3 E-05	5.9 E-04	9.6 E-06	9.5 E-05	6.8 E-04
Pancreas	4.0 E-06	3.4 E-05	2.5 E-04	4.9 E-05	3.8 E-04	2.5 E-03	1.7 E-05	1.6 E-04	1.3 E-03	1.8 E-05	1.7 E-04	1.4 E-03
Red Bone Marrow	7.9 E-06	7.1 E-05	1.5 E-03	1.0 E-04	8.1 E-04	1.7 E-02	3.7 E-05	3.5 E-04	7.8 E-03	3.7 E-05	3.2 E-04	7.9 E-03
Skin	3.0 E-06	2.7 E-05	1.8 E-04	4.2 E-05	3.1 E-04	1.8 E-03	1.3 E-05	1.4 E-04	8.9 E-04	1.3 E-05	1.4 E-04	9.5 E-04
Spleen	4.0 E-06	3.3 E-05	2.2 E-04	5.4 E-05	3.8 E-04	2.6 E-03	1.6 E-05	1.5 E-04	1.2 E-03	1.8 E-05	1.6 E-04	1.2 E-03
Testes	3.7 E-06	3.5 E-05	3.9 E-04	4.7 E-05	3.9 E-04	3.1 E-03	1.6 E-05	1.6 E-04	1.7 E-03	1.3 E-05	1.7 E-04	1.6 E-03
Thymus	3.03E-06	3.41E-05	2.41E-04	3.20E-05	3.68E-04	2.53E-03	1.39E-05	1.63E-04	1.16E-03	1.17E-05	1.74E-04	1.27E-03
Thyroid	4.75E-06	4.39E-05	3.59E-04	5.82E-05	4.99E-04	3.85E-03	2.05E-05	2.21E-04	1.76E-03	1.79E-05	2.37E-04	1.77E-03
Uterus	4.59E-06	3.31E-05	2.33E-04	4.85E-05	3.73E-04	2.52E-03	1.75E-05	1.67E-04	1.13E-03	2.13E-05	1.71E-04	1.11E-03

^a Based on ingestion of 30 to 80% of meat from cattle that had access to the Clinch River.

^b Based on ingestion of 10 to 60% of meat from cattle that had access to the Clinch River.

Table A.10 Organ doses (cSv) from all radionuclides for the ingestion of milk for individuals exposed during the entire study period (48 years)a.

Organs	CRM 20.5			CRM 14			CRM 3.5			CRM 0		
	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	97.5%
Adrenals	6.8 E-07	5.1 E-06	4.4 E-05	7.1 E-06	6.4 E-05	5.4 E-04	4.6 E-06	4.1 E-05	3.0 E-04	4.6 E-06	4.2 E-05	3.3 E-04
Bladder	5.5 E-07	5.4 E-06	4.1 E-05	6.4 E-06	6.3 E-05	5.3 E-04	4.1 E-06	4.3 E-05	3.1 E-04	4.3 E-06	4.2 E-05	3.1 E-04
Bone	1.1 E-05	7.8 E-05	7.0 E-04	1.3 E-04	8.4 E-04	6.8 E-03	1.0 E-04	5.9 E-04	5.2 E-03	9.0 E-05	6.2 E-04	5.0 E-03
Brain	4.2 E-07	4.1 E-06	3.7 E-05	5.6 E-06	5.3 E-05	4.9 E-04	4.0 E-06	3.5 E-05	2.6 E-04	4.3 E-06	3.3 E-05	2.6 E-04
Breast	5.2 E-07	3.9 E-06	3.8 E-05	5.3 E-06	4.6 E-05	4.3 E-04	3.5 E-06	3.1 E-05	2.7 E-04	4.0 E-06	3.1 E-05	2.8 E-04
Stomach	7.0 E-07	5.4 E-06	4.3 E-05	8.5 E-06	6.5 E-05	4.8 E-04	5.3 E-06	4.4 E-05	3.0 E-04	5.4 E-06	4.3 E-05	2.8 E-04
Small Intestine	6.5 E-07	5.0 E-06	4.4 E-05	6.8 E-06	5.7 E-05	4.0 E-04	4.7 E-06	3.7 E-05	2.8 E-04	4.9 E-06	3.9 E-05	3.0 E-04
Upper Large Intestine	1.0 E-06	7.4 E-06	4.7 E-05	1.3 E-05	7.9 E-05	5.9 E-04	9.3 E-06	5.2 E-05	3.5 E-04	9.0 E-06	5.3 E-05	3.7 E-04
Lower Large Intestine	1.5 E-06	1.1 E-05	6.5 E-05	2.3 E-05	1.3 E-04	7.4 E-04	1.5 E-05	9.0 E-05	4.5 E-04	1.5 E-05	9.0 E-05	5.1 E-04
Kidneys	6.5 E-07	5.0 E-06	4.2 E-05	7.4 E-06	5.9 E-05	5.0 E-04	4.6 E-06	4.0 E-05	3.4 E-04	5.6 E-06	4.0 E-05	3.0 E-04
Liver	6.3 E-07	5.5 E-06	5.1 E-05	6.6 E-06	6.4 E-05	5.7 E-04	5.0 E-06	4.2 E-05	3.2 E-04	5.0 E-06	4.2 E-05	3.7 E-04
Lungs	5.6 E-07	4.4 E-06	3.8 E-05	6.7 E-06	5.4 E-05	5.2 E-04	4.3 E-06	3.5 E-05	2.6 E-04	4.5 E-06	3.4 E-05	2.9 E-04
Ovaries	4.1 E-07	2.9 E-06	2.6 E-05	5.0 E-06	3.8 E-05	3.0 E-04	3.0 E-06	2.4 E-05	2.0 E-04	3.2 E-06	2.4 E-05	2.0 E-04
Pancreas	6.2 E-07	5.3 E-06	4.7 E-05	7.9 E-06	6.1 E-05	4.7 E-04	5.0 E-06	4.1 E-05	3.4 E-04	5.7 E-06	4.1 E-05	2.8 E-04
Red Bone Marrow	4.8 E-06	3.9 E-05	2.5 E-04	6.4 E-05	4.2 E-04	2.7 E-03	4.7 E-05	3.0 E-04	2.0 E-03	4.3 E-05	3.0 E-04	2.1 E-03
Skin	4.5 E-07	3.8 E-06	3.3 E-05	5.5 E-06	4.8 E-05	4.2 E-04	4.5 E-06	3.0 E-05	2.4 E-04	4.1 E-06	3.1 E-05	2.7 E-04
Spleen	5.4 E-07	5.1 E-06	4.5 E-05	7.0 E-06	6.2 E-05	5.3 E-04	4.7 E-06	3.9 E-05	3.1 E-04	5.0 E-06	4.0 E-05	3.1 E-04
Testes	5.6 E-07	5.1 E-06	6.0 E-05	5.5 E-06	6.2 E-05	8.5 E-04	4.1 E-06	4.0 E-05	4.7 E-04	4.6 E-06	3.9 E-05	4.0 E-04
Thymus	3.81E-07	5.08E-06	4.43E-05	4.58E-06	5.86E-05	5.40E-04	3.64E-06	3.98E-05	3.55E-04	3.47E-06	4.08E-05	3.39E-04
Thyroid	6.98E-07	6.64E-06	7.25E-05	7.91E-06	8.47E-05	7.68E-04	6.01E-06	5.57E-05	4.65E-04	5.97E-06	5.43E-05	4.92E-04
Uterus	5.63E-07	4.96E-06	4.68E-05	6.20E-06	6.14E-05	4.85E-04	4.29E-06	4.20E-05	2.99E-04	5.22E-06	4.03E-05	3.11E-04

a. Based on ingestion of 63 to 100% of milk from cattle that had access to the Clinch River.

APPENDIX B

Table B.1 Organ-specific risks of cancer from all radionuclides for a category I male consumer of fisha exposed during the entire study period (48 years).

Cancer Type	CRM 20.5			CRM 14			CRM 3.5			CRM 0		
	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	97.5%
Bladder	7.8 E-07	1.2 E-05	1.9 E-04	2.1 E-07	2.1 E-06	2.2 E-05	1.3 E-07	1.4 E-06	1.5 E-05	1.4 E-07	1.3 E-06	1.4 E-05
Stomach	8.1 E-08	3.1 E-06	1.4 E-04	1.8 E-08	5.6 E-07	1.3 E-05	1.1 E-08	3.6 E-07	9.7 E-06	1.1 E-08	3.6 E-07	1.0 E-05
Colon	2.5 E-06	2.7 E-05	2.8 E-04	5.9 E-07	4.7 E-06	4.4 E-05	3.2 E-07	3.3 E-06	2.7 E-05	3.4 E-07	3.2 E-06	3.1 E-05
Kidney	1.9 E-07	3.2 E-06	4.9 E-05	3.3 E-08	5.2 E-07	6.9 E-06	2.1 E-08	3.4 E-07	4.6 E-06	2.2 E-08	3.7 E-07	4.7 E-06
Liver	8.1 E-08	2.2 E-06	1.3 E-04	1.6 E-08	4.3 E-07	1.5 E-05	1.2 E-08	2.6 E-07	8.7 E-06	1.3 E-08	2.7 E-07	8.3 E-06
Lung	1.4 E-06	1.9 E-05	2.2 E-04	3.8 E-07	2.9 E-06	2.4 E-05	1.9 E-07	2.1 E-06	1.5 E-05	1.9 E-07	2.0 E-06	1.7 E-05
Pancreas	3.5 E-08	9.4 E-07	3.1 E-05	9.7 E-09	1.6 E-07	4.8 E-06	5.4 E-09	1.0 E-07	2.7 E-06	5.8 E-09	9.5 E-08	2.9 E-06
Leukemia (RBM ^b)	2.5 E-06	3.7 E-05	3.4 E-04	7.9 E-07	6.1 E-06	4.1 E-05	5.3 E-07	4.3 E-06	2.8 E-05	5.4 E-07	4.3 E-06	2.7 E-05
Thyroid	3.6 E-07	5.8 E-06	9.0 E-05	7.5 E-08	1.0 E-06	1.1 E-05	4.2 E-08	6.6 E-07	7.1 E-06	4.6 E-08	6.6 E-07	6.5 E-06

^a Consumption rate varies from 5.5 to 36.5 kg y⁻¹. It was assumed that 60% (range of 20 to 100%) of the fish was contaminated, and 85% (range of 80 to 90%) of the radioactivity in the fish was retained after processing (sections 7, 13.1).

^b RBM = Red Bone Marrow

Table B.2 Organ-specific risks of various types of cancer from all radionuclides for a category II male consumer of fisha exposed during the entire study period (48 years).

Cancer Type	CRM 20.5			CRM 14			CRM 3.5			CRM 0		
	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	97.5%
Bladder	3.6 E-07	4.4 E-06	9.0 E-05	7.4 E-08	8.7 E-07	9.6 E-06	4.4 E-08	5.9 E-07	6.3 E-06	5.1 E-08	5.5 E-07	6.8 E-06
Stomach	3.1 E-08	1.3 E-06	6.6 E-05	6.7 E-09	2.2 E-07	6.6 E-06	4.2 E-09	1.4 E-07	4.7 E-06	4.0 E-09	1.4 E-07	4.7 E-06
Colon	7.0 E-07	1.1 E-05	1.3 E-04	1.9 E-07	2.1 E-06	2.1 E-05	1.1 E-07	1.4 E-06	1.2 E-05	1.0 E-07	1.4 E-06	1.2 E-05
Kidney	5.0 E-08	1.5 E-06	2.3 E-05	1.5 E-08	2.4 E-07	3.0 E-06	9.7 E-09	1.6 E-07	2.0 E-06	9.5 E-09	1.7 E-07	2.0 E-06
Liver	3.5 E-08	1.1 E-06	3.9 E-05	9.0 E-09	1.9 E-07	5.3 E-06	6.1 E-09	1.2 E-07	3.9 E-06	6.1 E-09	1.2 E-07	3.6 E-06
Lung	5.1 E-07	7.4 E-06	8.0 E-05	1.2 E-07	1.3 E-06	1.1 E-05	7.0 E-08	8.5 E-07	7.2 E-06	6.5 E-08	8.7 E-07	7.0 E-06
Pancreas	1.5 E-08	4.2 E-07	1.2 E-05	3.1 E-09	7.0 E-08	2.1 E-06	1.7 E-09	4.6 E-08	1.2 E-06	2.0 E-09	4.6 E-08	1.2 E-06
Leukemia (RBM) ^b	8.6 E-07	1.6 E-05	1.3 E-04	2.5 E-07	2.7 E-06	1.9 E-05	1.5 E-07	1.9 E-06	1.2 E-05	1.5 E-07	1.9 E-06	1.2 E-05
Thyroid	1.4 E-07	2.8 E-06	3.6 E-05	2.7 E-08	4.3 E-07	4.7 E-06	2.1 E-08	3.1 E-07	3.4 E-06	1.7 E-08	3.0 E-07	3.0 E-06

^a Consumption rate varies from 1.5 to 19.7 kg y⁻¹. It was assumed that 60% (range of 20 to 100%) of the fish was contaminated, and 85% (range of 80 to 90%) of the radioactivity in the fish was retained after processing (sections 7, 13.1).

^b RBM = Red Bone Marrow

Table B.3 Organ-specific risks of various types of cancer from all radionuclides for a category III male consumer of fisha exposed during the entire study period (48 years).

Cancer Type	CRM 20.5			CRM 14			CRM 3.5			CRM 0		
	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	97.5%
Bladder	6.0 E-08	1.1 E-06	2.0 E-05	1.6 E-08	2.0 E-07	2.5 E-06	1.1 E-08	1.3 E-07	1.5 E-06	9.2 E-09	1.3 E-07	1.8 E-06
Stomach	6.1 E-09	3.2 E-07	1.1 E-05	1.4 E-09	5.2 E-08	1.7 E-06	8.5 E-10	3.3 E-08	1.2 E-06	9.0 E-10	3.6 E-08	1.0 E-06
Colon	1.7 E-07	2.5 E-08	3.4 E-05	4.8 E-08	4.7 E-07	4.7 E-06	3.1 E-08	3.1 E-07	2.9 E-08	2.9 E-08	3.2 E-07	3.3 E-06
Kidney	1.3 E-08	3.4 E-07	4.8 E-06	3.5 E-09	5.6 E-08	8.9 E-07	2.1 E-09	3.9 E-08	5.2 E-07	2.1 E-09	3.7 E-08	5.0 E-07
Liver	7.0 E-09	2.3 E-07	8.6 E-06	1.1 E-09	4.6 E-08	1.4 E-06	8.4 E-10	2.9 E-08	9.0 E-07	8.8 E-10	2.8 E-08	8.9 E-07
Lung	1.1 E-07	1.8 E-06	1.6 E-05	2.5 E-08	3.2 E-07	2.6 E-06	1.7 E-08	2.1 E-07	1.7 E-06	1.8 E-08	2.1 E-07	1.8 E-06
Pancreas	3.0 E-09	9.4 E-08	2.4 E-06	6.8 E-10	1.5 E-08	4.8 E-07	4.2 E-10	1.0 E-08	2.4 E-07	4.0 E-10	1.0 E-08	3.4 E-07
Leukemia (RBM ^b)	1.8 E-07	3.8 E-06	3.7 E-05	6.0 E-08	6.7 E-07	5.5 E-06	4.0 E-08	4.3 E-07	3.2 E-06	3.5 E-08	4.4 E-07	3.3 E-06
Thyroid	2.8 E-08	5.9 E-07	9.6 E-06	5.8 E-09	1.0 E-07	1.1 E-06	3.8 E-09	6.7 E-08	8.2 E-07	4.1 E-09	6.7 E-08	7.1 E-07

* Consumption rate varies from 0.3 to 4.9 kg y⁻¹. It was assumed that 60% (range of 20 to 100%) of the fish was contaminated, and 85% (range of 80 to 90%) of the radioactivity in the fish was retained after processing (sections 7, 13.1).

^b RBM = Red Bone Marrow

Table B.4 Organ-specific risks of various types of cancer from all radionuclides for a category I female consumer of fisha exposed during the entire study period (48 years).

Cancer Type	CRM 20.5			CRM 14			CRM 3.5			CRM 0		
	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	97.5%
Bladder	8.5 E-07	8.9 E-06	1.7 E-04	1.6 E-07	1.6 E-06	2.1 E-05	1.1 E-07	1.1 E-06	1.2 E-05	1.1 E-07	1.1 E-06	1.3 E-05
Breast	4.3 E-06	5.5 E-05	9.2 E-04	1.4 E-06	9.7 E-06	1.1 E-04	8.5 E-07	6.6 E-06	6.9 E-05	9.1 E-07	6.5 E-06	7.1 E-05
Stomach	7.6 E-08	2.4 E-06	1.0 E-04	2.0 E-08	4.3 E-07	9.0 E-06	1.2 E-08	2.8 E-07	6.5 E-06	1.4 E-08	2.7 E-07	6.5 E-06
Colon	1.6 E-06	2.2 E-05	2.6 E-04	5.2 E-07	4.0 E-06	3.4 E-05	3.1 E-07	2.7 E-06	2.3 E-05	3.4 E-07	2.8 E-06	2.3 E-05
Kidney	1.2 E-07	2.6 E-06	4.0 E-05	2.7 E-08	4.5 E-07	5.3 E-06	2.1 E-08	3.2 E-07	4.0 E-06	1.9 E-08	3.0 E-07	4.4 E-06
Liver	6.4 E-08	2.0 E-06	7.7 E-05	1.3 E-08	4.0 E-07	9.4 E-06	9.9 E-09	2.7 E-07	6.5 E-06	9.3 E-09	2.5 E-07	6.1 E-06
Lung	1.2 E-06	1.3 E-05	2.0 E-04	3.1 E-07	2.6 E-06	1.9 E-05	2.1 E-07	1.7 E-06	1.1 E-05	2.0 E-07	1.7 E-06	1.3 E-05
Ovarian	2.7 E-07	5.1 E-06	8.9 E-05	8.0 E-08	9.8 E-07	9.6 E-06	4.8 E-08	6.5 E-07	6.1 E-06	5.4 E-08	6.1 E-07	6.2 E-06
Pancreas	3.5 E-08	6.8 E-07	2.8 E-05	8.6 E-09	1.3 E-07	3.2 E-06	4.5 E-09	9.2 E-08	1.9 E-06	5.2 E-09	8.4 E-08	2.1 E-06
Leukemia (RBM ^b)	2.5 E-06	2.7 E-05	4.0 E-04	7.1 E-07	5.1 E-06	3.7 E-05	4.4 E-07	3.5 E-06	2.5 E-05	4.3 E-07	3.5 E-06	2.3 E-05
Thyroid	3.6 E-07	4.8 E-06	8.8 E-05	7.6 E-08	8.7 E-07	8.9 E-06	5.2 E-08	5.5 E-07	6.2 E-06	5.3 E-08	5.7 E-07	6.1 E-06

^a Consumption rate varies from 4.6 to 31.7 kg y⁻¹. It was assumed that 60% (range of 20 to 100%) of the fish was contaminated, and 85% (range of 80 to 90%) of the radioactivity in the fish was retained after processing (sections 7, 13.1).

^b RBM = Red Bone Marrow

Table B.5 Organ-specific risks of various types of cancer from all radionuclides for a category II female consumer of fish exposed during the entire study period (48 years).

Cancer Type	CRM 20.5			CRM 14			CRM 3.5			CRM 0		
	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	97.5%
Bladder	2.2 E-07	3.8 E-06	8.4 E-05	5.0 E-08	6.9 E-07	1.1 E-05	3.5 E-08	4.6 E-07	6.9 E-06	3.9 E-08	4.6 E-07	5.9 E-06
Breast	1.9 E-06	2.3 E-05	4.1 E-04	5.0 E-07	4.2 E-06	4.9 E-05	3.2 E-07	2.8 E-06	3.5 E-05	2.9 E-07	2.8 E-06	3.3 E-05
Stomach	3.6 E-08	9.8 E-07	3.2 E-05	7.0 E-09	1.8 E-07	4.4 E-06	4.9 E-09	1.2 E-07	2.8 E-06	5.1 E-09	1.2 E-07	2.8 E-06
Colon	5.8 E-07	9.3 E-06	1.4 E-04	1.4 E-07	1.6 E-06	1.8 E-05	1.0 E-07	1.2 E-06	1.0 E-05	8.9 E-08	1.2 E-06	1.1 E-05
Kidney	4.8 E-08	1.1 E-06	1.9 E-05	1.3 E-08	2.0 E-07	3.1 E-06	8.1 E-09	1.4 E-07	2.1 E-06	7.9 E-09	1.3 E-07	2.1 E-06
Liver	2.3 E-08	8.3 E-07	3.2 E-05	5.5 E-09	1.7 E-07	5.0 E-06	3.9 E-09	1.1 E-07	2.5 E-06	3.9 E-09	1.1 E-07	2.5 E-06
Lung	4.8 E-07	5.7 E-06	8.2 E-05	1.1 E-07	1.1 E-06	9.9 E-06	7.1 E-08	7.0 E-07	5.5 E-06	6.7 E-08	7.0 E-07	6.4 E-06
Ovarian	1.1 E-07	2.2 E-06	4.4 E-05	3.0 E-08	3.8 E-07	4.3 E-06	2.1 E-08	2.4 E-07	3.1 E-06	2.0 E-08	2.4 E-07	3.2 E-06
Pancreas	1.0 E-08	3.3 E-07	1.2 E-05	3.2 E-09	5.5 E-08	1.5 E-06	1.8 E-09	3.8 E-08	8.2 E-07	1.9 E-09	3.5 E-08	8.7 E-07
Leukemia (RBM ^a)	8.6 E-07	1.2 E-05	1.8 E-04	2.3 E-07	2.2 E-06	1.7 E-05	1.7 E-07	1.6 E-06	1.2 E-05	1.5 E-07	1.5 E-06	1.1 E-05
Thyroid	1.2 E-07	2.1 E-06	4.0 E-05	3.0 E-08	3.7 E-07	5.0 E-06	1.9 E-08	2.4 E-07	3.2 E-06	1.8 E-08	2.4 E-07	3.2 E-06

^a Consumption rate varies from 1.5 to 15.6 kg y⁻¹. It was assumed that 60% (range of 20 to 100%) of the fish was contaminated, and 85% (range of 80 to 90%) of the radioactivity in the fish was retained after processing (sections 7, 13.1).

^b RBM = Red Bone Marrow

Table B.6 Organ-specific risks of various types of cancer from all radionuclides for a category III female consumer of fisha exposed during the entire study period (48 years).

Cancer Type	CRM 20.5			CRM 14			CRM 3.5			CRM 0		
	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	97.5%
Bladder	5.7 E-08	9.0 E-07	1.7 E-05	1.3 E-08	1.6 E-07	2.6 E-06	8.0 E-09	1.1 E-07	1.9 E-06	8.3 E-09	1.1 E-07	1.7 E-06
Breast	3.7 E-07	5.6 E-06	1.0 E-04	9.0 E-08	9.9 E-07	1.3 E-05	5.4 E-08	6.4 E-07	8.1 E-06	5.2 E-08	6.6 E-07	8.4 E-06
Stomach	6.3 E-09	2.5 E-07	8.9 E-06	1.4 E-09	4.2 E-08	1.2 E-06	1.0 E-09	2.9 E-08	7.0 E-07	8.9 E-10	2.9 E-08	7.5 E-07
Colon	1.4 E-07	2.0 E-06	3.2 E-05	3.6 E-08	3.7 E-07	4.5 E-06	2.9 E-08	2.5 E-07	3.3 E-06	2.5 E-08	2.6 E-07	2.8 E-06
Kidney	1.0 E-08	2.7 E-07	5.2 E-06	2.2 E-09	4.7 E-08	6.9 E-07	1.5 E-09	3.1 E-08	4.5 E-07	1.6 E-09	3.0 E-08	5.0 E-07
Liver	6.0 E-09	2.0 E-07	8.0 E-06	1.2 E-09	3.7 E-08	1.2 E-06	8.6 E-10	2.4 E-08	7.8 E-07	8.4 E-10	2.4 E-08	8.4 E-07
Lung	1.0 E-07	1.3 E-06	2.0 E-05	2.4 E-08	2.4 E-07	2.7 E-06	1.4 E-08	1.7 E-07	1.7 E-06	1.3 E-08	1.6 E-07	1.6 E-06
Ovarian	2.3 E-08	5.2 E-07	1.0 E-05	6.8 E-09	8.5 E-08	1.3 E-06	4.2 E-09	5.7 E-08	7.2 E-07	4.1 E-09	5.6 E-08	8.5 E-07
Pancreas	3.1 E-09	7.3 E-08	2.7 E-06	6.9 E-10	1.2 E-08	3.9 E-07	4.4 E-10	8.5 E-09	2.4 E-07	4.8 E-10	8.2 E-09	2.6 E-07
Leukemia (RBM ^b)	1.6 E-07	2.7 E-06	4.9 E-05	5.4 E-08	4.8 E-07	5.0 E-06	3.3 E-08	3.3 E-07	3.2 E-06	3.5 E-08	3.3 E-07	3.2 E-06
Thyroid	3.0 E-08	4.8 E-07	1.2 E-05	6.3 E-09	9.1 E-08	1.1 E-06	4.1 E-09	5.7 E-08	8.5 E-07	4.0 E-09	5.9 E-08	7.0 E-07

^a Consumption rate varies from 0.2 to 4.2 kg y⁻¹. It was assumed that 60% (range of 20 to 100%) of the fish was contaminated,

and 85% (range of 80 to 90%) of the radioactivity in the fish was retained after processing (sections 7, 13.1).

^b RBM = Red Bone Marrow

Table B.7 Organ-specific risks of various types of cancer from all radionuclides for external exposure to shoreline sediment during the entire study period (48 years).

Cancer Type	CRM 20.5			CRM 14			CRM 3.5			CRM 0		
	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	97.5%
Bladder	2.6 E-08	2.3 E-07	2.0 E-06	1.1 E-07	8.1 E-07	6.8 E-06	1.1 E-07	8.5 E-07	6.4 E-06	1.2 E-07	9.6 E-07	6.9 E-06
Breast	3.3 E-07	2.1 E-06	1.3 E-05	1.1 E-06	7.7 E-06	5.9 E-05	1.4 E-06	8.1 E-06	5.2 E-05	1.5 E-06	8.7 E-06	5.8 E-05
Stomach	2.5 E-09	5.8 E-08	9.7 E-07	8.7 E-09	2.1 E-07	4.4 E-06	9.6 E-09	2.1 E-07	4.6 E-06	1.0 E-08	2.3 E-07	5.2 E-06
Colon	4.6 E-08	3.4 E-07	2.7 E-06	1.9 E-07	1.3 E-06	1.0 E-05	2.1 E-07	1.3 E-06	9.6 E-06	2.4 E-07	1.5 E-06	1.1 E-05
Kidney	5.8 E-09	6.1 E-08	5.2 E-07	1.5 E-08	2.5 E-07	2.8 E-06	1.7 E-08	2.5 E-07	2.5 E-06	1.6 E-08	2.7 E-07	2.7 E-06
Liver	2.2 E-09	4.9 E-08	1.0 E-06	7.2 E-09	1.8 E-07	3.6 E-06	8.3 E-09	1.8 E-07	3.3 E-06	9.5 E-09	2.0 E-07	3.5 E-06
Lung	6.1 E-08	4.1 E-07	2.0 E-06	2.1 E-07	1.4 E-06	8.9 E-06	2.2 E-07	1.4 E-06	9.1 E-06	2.5 E-07	1.6 E-06	1.0 E-05
Ovarian	1.2 E-08	1.1 E-07	9.6 E-07	4.4 E-08	4.5 E-07	4.2 E-06	4.5 E-08	4.5 E-07	4.3 E-06	5.6 E-08	4.9 E-07	4.8 E-06
Pancreas	9.4 E-10	1.7 E-08	3.0 E-07	4.1 E-09	6.6 E-08	1.0 E-06	4.0 E-09	6.3 E-08	9.3 E-07	4.6 E-09	7.2 E-08	1.1 E-06
Leukemia (RBM*)	8.5 E-08	5.0 E-07	3.3 E-06	2.4 E-07	1.8 E-06	1.3 E-05	3.0 E-07	1.8 E-06	1.2 E-05	3.1 E-07	2.0 E-06	1.3 E-05
Thyroid	1.5 E-08	1.2 E-07	8.6 E-07	5.0 E-08	4.2 E-07	3.0 E-06	5.1 E-08	4.3 E-07	3.1 E-06	6.1 E-08	4.8 E-07	3.3 E-06

* RBM = Red Bone Marrow

Table B.8 Organ-specific risks of various types of cancer from all radionuclides for the ingestion of drinking water during the entire study period (48 years).

Cancer Type	CRM 14			CRM 35			CRM 0, stationary ^b			CRM 0, mobile		
	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	97.5%
Bladder	7.4 E-09	6.9 E-08	9.3 E-07	4.6 E-09	4.5 E-08	6.7 E-07	3.2 E-10	4.4 E-09	8.1 E-08	3.0 E-10	3.7 E-09	6.2 E-08
Breast	5.4 E-08	4.3 E-07	4.4 E-06	3.1 E-08	3.0 E-07	3.3 E-06	2.1 E-09	2.9 E-08	4.5 E-07	1.7 E-09	2.4 E-08	3.3 E-07
Stomach	1.7 E-09	3.6 E-08	1.2 E-06	9.1 E-10	2.5 E-08	7.7 E-07	7.1 E-11	2.5 E-09	1.0 E-07	7.1 E-11	2.0 E-09	7.8 E-08
Colon	5.2 E-07	3.9 E-06	2.4 E-05	4.2 E-07	3.0 E-06	1.8 E-05	3.2 E-08	3.0 E-07	2.7 E-06	2.2 E-08	2.5 E-07	2.0 E-06
Kidney	1.8 E-09	2.2 E-08	2.9 E-07	1.1 E-09	1.4 E-08	2.0 E-07	6.6 E-11	1.2 E-09	2.6 E-08	4.4 E-11	9.8 E-10	2.1 E-08
Liver	6.3 E-10	1.5 E-08	4.3 E-07	3.9 E-10	9.7 E-09	4.1 E-07	2.5 E-11	1.1 E-09	4.1 E-08	1.9 E-11	9.1 E-10	3.8 E-08
Lung	1.5 E-08	1.1 E-07	1.0 E-06	8.7 E-09	7.0 E-08	9.4 E-07	5.6 E-10	7.5 E-09	7.5 E-08	4.3 E-10	6.3 E-09	6.6 E-08
Ovarian	3.6 E-09	4.2 E-08	6.0 E-07	2.3 E-09	2.8 E-08	5.3 E-07	1.9 E-10	3.2 E-09	4.1 E-08	1.1 E-10	2.5 E-09	3.6 E-08
Pancreas	3.1 E-10	6.2 E-09	1.0 E-07	2.2 E-10	3.9 E-09	8.8 E-08	1.8 E-11	3.9 E-10	1.1 E-08	1.7 E-11	3.5 E-10	8.8 E-09
Leukemia (RBM ^c)	5.7 E-07	2.9 E-06	2.0 E-05	3.0 E-07	1.4 E-06	7.7 E-06	1.1 E-08	1.1 E-07	7.4 E-07	9.6 E-09	8.7 E-08	6.2 E-07
Thyroid	3.5 E-09	3.6 E-08	4.0 E-07	1.8 E-09	2.4 E-08	3.2 E-07	2.1 E-10	2.0 E-09	4.5 E-08	1.6 E-10	1.7 E-09	3.0 E-08

^a Unless otherwise noted, an ingestion of 20 to 60% of filtered, treated water from the Clinch River is assumed.

^b An ingestion of 20 to 80% of filtered, treated water from the Clinch River is assumed for an individual who resides and works near CRM 0.

^c RBM = Red Bone Marrow

Table B.9 Organ-specific risks of various types of cancer from all radionuclides for the ingestion of meat during the entire study period (48 years).

Cancer Type	CRM 20.5 ^a			CRM 14 ^a			CRM 3.5 ^b			CRM 0 ^c		
	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	97.5%
Bladder	7.7 E-11	9.3 E-10	9.7 E-09	8.5 E-10	1.0 E-08	1.2 E-07	3.5 E-10	4.8 E-09	5.4 E-08	3.3 E-10	4.3 E-09	4.7 E-08
Breast	4.9 E-10	6.1 E-09	4.5 E-08	7.9 E-09	7.4 E-08	5.4 E-07	2.2 E-09	3.1 E-08	2.3 E-07	2.1 E-09	3.0 E-08	2.7 E-07
Stomach	9.0 E-12	2.9 E-10	9.3 E-09	1.4 E-10	3.5 E-09	8.5 E-08	5.8 E-11	1.3 E-09	3.8 E-08	5.5 E-11	1.4 E-09	4.1 E-08
Colon	4.8 E-10	1.2 E-08	2.3 E-07	6.1 E-09	1.1 E-07	1.8 E-06	2.7 E-09	5.4 E-08	9.5 E-07	2.1 E-09	5.4 E-08	8.2 E-07
Kidney	1.3 E-11	2.6 E-10	3.2 E-09	1.5 E-10	3.0 E-09	4.0 E-08	5.9 E-11	1.4 E-09	1.8 E-08	6.2 E-11	1.4 E-09	1.8 E-08
Liver	6.6 E-12	2.4 E-10	6.6 E-09	8.2 E-11	2.6 E-09	7.4 E-08	3.7 E-11	1.1 E-09	2.4 E-08	3.6 E-11	1.1 E-09	3.1 E-08
Lung	1.6 E-10	1.5 E-09	1.3 E-08	2.0 E-09	1.7 E-08	1.4 E-07	6.9 E-10	7.1 E-09	5.7 E-08	5.3 E-10	6.7 E-09	6.4 E-08
Ovarian	4.6 E-11	5.2 E-10	7.8 E-09	4.5 E-10	5.8 E-09	7.1 E-08	1.8 E-10	2.5 E-09	3.6 E-08	1.7 E-10	2.5 E-09	3.1 E-08
Pancreas	3.3 E-12	8.7 E-11	2.2 E-09	3.7 E-11	9.1 E-10	2.1 E-08	1.6 E-11	3.4 E-10	8.6 E-09	1.9 E-11	3.8 E-10	8.6 E-09
Leukemia (RBM ^c)	4.5 E-10	4.5 E-09	8.7 E-08	4.9 E-09	5.5 E-08	1.1 E-06	1.7 E-09	2.3 E-08	5.2 E-07	1.8 E-09	2.2 E-08	4.5 E-07
Thyroid	3.7 E-11	4.8 E-10	4.7 E-09	4.4 E-10	5.7 E-09	6.2 E-08	1.4 E-10	2.4 E-09	2.7 E-08	1.4 E-10	2.6 E-09	2.1 E-08

^a Based on ingestion of 30 to 80% of meat from cattle that had access to the Clinch River.

^b Based on ingestion of 10 to 60% of meat from cattle that had access to the Clinch River.

^c RBM = Rad Bone Marrow

Table B.10 Organ-specific risks of various types of cancer from all radionuclides for the ingestion of milks during the entire study period (48 years).

Cancer Type	CRM 20.5			CRM 14			CRM 3.5			CRM 0		
	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	97.5%
Bladder	1.3 E-11	1.6 E-10	2.0 E-09	1.5 E-10	1.8 E-09	2.3 E-08	9.8 E-11	1.3 E-09	1.5 E-08	1.1 E-10	1.2 E-09	1.4 E-08
Breast	7.8 E-11	9.7 E-10	8.8 E-09	8.6 E-10	1.2 E-08	1.1 E-07	5.8 E-10	7.7 E-09	6.6 E-08	6.4 E-10	7.6 E-09	6.4 E-08
Stomach	1.5 E-12	3.7 E-11	9.7 E-10	1.8 E-11	4.5 E-10	1.1 E-08	1.2 E-11	2.8 E-10	8.0 E-09	1.3 E-11	2.8 E-10	6.4 E-09
Colon	5.5 E-11	5.3 E-10	5.5 E-09	5.5 E-10	6.4 E-09	6.1 E-08	4.5 E-10	4.5 E-09	3.6 E-08	4.2 E-10	4.5 E-09	3.7 E-08
Kidney	2.3 E-12	4.4 E-11	6.3 E-10	2.6 E-11	4.9 E-10	7.0 E-09	1.7 E-11	3.5 E-10	5.5 E-09	1.6 E-11	3.4 E-10	4.9 E-09
Liver	9.1 E-13	3.8 E-11	1.1 E-09	9.3 E-12	3.9 E-10	1.3 E-08	7.3 E-12	2.6 E-10	7.6 E-09	6.7 E-12	2.7 E-10	6.7 E-09
Lung	1.9 E-11	2.1 E-10	2.6 E-09	2.4 E-10	2.5 E-09	3.5 E-08	1.7 E-10	1.7 E-09	2.0 E-08	1.7 E-10	1.6 E-09	1.8 E-08
Ovarian	6.9 E-12	8.8 E-11	1.2 E-09	6.8 E-11	1.0 E-09	1.4 E-08	4.5 E-11	6.9 E-10	9.2 E-09	4.5 E-11	6.4 E-10	8.6 E-09
Pancreas	5.6 E-13	1.3 E-11	3.4 E-10	6.6 E-12	1.5 E-10	4.2 E-09	3.7 E-12	9.5 E-11	2.3 E-09	4.2 E-12	9.7 E-11	2.6 E-09
Leukemia (RBM ^a)	2.2 E-10	2.3 E-09	1.9 E-08	2.7 E-09	2.9 E-08	2.0 E-07	2.3 E-09	2.0 E-08	1.4 E-07	2.1 E-09	2.1 E-08	1.5 E-07
Thyroid	6.2 E-12	6.8 E-11	8.7 E-10	8.9 E-11	8.9 E-10	1.1 E-08	6.0 E-11	6.0 E-10	5.8 E-09	6.6 E-11	6.0 E-10	6.8 E-09

^a Based on ingestion of 63 to 100% of milk from cattle that had access to the Clinch River.

^b RBM = Red Bone Marrow

APPENDIX C

Table C.1 Excess lifetime risk resulting from the consumption of fish for males exposed during the entire study period (48 years).

Location = CRM 20.5									
Isotope	Category 1 Male			Category 2 Male			Category 3 Male		
	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	97.5%
Cs-137	3.0E-05	2.6E-04	3.4E-03	1.2E-05	1.2E-04	1.4E-03	2.8E-06	2.7E-05	3.6E-04
Ru-106	9.8E-08	1.7E-06	3.0E-05	3.9E-08	7.3E-07	1.3E-05	1.1E-08	1.8E-07	3.0E-06
Sr-90	6.8E-07	1.1E-05	1.2E-04	2.2E-07	3.8E-06	7.3E-05	5.2E-08	9.7E-07	1.5E-05
Co-60	6.6E-08	9.8E-07	1.4E-05	2.9E-08	4.1E-07	6.1E-06	5.9E-09	9.2E-08	1.4E-06
Total*	3.6E-05	2.8E-04	3.5E-03	1.4E-05	1.3E-04	1.5E-03	3.1E-06	2.9E-05	3.7E-04
Location = CRM 14									
Isotope	Category 1 Male			Category 2 Male			Category 3 Male		
	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	97.5%
Cs-137	6.7E-06	5.1E-05	4.0E-04	2.4E-06	2.1E-05	1.5E-04	6.4E-07	5.4E-06	3.4E-05
Ru-106	2.6E-08	3.4E-07	3.5E-06	1.0E-08	1.4E-07	1.5E-06	2.0E-09	3.1E-08	3.6E-07
Sr-90	1.6E-07	1.9E-06	1.9E-05	5.5E-08	7.6E-07	1.1E-05	1.2E-08	1.6E-07	2.1E-06
Co-60	2.0E-08	1.9E-07	1.6E-06	7.0E-09	7.9E-08	6.7E-07	1.5E-09	1.8E-08	1.7E-07
Total*	8.2E-06	5.7E-05	4.1E-04	2.9E-06	2.2E-05	1.6E-04	6.8E-07	5.8E-06	3.5E-05
Location = CRM 3.5									
Isotope	Category 1 Male			Category 2 Male			Category 3 Male		
	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	97.5%
Cs-137	4.4E-06	3.4E-05	2.3E-04	1.7E-06	1.3E-05	1.0E-04	3.8E-07	3.4E-06	2.2E-05
Ru-106	2.1E-08	2.8E-07	3.2E-06	8.0E-09	1.1E-07	1.5E-06	1.7E-09	2.6E-08	3.8E-07
Sr-90	1.1E-07	1.4E-06	1.4E-05	4.2E-08	5.4E-07	7.7E-06	8.5E-09	1.2E-07	1.6E-06
Co-60	1.3E-08	1.3E-07	1.1E-06	4.7E-09	5.8E-08	5.4E-07	1.0E-09	1.4E-08	1.3E-07
Total*	5.2E-06	3.8E-05	2.4E-04	2.1E-06	1.4E-05	1.1E-04	4.6E-07	3.8E-06	2.2E-05
Location = CRM 0									
Isotope	Category 1 Male			Category 2 Male			Category 3 Male		
	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	97.5%
Cs-137	4.4E-06	3.4E-05	2.6E-04	1.5E-06	1.3E-05	1.0E-04	3.8E-07	3.3E-06	2.4E-05
Ru-106	1.8E-08	2.8E-07	3.3E-06	7.1E-09	1.2E-07	1.7E-06	1.2E-09	2.5E-08	3.2E-07
Sr-90	1.1E-07	1.4E-06	1.3E-05	4.3E-08	5.4E-07	8.3E-06	9.2E-09	1.2E-07	1.7E-06
Co-60	1.4E-08	1.4E-07	1.4E-06	5.1E-09	5.7E-08	5.3E-07	1.0E-09	1.2E-08	1.4E-07
Total*	5.6E-06	3.7E-05	2.6E-04	1.8E-06	1.5E-05	1.1E-04	4.3E-07	3.6E-06	2.4E-05

* Because the total risks are propagated using Monte Carlo techniques, the percentiles may not add directly.

Table C.2 Excess lifetime risk resulting from the consumption of fish for females exposed during the entire study period (48 years).

Location = CRM 20.5									
Isotope	Category 1 Female			Category 2 Female			Category 3 Female		
	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	97.5%
Cs-137	2.4E-05	2.2E-04	2.8E-03	9.6E-06	9.6E-05	1.1E-03	2.2E-06	2.2E-05	3.0E-04
Ru-106	8.1E-08	1.4E-06	2.5E-05	3.2E-08	6.0E-07	1.1E-05	9.1E-09	1.5E-07	2.5E-06
Sr-90	5.5E-07	9.0E-06	1.0E-04	1.8E-07	3.1E-06	6.1E-05	4.3E-08	7.9E-07	1.2E-05
Co-60	5.5E-08	8.1E-07	1.1E-05	2.4E-08	3.3E-07	5.0E-06	4.9E-09	7.6E-08	1.2E-06
Total*	2.9E-05	2.3E-04	2.8E-03	1.2E-05	1.1E-04	1.3E-03	2.5E-06	2.4E-05	3.1E-04
Location = CRM 14									
Isotope	Category 1 Female			Category 2 Female			Category 3 Female		
	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	97.5%
Cs-137	5.5E-06	4.3E-05	3.3E-04	2.0E-06	1.7E-05	1.2E-04	5.2E-07	4.4E-06	2.8E-05
Ru-106	2.1E-08	2.8E-07	2.9E-06	8.1E-09	1.1E-07	1.2E-06	1.7E-09	2.6E-08	2.9E-07
Sr-90	1.3E-07	1.6E-06	1.6E-05	4.6E-08	6.3E-07	8.7E-06	9.9E-09	1.3E-07	1.7E-06
Co-60	1.6E-08	1.5E-07	1.3E-06	5.8E-09	6.5E-08	5.6E-07	1.3E-09	1.4E-08	1.4E-07
Total*	6.7E-06	4.8E-05	3.4E-04	2.4E-06	1.8E-05	1.3E-04	5.6E-07	4.8E-06	2.9E-05
Location = CRM 3.5									
Isotope	Category 1 Female			Category 2 Female			Category 3 Female		
	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	97.5%
Cs-137	3.6E-06	2.8E-05	1.9E-04	1.4E-06	1.1E-05	8.5E-05	3.1E-07	2.8E-06	1.8E-05
Ru-106	1.7E-08	2.3E-07	2.6E-06	6.6E-09	9.0E-08	1.2E-06	1.4E-09	2.1E-08	3.1E-07
Sr-90	9.2E-08	1.1E-06	1.2E-05	3.5E-08	4.4E-07	6.3E-06	7.1E-09	9.5E-08	1.3E-06
Co-60	1.0E-08	1.1E-07	8.9E-07	3.8E-09	4.7E-08	4.4E-07	8.2E-10	1.1E-08	1.1E-07
Total*	4.3E-06	3.1E-05	2.0E-04	1.7E-06	1.2E-05	8.8E-05	3.8E-07	3.1E-06	1.8E-05
Location = CRM 0									
Isotope	Category 1 Female			Category 2 Female			Category 3 Female		
	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	97.5%
Cs-137	3.6E-06	2.8E-05	2.1E-04	1.3E-06	1.1E-05	8.7E-05	3.2E-07	2.7E-06	1.9E-05
Ru-106	1.5E-08	2.3E-07	2.7E-06	5.9E-09	1.0E-07	1.4E-06	1.0E-09	2.0E-08	2.6E-07
Sr-90	9.4E-08	1.1E-06	1.1E-05	3.4E-08	4.4E-07	6.9E-06	7.6E-09	9.6E-08	1.4E-06
Co-60	1.1E-08	1.1E-07	1.2E-06	4.3E-09	4.7E-08	4.4E-07	8.5E-10	1.0E-08	1.1E-07
Total*	4.6E-06	3.0E-05	2.1E-04	1.5E-06	1.2E-05	9.0E-05	3.6E-07	3.0E-06	2.0E-05

* Because the total risks are propagated using Monte Carlo techniques, the percentiles may not add directly.

Table C.3 Radionuclide-specific risks from additional exposure pathways for individuals exposed during the entire study period (48 years)

External												
Isotope	CRM 20.5			CRM 14			CRM 3.5			CRM 0		
	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	97.5%
Cs-137	1.1E-06	5.8E-06	2.7E-05	3.2E-06	1.7E-05	7.6E-05	2.7E-06	1.3E-05	5.8E-05	3.1E-06	1.5E-05	6.9E-05
Ru-106	9.1E-09	4.5E-08	2.1E-07	5.3E-08	2.6E-07	1.2E-06	1.3E-07	6.5E-07	2.7E-06	1.3E-07	6.5E-07	2.8E-06
Sr-90	3.9E-11	2.0E-10	8.9E-10	2.8E-10	1.4E-09	6.3E-09	3.8E-10	1.7E-09	7.0E-09	4.3E-10	1.9E-09	8.6E-09
Co-60	2.2E-07	1.1E-06	4.9E-06	1.4E-06	7.4E-06	3.4E-05	2.0E-06	1.1E-05	4.8E-05	2.5E-06	1.2E-05	5.1E-05
Nb-95	8.0E-11	4.7E-10	2.2E-09	3.1E-09	1.6E-08	9.9E-08	6.0E-09	3.7E-08	3.3E-07	5.6E-09	3.6E-08	3.5E-07
Zr-95	3.2E-11	1.7E-10	8.1E-10	3.7E-08	1.8E-07	8.7E-07	8.2E-08	4.7E-07	2.3E-06	8.8E-08	4.5E-07	2.1E-06
Ce-144	1.1E-12	5.9E-12	2.8E-11	8.6E-09	4.3E-08	2.0E-07	1.7E-08	8.2E-08	3.5E-07	2.0E-08	9.3E-08	4.4E-07
Total*	1.3E-06	7.0E-06	3.2E-05	4.7E-06	2.5E-05	1.1E-04	4.9E-06	2.6E-05	1.1E-04	6.2E-06	2.8E-05	1.2E-04
Drinking Water												
Isotope	CRM 14			CRM 3.5			CRM 0, stationary			CRM 0, mobile		
	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	97.5%
Cs-137	5.1E-08	2.2E-07	9.7E-07	1.9E-08	6.6E-08	2.3E-07	8.4E-10	6.8E-09	3.4E-08	8.3E-10	5.3E-09	2.5E-08
Ru-106	1.7E-06	7.1E-06	3.3E-05	1.3E-06	5.6E-06	2.2E-05	6.4E-08	6.5E-07	3.7E-06	6.5E-08	4.9E-07	3.1E-06
Sr-90	9.0E-07	3.9E-06	1.8E-05	4.3E-07	1.8E-06	8.2E-06	1.6E-08	1.3E-07	6.9E-07	1.6E-08	1.0E-07	5.8E-07
Total*	3.5E-06	1.2E-05	4.6E-05	2.1E-06	8.2E-06	2.6E-05	8.7E-08	8.3E-07	4.5E-06	8.2E-08	6.5E-07	3.6E-06
Meat												
Isotope	CRM 20.5			CRM 14			CRM 3.5			CRM 0		
	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	97.5%
Cs-137	2.0E-09	1.6E-08	1.1E-07	2.7E-08	1.8E-07	1.2E-06	7.1E-09	7.7E-08	5.8E-07	8.8E-09	8.0E-08	5.4E-07
Ru-106	4.6E-10	1.9E-08	2.4E-07	3.7E-09	1.7E-07	2.2E-06	1.9E-09	8.0E-08	1.2E-06	1.7E-09	7.5E-08	1.3E-06
Sr-90	7.6E-11	2.8E-09	1.1E-07	7.8E-10	3.0E-08	8.2E-07	2.9E-10	1.3E-08	4.3E-07	3.4E-10	1.3E-08	4.2E-07
Co-60	2.0E-12	5.4E-11	1.8E-09	7.0E-12	2.4E-10	7.0E-09	1.8E-12	1.0E-10	2.9E-09	3.0E-12	8.9E-11	3.3E-09
Total*	6.2E-09	5.0E-08	3.4E-07	5.2E-08	5.3E-07	3.6E-06	2.1E-08	2.3E-07	2.0E-06	2.8E-08	2.4E-07	1.6E-06
Milk												
Isotope	CRM 20.5			CRM 14			CRM 3.5			CRM 0		
	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	97.5%	2.5%	50%	97.5%
Cs-137	2.4E-10	3.5E-09	2.7E-08	3.1E-09	4.2E-08	3.4E-07	2.2E-09	2.8E-08	2.3E-07	2.2E-09	2.7E-08	2.3E-07
Ru-106	3.2E-10	2.6E-09	2.4E-07	4.5E-09	2.9E-08	2.4E-07	3.3E-09	2.1E-08	1.7E-07	3.6E-09	2.1E-08	1.7E-07
Sr-90	3.1E-12	9.8E-11	1.8E-09	1.5E-11	4.0E-10	6.3E-09	1.2E-11	2.7E-10	4.5E-09	1.2E-11	2.7E-10	5.3E-09
Co-60	1.2E-09	7.6E-09	4.3E-08	1.3E-08	8.6E-08	4.8E-07	9.3E-09	5.9E-08	3.2E-07	9.3E-09	6.0E-08	2.9E-07
Total*	6.2E-09	5.0E-08	3.4E-07	5.2E-08	5.3E-07	3.6E-06	2.1E-08	2.3E-07	2.0E-06	2.8E-08	2.4E-07	1.6E-06

* Because the total risks are propagated using Monte Carlo techniques, the percentiles may not add directly.

APPENDIX D

Table D.1 Risks summed over various pathways for males exposed during the entire study period (48 years) at CRM 0.

	Male - Category I			Male - Category II			Male - Category III		
	95% subjective confidence interval			95% subjective confidence interval			95% subjective confidence interval		
	2.50%	50.00%	97.50%	2.50%	50.00%	97.50%	2.50%	50.00%	97.50%
Drinking Water									
Cs-137	6.5 E-10	5.9 E-09	3.4 E-08	6.5 E-10	5.9 E-09	3.4 E-08	6.5 E-10	5.9 E-09	3.4 E-08
Ru-106	5.9 E-08	5.6 E-07	3.7 E-06	5.9 E-08	5.6 E-07	3.7 E-06	5.9 E-08	5.6 E-07	3.7 E-06
Sr-90	1.3 E-08	1.2 E-07	9.6 E-07	1.3 E-08	1.2 E-07	9.6 E-07	1.3 E-08	1.2 E-07	9.6 E-07
Total	7.3 E-08	6.9 E-07	4.7 E-06	7.3 E-08	6.9 E-07	4.7 E-06	7.3 E-08	6.9 E-07	4.7 E-06
Fish									
Cs-137	3.4 E-06	2.8 E-05	2.4 E-04	1.2 E-06	1.2 E-05	1.1 E-04	2.6 E-07	2.7 E-06	2.8 E-05
Ru-106	2.2 E-08	2.6 E-07	3.7 E-06	9.1 E-09	1.1 E-07	1.3 E-06	1.8 E-09	2.5 E-08	3.4 E-07
Sr-90	2.6 E-07	2.1 E-06	2.4 E-05	7.9 E-08	9.0 E-07	1.1 E-05	2.0 E-08	2.0 E-07	2.9 E-06
Co-60	4.1 E-09	6.4 E-08	8.9 E-07	1.5 E-09	2.7 E-08	4.2 E-07	3.4 E-10	5.8 E-09	1.1 E-07
Total	3.7 E-06	3.1 E-05	2.7 E-04	1.3 E-06	1.3 E-05	1.3 E-04	2.8 E-07	2.9 E-06	3.2 E-05
External									
Cs-137	3.3 E-06	1.4 E-05	6.8 E-05	3.3 E-06	1.4 E-05	6.8 E-05	3.3 E-06	1.4 E-05	6.8 E-05
Ru-106	1.4 E-07	6.3 E-07	3.0 E-06	1.4 E-07	6.3 E-07	3.0 E-06	1.4 E-07	6.3 E-07	3.0 E-06
Sr-90	4.3 E-10	1.9 E-09	8.6 E-09	4.3 E-10	1.9 E-09	8.6 E-09	4.3 E-10	1.9 E-09	8.6 E-09
Co-60	2.6 E-06	1.1 E-05	5.2 E-05	2.6 E-06	1.1 E-05	5.2 E-05	2.6 E-06	1.1 E-05	5.2 E-05
Nb-95	5.9 E-09	3.4 E-08	3.3 E-07	5.9 E-09	3.4 E-08	3.3 E-07	5.9 E-09	3.4 E-08	3.3 E-07
Sr-95	9.4 E-08	4.2 E-07	2.2 E-06	9.4 E-08	4.2 E-07	2.2 E-06	9.4 E-08	4.2 E-07	2.2 E-06
Ce-144	2.0 E-08	8.9 E-08	4.1 E-07	2.0 E-08	8.9 E-08	4.1 E-07	2.0 E-08	8.9 E-08	4.1 E-07
Total	6.3 E-06	2.7 E-05	1.3 E-04	6.3 E-06	2.7 E-05	1.3 E-04	6.3 E-06	2.7 E-05	1.3 E-04
Summed Risk									
Cs-137	6.7 E-06	4.3 E-05	3.1 E-04	4.4 E-06	2.6 E-05	1.8 E-04	3.5 E-06	1.7 E-05	9.7 E-05
Ru-106	2.2 E-07	1.5 E-06	1.0 E-05	2.1 E-07	1.3 E-06	8.1 E-06	2.0 E-07	1.2 E-06	7.1 E-06
Sr-90	2.7 E-07	2.2 E-06	2.5 E-05	9.3 E-08	1.0 E-06	1.2 E-05	3.4 E-08	3.2 E-07	3.9 E-06
Co-60	2.6 E-06	1.1 E-05	5.3 E-05	2.6 E-06	1.1 E-05	5.2 E-05	2.6 E-06	1.1 E-05	5.2 E-05
Nb-95	5.9 E-09	3.4 E-08	3.3 E-07	5.9 E-09	3.4 E-08	3.3 E-07	5.9 E-09	3.4 E-08	3.3 E-07
Sr-95	9.4 E-08	4.2 E-07	2.2 E-06	9.4 E-08	4.2 E-07	2.2 E-06	9.4 E-08	4.2 E-07	2.2 E-06
Ce-144	2.0 E-08	8.9 E-08	4.1 E-07	2.0 E-08	8.9 E-08	4.1 E-07	2.0 E-08	8.9 E-08	4.1 E-07
Total Summed Risk	1.0 E-05	5.8 E-05	4.0 E-04	7.6 E-06	4.1 E-05	2.6 E-04	6.6 E-06	3.1 E-05	1.6 E-04

Table D.2 Risks summed over various pathways for males exposed during the entire study period (48 years) at CRM 3.5.

	Male - Category I			Male - Category II			Male - Category III		
	95% subjective confidence interval	50.00%	97.50%	95% subjective confidence interval	50.00%	97.50%	95% subjective confidence interval	50.00%	97.50%
Drinking Water									
Cs-137	2.4 E-08	1.3 E-07	7.2 E-07	2.4 E-08	1.3 E-07	7.2 E-07	2.4 E-08	1.2 E-07	7.2 E-07
Ru-106	1.4 E-06	5.5 E-06	2.8 E-05	1.4 E-06	5.5 E-06	2.8 E-05	1.2 E-06	5.8 E-06	2.5 E-05
Sr-90	5.9 E-07	2.6 E-06	1.6 E-05	5.9 E-07	2.6 E-06	1.6 E-05	5.2 E-07	2.7 E-06	1.4 E-05
Total	2.0 E-06	8.3 E-06	4.4 E-05	2.0 E-06	8.3 E-06	4.4 E-05	1.8 E-06	8.6 E-06	3.9 E-05
Fish									
Cs-137	3.2 E-06	3.0 E-05	2.5 E-04	1.2 E-06	1.3 E-05	1.2 E-04	2.4 E-07	2.9 E-06	2.8 E-05
Ru-106	2.6 E-08	2.8 E-07	3.0 E-06	1.1 E-08	1.1 E-07	1.4 E-06	2.1 E-09	2.5 E-08	3.7 E-07
Sr-90	2.3 E-07	2.3 E-06	2.1 E-05	8.5 E-08	9.1 E-07	1.1 E-05	1.9 E-08	2.2 E-07	1.9 E-06
Co-60	3.9 E-09	6.6 E-08	9.6 E-07	1.6 E-09	2.6 E-08	5.0 E-07	2.5 E-10	6.4 E-09	8.9 E-08
Total	3.5 E-06	3.3 E-05	2.7 E-04	1.3 E-06	1.4 E-05	1.3 E-04	2.6 E-07	3.2 E-06	3.0 E-05
External									
Cs-137	2.6 E-06	1.3 E-05	5.3 E-05	2.6 E-06	1.3 E-05	5.3 E-05	2.8 E-06	1.3 E-05	5.4 E-05
Ru-106	1.2 E-07	6.4 E-07	2.7 E-06	1.2 E-07	6.4 E-07	2.7 E-06	1.4 E-07	6.1 E-07	2.3 E-06
Sr-90	3.1 E-10	1.7 E-09	6.7 E-09	3.1 E-10	1.7 E-09	6.7 E-09	3.4 E-10	1.6 E-09	6.1 E-09
Co-60	2.0 E-06	1.0 E-05	4.3 E-05	2.0 E-06	1.0 E-05	4.3 E-05	2.3 E-06	1.0 E-05	4.1 E-05
Nb-95	5.8 E-09	3.5 E-08	3.7 E-07	5.8 E-09	3.5 E-08	3.7 E-07	6.0 E-09	3.6 E-08	5.0 E-07
Sr-95	7.2 E-08	4.3 E-07	2.5 E-06	7.2 E-08	4.3 E-07	2.5 E-06	8.4 E-08	4.2 E-07	2.0 E-06
Ce-144	1.5 E-08	7.9 E-08	3.6 E-07	1.5 E-08	7.9 E-08	3.6 E-07	1.8 E-08	7.6 E-08	3.2 E-07
Total	4.6 E-06	2.5 E-05	1.0 E-04	4.6 E-06	2.5 E-05	1.0 E-04	5.7 E-06	2.5 E-05	9.6 E-05
Summed Risk									
Cs-137	5.8 E-06	4.3 E-05	3.0 E-04	3.7 E-06	2.6 E-05	1.7 E-04	3.1 E-06	1.6 E-05	8.2 E-05
Ru-106	1.5 E-06	6.4 E-06	3.3 E-05	1.5 E-06	6.3 E-06	3.2 E-05	1.4 E-06	6.4 E-06	2.7 E-05
Sr-90	8.1 E-07	5.0 E-06	3.7 E-05	6.7 E-07	3.5 E-06	2.7 E-05	5.4 E-07	2.9 E-06	1.6 E-05
Co-60	2.0 E-06	1.1 E-05	4.4 E-05	2.0 E-06	1.1 E-05	4.4 E-05	2.3 E-06	1.0 E-05	4.1 E-05
Nb-95	5.8 E-09	3.5 E-08	3.7 E-07	5.8 E-09	3.5 E-08	3.7 E-07	6.0 E-09	3.6 E-08	5.0 E-07
Sr-95	7.2 E-08	4.3 E-07	2.5 E-06	7.2 E-08	4.3 E-07	2.5 E-06	8.4 E-08	4.2 E-07	2.0 E-06
Ce-144	1.5 E-08	7.9 E-08	3.6 E-07	1.5 E-08	7.9 E-08	3.6 E-07	1.8 E-08	7.6 E-08	3.2 E-07
Total Summed Risk	1.0 E-05	6.5 E-05	4.2 E-04	7.8 E-06	4.6 E-05	2.8 E-04	7.7 E-06	3.6 E-05	1.7 E-04

Table D.3 Risks summed over various pathways for males exposed during the entire study period (48 years) at CRM 14.

	Male - Category I			Male - Category II			Male - Category III		
	95% subjective confidence interval	50.00%	97.50%	95% subjective confidence interval	50.00%	97.50%	95% subjective confidence interval	50.00%	97.50%
Drinking Water									
Cs-137	3.3 E-08	1.9 E-07	1.1 E-06	3.4 E-08	1.9 E-07	1.0 E-06	3.4 E-08	1.9 E-07	1.0 E-06
Ru-106	1.5 E-06	6.9 E-06	3.5 E-05	1.4 E-06	6.9 E-06	3.3 E-05	1.4 E-06	6.9 E-06	3.3 E-05
Sr-90	6.9 E-07	3.6 E-06	2.2 E-05	7.6 E-07	3.6 E-06	2.1 E-05	7.6 E-07	3.6 E-06	2.1 E-05
Total	2.2 E-06	1.1 E-05	5.8 E-05	2.2 E-06	1.1 E-05	5.5 E-05	2.2 E-06	1.1 E-05	5.5 E-05
Fish									
Cs-137	5.5 E-06	4.5 E-05	4.0 E-04	1.8 E-06	1.9 E-05	1.8 E-04	3.6 E-07	4.5 E-06	4.0 E-05
Ru-106	2.8 E-08	3.2 E-07	3.5 E-06	9.9 E-09	1.3 E-07	1.6 E-06	2.5 E-09	2.9 E-08	4.1 E-07
Sr-90	3.2 E-07	3.2 E-06	2.8 E-05	1.4 E-07	1.3 E-06	1.1 E-05	2.6 E-08	3.0 E-07	2.6 E-06
Co-60	5.1 E-09	8.9 E-08	1.4 E-06	1.6 E-09	3.6 E-08	6.5 E-07	3.0 E-10	8.8 E-09	1.4 E-07
Total	5.8 E-06	4.9 E-05	4.3 E-04	1.9 E-06	2.0 E-05	1.9 E-04	3.9 E-07	4.9 E-06	4.3 E-05
External									
Cs-137	2.7 E-06	1.6 E-05	7.5 E-05	3.2 E-06	1.7 E-05	6.4 E-05	3.2 E-06	1.7 E-05	6.4 E-05
Ru-106	4.4 E-08	2.5 E-07	1.1 E-06	4.9 E-08	2.6 E-07	1.0 E-06	4.9 E-08	2.6 E-07	1.0 E-06
Sr-90	2.3 E-10	1.4 E-09	6.2 E-09	2.6 E-10	1.4 E-09	5.6 E-09	2.6 E-10	1.4 E-09	5.6 E-09
Co-60	1.2 E-06	7.2 E-06	3.3 E-05	1.4 E-06	7.2 E-06	3.0 E-05	1.4 E-06	7.2 E-06	3.0 E-05
Nb-95	2.6 E-09	1.8 E-08	9.1 E-08	2.8 E-09	1.6 E-08	9.2 E-08	2.8 E-09	1.6 E-08	9.2 E-08
Sr-95	3.0 E-08	1.7 E-07	9.0 E-07	3.3 E-08	1.8 E-07	8.0 E-07	3.3 E-08	1.8 E-07	8.0 E-07
Ce-144	7.4 E-09	4.3 E-08	2.1 E-07	8.5 E-09	4.4 E-08	1.7 E-07	8.5 E-09	4.4 E-08	1.7 E-07
Total	4.1 E-06	2.4 E-05	1.1 E-04	4.6 E-06	2.5 E-05	9.6 E-05	4.6 E-06	2.5 E-05	9.6 E-05
Summed Risk									
Cs-137	8.2 E-06	6.2 E-05	4.7 E-04	5.0 E-06	3.6 E-05	2.4 E-04	3.6 E-06	2.2 E-05	1.1 E-04
Ru-106	1.5 E-06	7.4 E-06	3.9 E-05	1.5 E-06	7.3 E-06	3.6 E-05	1.5 E-06	7.2 E-06	3.5 E-05
Sr-90	1.0 E-06	6.9 E-06	5.0 E-05	8.9 E-07	4.8 E-06	3.2 E-05	7.8 E-07	3.9 E-06	2.3 E-05
Co-60	1.3 E-06	7.3 E-06	3.5 E-05	1.4 E-06	7.2 E-06	3.1 E-05	1.4 E-06	7.2 E-06	3.0 E-05
Nb-95	2.6 E-09	1.8 E-08	9.1 E-08	2.8 E-09	1.6 E-08	9.2 E-08	2.8 E-09	1.6 E-08	9.2 E-08
Sr-95	3.0 E-08	1.7 E-07	9.0 E-07	3.3 E-08	1.8 E-07	8.0 E-07	3.3 E-08	1.8 E-07	8.0 E-07
Ce-144	7.4 E-09	4.3 E-08	2.1 E-07	8.5 E-09	4.4 E-08	1.7 E-07	8.5 E-09	4.4 E-08	1.7 E-07
Total Summed Risk	1.2 E-05	8.4 E-05	5.9 E-04	8.8 E-06	5.5 E-05	3.4 E-04	7.2 E-06	4.0 E-05	1.9 E-04

Table D.4 Risks summed over various pathways for males exposed during the entire study period (48 years) at CRM 20.5.

	Male - Category I			Male - Category II			Male - Category III		
	95% subjective confidence interval	50.00%	97.50%	95% subjective confidence interval	50.00%	97.50%	95% subjective confidence interval	50.00%	97.50%
Fish									
Cs-137	1.8 E-05	2.6 E-04	3.3 E-03	9.2 E-06	1.0 E-04	1.5 E-03	1.5 E-06	2.5 E-05	3.6 E-04
Ru-106	1.0 E-07	1.6 E-06	2.7 E-05	3.1 E-08	6.9 E-07	1.3 E-05	9.0 E-09	1.7 E-07	3.5 E-06
Sr-90	1.4 E-06	1.6 E-05	2.2 E-04	6.3 E-07	6.6 E-06	1.0 E-04	1.3 E-07	1.7 E-06	2.7 E-05
Co-60	1.8 E-08	4.7 E-07	1.3 E-05	6.4 E-09	2.0 E-07	5.9 E-06	1.5 E-09	4.7 E-08	1.2 E-06
Total	1.9 E-05	2.8 E-04	3.5 E-03	9.8 E-06	1.1 E-04	1.7 E-03	1.7 E-06	2.7 E-05	3.9 E-04
External									
Cs-137	2.3 E-06	7.1 E-06	2.1 E-05	2.3 E-06	7.1 E-06	2.1 E-05	2.3 E-06	7.1 E-06	2.1 E-05
Ru-106	2.3 E-08	8.4 E-08	2.7 E-07	2.3 E-08	8.4 E-08	2.7 E-07	2.3 E-08	8.4 E-08	2.7 E-07
Sr-90	7.7 E-11	2.4 E-10	6.9 E-10	7.7 E-11	2.4 E-10	6.9 E-10	7.7 E-11	2.4 E-10	6.9 E-10
Co-60	5.2 E-07	1.6 E-06	4.9 E-06	5.2 E-07	1.6 E-06	4.9 E-06	5.2 E-07	1.6 E-06	4.9 E-06
Nb-95	9.1 E-12	4.7 E-11	2.4 E-10	9.1 E-12	4.7 E-11	2.4 E-10	9.1 E-12	4.7 E-11	2.4 E-10
Sr-95	1.4 E-10	6.3 E-10	3.2 E-09	1.4 E-10	6.3 E-10	3.2 E-09	1.4 E-10	6.3 E-10	3.2 E-09
Ce-144	2.7 E-10	1.2 E-09	4.9 E-09	2.7 E-10	1.2 E-09	4.9 E-09	2.7 E-10	1.2 E-09	4.9 E-09
Total	2.8 E-06	9.0 E-06	2.6 E-05	2.8 E-06	9.0 E-06	2.6 E-05	2.8 E-06	9.0 E-06	2.6 E-05
Summed Risk									
Cs-137	2.0 E-05	2.6 E-04	3.3 E-03	1.1 E-05	1.1 E-04	1.6 E-03	3.8 E-06	3.2 E-05	3.8 E-04
Ru-106	1.3 E-07	1.7 E-06	2.7 E-05	5.4 E-08	7.7 E-07	1.3 E-05	3.2 E-08	2.5 E-07	3.8 E-06
Sr-90	1.4 E-06	1.6 E-05	2.2 E-04	6.3 E-07	6.6 E-06	1.0 E-04	1.3 E-07	1.7 E-06	2.7 E-05
Co-60	5.3 E-07	2.1 E-06	1.8 E-05	5.2 E-07	1.8 E-06	1.1 E-05	5.2 E-07	1.7 E-06	6.1 E-06
Nb-95	9.1 E-12	4.7 E-11	2.4 E-10	9.1 E-12	4.7 E-11	2.4 E-10	9.1 E-12	4.7 E-11	2.4 E-10
Sr-95	1.4 E-10	6.3 E-10	3.2 E-09	1.4 E-10	6.3 E-10	3.2 E-09	1.4 E-10	6.3 E-10	3.2 E-09
Ce-144	2.7 E-10	1.2 E-09	4.9 E-09	2.7 E-10	1.2 E-09	4.9 E-09	2.7 E-10	1.2 E-09	4.9 E-09
Total Summed Risk	2.2 E-05	2.8 E-04	3.6 E-03	1.3 E-05	1.2 E-04	1.7 E-03	4.5 E-06	3.6 E-05	4.1 E-04

Table D.5 Risks summed for fish consumption at CRM 20.5 and drinking water consumption and external exposure at CRM 14 for males exposed during the entire study period (48 years).

	Male - Category I			Male - Category II			Male - Category III		
	95% subjective confidence interval	50.00%	97.50%	95% subjective confidence interval	50.00%	97.50%	95% subjective confidence interval	50.00%	97.50%
Drinking Water									
Cs-137	3.2 E-08	1.9 E-07	1.1 E-06	3.2 E-08	1.9 E-07	1.1 E-06	3.2 E-08	1.9 E-07	1.1 E-06
Ru-106	1.4 E-06	6.8 E-06	3.1 E-05	1.4 E-06	6.8 E-06	3.1 E-05	1.4 E-06	6.8 E-06	3.1 E-05
Sr-90	6.2 E-07	3.7 E-06	2.2 E-05	6.2 E-07	3.7 E-06	2.2 E-05	6.2 E-07	3.7 E-06	2.2 E-05
Total	2.0 E-06	1.1 E-05	5.5 E-05	2.0 E-06	1.1 E-05	5.5 E-05	2.0 E-06	1.1 E-05	5.5 E-05
Fish									
Cs-137	2.4 E-05	2.4 E-04	3.3 E-03	8.2 E-06	1.0 E-04	1.6 E-03	1.8 E-06	2.3 E-05	3.3 E-04
Ru-106	1.2 E-07	1.8 E-06	2.6 E-05	4.2 E-08	7.1 E-07	9.0 E-06	7.7 E-09	1.6 E-07	2.7 E-06
Sr-90	1.6 E-06	1.6 E-05	2.5 E-04	5.2 E-07	6.6 E-06	1.2 E-04	1.2 E-07	1.4 E-06	3.1 E-05
Co-60	2.6 E-08	4.7 E-07	8.8 E-06	8.7 E-09	2.0 E-07	4.4 E-06	2.1 E-09	4.3 E-08	1.0 E-06
Total	2.6 E-05	2.6 E-04	3.6 E-03	8.7 E-06	1.1 E-04	1.8 E-03	1.9 E-06	2.5 E-05	3.7 E-04
External									
Cs-137	3.4 E-06	1.6 E-05	8.1 E-05	3.4 E-06	1.6 E-05	8.1 E-05	3.4 E-06	1.6 E-05	8.1 E-05
Ru-106	5.3 E-08	2.5 E-07	1.3 E-06	5.3 E-08	2.5 E-07	1.3 E-06	5.3 E-08	2.5 E-07	1.3 E-06
Sr-90	2.8 E-10	1.4 E-09	6.6 E-09	2.8 E-10	1.4 E-09	6.6 E-09	2.8 E-10	1.4 E-09	6.6 E-09
Co-60	1.5 E-06	7.1 E-06	3.5 E-05	1.5 E-06	7.1 E-06	3.5 E-05	1.5 E-06	7.1 E-06	3.5 E-05
Nb-95	3.1 E-09	1.6 E-08	1.0 E-07	3.1 E-09	1.6 E-08	1.0 E-07	3.1 E-09	1.6 E-08	1.0 E-07
Sr-95	3.5 E-08	1.8 E-07	9.0 E-07	3.5 E-08	1.8 E-07	9.0 E-07	3.5 E-08	1.8 E-07	9.0 E-07
Ce-144	8.5 E-09	4.1 E-08	2.1 E-07	8.5 E-09	4.1 E-08	2.1 E-07	8.5 E-09	4.1 E-08	2.1 E-07
Total	5.1 E-06	2.4 E-05	1.2 E-04	5.1 E-06	2.4 E-05	1.2 E-04	5.1 E-06	2.4 E-05	1.2 E-04
Summed Risk									
Cs-137	2.7 E-05	2.6 E-04	3.4 E-03	1.2 E-05	1.2 E-04	1.7 E-03	5.3 E-06	4.0 E-05	4.2 E-04
Ru-106	1.6 E-06	8.8 E-06	5.8 E-05	1.5 E-06	7.7 E-06	4.2 E-05	1.5 E-06	7.2 E-06	3.5 E-05
Sr-90	2.2 E-06	2.0 E-05	2.7 E-04	1.1 E-06	1.0 E-05	1.5 E-04	7.4 E-07	5.1 E-06	5.4 E-05
Co-60	1.5 E-06	7.6 E-06	4.4 E-05	1.5 E-06	7.3 E-06	4.0 E-05	1.5 E-06	7.1 E-06	3.6 E-05
Nb-95	3.1 E-09	1.6 E-08	1.0 E-07	3.1 E-09	1.6 E-08	1.0 E-07	3.1 E-09	1.6 E-08	1.0 E-07
Sr-95	3.5 E-08	1.8 E-07	9.0 E-07	3.5 E-08	1.8 E-07	9.0 E-07	3.5 E-08	1.8 E-07	9.0 E-07
Ce-144	8.5 E-09	4.1 E-08	2.1 E-07	8.5 E-09	4.1 E-08	2.1 E-07	8.5 E-09	4.1 E-08	2.1 E-07
Total Summed Risk	3.3 E-05	3.0 E-04	3.8 E-03	1.6 E-05	1.4 E-04	1.9 E-03	9.0 E-06	5.9 E-05	5.4 E-04

VITA

Brian A. Thomas was born in Sevierville, Tennessee on December 15, 1971. He went to Sevier County High School where he graduated in June 1990. The following September he entered Carson Newman College in Jefferson City, TN with an interest in the engineering field. Two years later after completing most of the core classes required for graduation, he transferred to The University of Tennessee at Knoxville and graduated in May 1995 with a Bachelor of Science degree in Nuclear Engineering. Since 1993, he has worked under the direction of Dr. F. Owen Hoffman at SENES Oak Ridge, Inc., Center for Risk Analysis. In December 1998 he received a Master of Science degree in Nuclear Engineering.

He has performed quantitative uncertainty analysis of the human health risk assessment for the Lower Watts Bar Reservoir and for the Clinch River and Poplar Creek systems in Oak Ridge, Tennessee. He has published a comparative analysis of the effects of choosing different distributions to represent parameter uncertainty in various models. He participated in the Oak Ridge Dose Reconstruction Project that estimated off-site doses and risks to individuals residing near the Oak Ridge Reservation after 1944.

His additional interests include spending time with his daughter and family, mountain bike racing, running, and any kind of exercise.