We first calculated the exposure to contaminants. Contaminants reach us via four pathways: contact with the skin, ingestion, inhalation, and external radiation. External radiation is different from contact with the skin in that with external radiation the contaminant need not actually come into contact with the human body. In the exposure equations, we used the concentrations of contaminants in sediment, soil, seep water, surface water, food products, and cultural materials.

5.2.1.1 Human Exposure Equations Derived by Pathway

The following equations represent the total exposure of a person to radionuclides or chemicals. These equations describe just the exposure or intake, not the dose or risk from those exposures. The risk is included in the revised equations in Section 5.2.1.3.

External Radiation Exposure

$$Dose_{ext} = [C_{sed} * ET_{sed} * EF_{sed} * DF1 + C_{river} * ET_{swim} * EF_{swim} * DF2 + C_{river} * ET_{boat} * EF_{boat} * DF3] * ED \quad (5.1)$$

where

- C_{river} = radionuclide concentration in river water (pCi/L)
- C_{sed} = radionuclide concentration in sediment (pCi/g)
- DF1 = dose conversion factor for soil and sediment (rem/hr per pCi/g)
- DF2 = dose conversion factor for swimming (rem/hr per pCi/L)
- DF3 = dose conversion factor for boating (rem/hr per pCi/L)
- $Dose_{ext}$ = dose from external radionuclides (rem)
- ED = exposure duration (year)
- EF_{boat} = exposure frequency for boating (days/year)
- EF_{sed} = exposure frequency for sediment (days/year)
- EF_{swim} = exposure frequency for swimming (days/year)
- ET_{boat} = exposure time for boating (hours/day)
- ET_{sed} = exposure time for sediment (hours/day)
- ET_{swim} = exposure time for swimming (hours/day)

Dermal Exposure (Carcinogenic, Non-Carcinogenic, Non-Radioactive)

$$DAD = [C_{sed} * AF_{sed} * ABS * SA_{sed} * EF_{sed} * CF1 + (C_{other} * K_p * SA_{other} * ET_{other} * EF_{other} + C_{seep} * K_p * SA_{seep} * ET_{seep} * EF_{seep}) * CF3 + C_{river} * K_p * SA_{river} * ET_{river} * EF_{river} * CF3] * ED/(BW * AT) \quad (5.2)$$

where

- ABS = material-specific absorption factor (unitless)
- AF_{sed} = adherence factor for sediment (mg/cm^2 per day)
- AT = averaging time (year x 365 days/year)
- BW = body weight (kg)

C_{other} = contaminant concentration in cultural materials made airborne (defined in the scenarios as seep water used in sweat lodges) (mg/L)
C_{river} = contaminant concentration in river water (mg/L)
C_{sed} = contaminant concentration in sediment (mg/kg)
C_{seep} = contaminant concentration in seep/spring water (mg/L)
CF1 = unit conversion factor (1E-6 kg/mg)
CF3 = unit conversion factor (1E-3 L/cm^3)
DAD = dose from dermal absorption (mg/kg per day)
ED = exposure duration (year)
EF_{other} = exposure frequency to cultural activities (sweat lodge) (days/year)
EF_{river} = exposure frequency to river water (days/year)
EF_{sed} = exposure frequency to sediment (days/year)
EF_{seep} = exposure frequency to seep/spring water (days/year)
ET_{other} = exposure time to cultural activities (sweat lodge) (hours/day)
ET_{river} = exposure time to river water (hours/day)
ET_{seep} = exposure time to seep/spring water (hours/day)
K_p = permeability coefficient for a chemical in water through skin (cm/hour)
SA_{other} = body surface area exposed during cultural activities (sweat lodge) (cm^2)
SA_{river} = body surface area exposed to river water (cm^2)
SA_{sed} = body surface area exposed to sediment (cm^2)
SA_{seep} = body surface area exposed to seep/spring water (cm^2)

Inhalation Exposure (Non-Radioactive)

$$INH = (C_{seep} * VF * ET_{seep} * EF_{seep} + C_{river} * VF * ET_{river} * EF_{river} + C_{other} * CF_{other} * ET_{other} * EF_{other}) * ED * BR/(BW * AT * CF4) \quad (5.3)$$

where

AT = averaging time (year x 365 days/year)
BR = inhalation (breathing) rate (m^3/day)
BW = body weight (kg)
C_{other} = contaminant concentration in cultural materials made airborne (defined in the scenarios as volatilized seep water used in sweat lodges) (mg/L)
C_{river} = contaminant concentration in river water (mg/L)
C_{seep} = contaminant concentration in seep/spring water (mg/L)
CF4 = unit conversion factor (24 hours/day)
CF_{other} = factor relating cultural materials to air concentration (defined in the scenarios as volatilized seep water used in sweat lodges) (L/m^3)
ED = exposure duration (year)
EF_{other} = exposure frequency to materials resuspended from cultural activities (day/year)
EF_{river} = exposure frequency to volatilized river water (day/year)
EF_{seep} = exposure frequency to volatilized seep/spring water (day/year)
ET_{other} = exposure time for breathing materials suspended from cultural activities (hours/day)

ET_{river}	=	exposure time for breathing volatilized river water (hours/day)
ET_{seep}	=	exposure time for breathing volatilized seep/spring water (hours/day)
INH	=	chronic daily inhalation intake (mg/kg per day)
VF	=	volatilization factor (L/m^3)

Inhalation Exposure (Radioactive)

$$Dose_{inh} = (C_{seep} * VF * ET_{seep} * EF_{seep} + C_{river} * VF * ET_{river} * EF_{river} + C_{other} * CF_{other} * ET_{other} * EF_{other} * CF5) * ED * BR * DF5/CF4 \quad (5.4)$$

where

BR	=	inhalation rate (m^3/day)
C_{other}	=	radionuclide concentration in cultural materials made airborne (defined in the scenarios as volatized seep water used in sweat lodges) (pCi/g)
C_{river}	=	radionuclide concentration in river water (pCi/L)
C_{seep}	=	radionuclide concentration in seep/spring water (pCi/L)
CF4	=	unit conversion factor (24 hours/day)
CF5	=	unit conversion factor (1000 g/kg)
CF_{other}	=	factor relating cultural materials to air concentration (defined in the scenarios as volatilized seep water used in sweat lodges) (L/m^3)
DF5	=	dose conversion factor for inhalation (rem/pCi)
$Dose_{inh}$	=	dose from inhalation of radionuclides (rem)
ED	=	exposure duration (year)
EF_{other}	=	exposure frequency to materials resuspended during cultural activities (days/year)
EF_{river}	=	exposure frequency to volatilized river water (days/year)
EF_{seep}	=	exposure frequency to volatilized seep/spring water (days/year)
ET_{other}	=	exposure time for breathing materials suspended during cultural activities (hours/day)
ET_{river}	=	exposure time for breathing volatilized river water (hours/day)
ET_{seep}	=	exposure time for breathing volatilized seep/spring water (hours/day)
VF	=	volatilization factor (L/m^3)

Ingestion Exposure (Non-Radioactive)

$$ING = (C_{sed} * IR_{sed} + C_{river} * IR_{river} + C_{seep} * IR_{seep} + C_{fish} * IR_{fish} + C_{leafy} * IR_{leafy} + C_{root} * IR_{root} + C_{meat} * IR_{meat} + C_{bird} * IR_{bird}) * EF * ED/(AT * BW) \quad (5.5)$$

where

AT	=	averaging time (year x 365 days/yr)
BW	=	body weight (kg)
C_{bird}	=	contaminant concentration in domestic and wild birds (mg/kg)
C_{fish}	=	contaminant concentration in fish (mg/kg)

C_{leafy} = contaminant concentration in above-ground vegetation (mg/kg)
C_{meat} = contaminant concentration in meat (mg/kg)
C_{river} = contaminant concentration in river water (mg/kg)
C_{root} = contaminant concentration in root vegetables (mg/kg)
C_{sed} = contaminant concentration in sediment (mg/kg)
C_{seep} = contaminant concentration in seep/spring water (mg/kg)
ED = exposure duration (year)
EF = exposure frequency (days/year)
ING = chronic daily ingestion rate (mg/kg per day)
IR_{bird} = ingestion rate of domestic and wild birds (kg/day)
IR_{fish} = ingestion rate of fish (kg/day)
IR_{leafy} = ingestion rate of above-ground vegetation (kg/day)
IR_{meat} = ingestion rate of meat (kg/day)
IR_{river} = ingestion rate of river water (kg/day)
IR_{root} = ingestion rate of root vegetables (kg/day)
IR_{sed} = ingestion rate of sediment (kg/day)
IR_{seep} = ingestion rate of seep/spring water (kg/day)

Ingestion Exposure (Radioactive)

$$Dose_{ing} = (C_{sed} * IR_{sed} + C_{river} * IR_{river} + C_{seep} * IR_{seep} + C_{fish} * Ir_{fish} + C_{leafy} * IR_{leafy} + C_{root} * IR_{root} + C_{meat} * IR_{meat} + C_{bird} * IR_{bird}) * EF * ED * CF5 * DF6 \quad (5.6)$$

where

C_{bird} = radionuclide concentration in domestic and wild birds (pCi/g)
C_{fish} = radionuclide concentration in fish (pCi/g)
C_{leafy} = radionuclide concentration in above-ground vegetation (pCi/g)
C_{meat} = radionuclide concentration in meat (pCi/g)
C_{river} = radionuclide concentration in river water (pCi/g)
C_{root} = radionuclide concentration in root vegetables (pCi/g)
C_{sed} = radionuclide concentration in sediment (pCi/g)
C_{seep} = radionuclide concentration in seep/spring water (pCi/g)
CF5 = unit conversion factor (1000 g/kg)
DF6 = dose conversion factor for ingestion (rem/pCi)
$Dose_{ing}$ = dose from ingestion (rem)
ED = exposure duration (year)
EF = exposure frequency (days/year)
IR_{bird} = ingestion rate of domestic and wild birds (kg/day)
IR_{fish} = ingestion rate of fish (kg/day)
IR_{leafy} = ingestion rate of above-ground vegetation (kg/day)
IR_{meat} = ingestion rate of meat (kg/day)
IR_{river} = ingestion rate of river water (kg/day)

IR_{root} = ingestion rate of root vegetables (kg/day)
IR_{sed} = ingestion rate of sediment (kg/day)
IR_{seep} = ingestion rate of seep/spring water (kg/day)

5.2.1.2 Estimate of Environmental Concentrations of Contaminants

The equations defined in Section 5.2.1.1 required both the concentrations of contaminants in the measured media (sediment, seep water, surface water) and also in food products, such as fish, birds, meat, and vegetables that become contaminated through contact with these media. To determine the concentrations in vegetation, the human exposure model used the data (Section 3.0) for the contaminant concentrations in the media and the results of the ecological model (Section 4.2), summarized as transfer coefficients. The same transfer coefficients were assumed to apply to all terrestrial vegetation. Therefore, concentrations estimated for riparian vegetation were assumed to be the same as those estimated for food products. In this way, the human and ecological models were directly connected and thus consistent. The estimate of concentrations in these food products is described here.

Fish. The contaminant concentration in fish for a segment was related to the contaminant concentration in Columbia River water in that segment as

$$C_{fish} = C_{river} * BIO_{fish} \tag{5.7}$$

where

C_{fish} = analyte concentration in fish (pCi or µg/kg)
C_{river} = analyte concentration in river water (pCi or µg/L)
BIO_{fish} = analyte-specific bioaccumulation factor derived from the CRCIA ecosystem model results (pCi/kg per pCi/L or µg/kg per µg/kg)

Foods. The contaminant concentrations in terrestrial foods were related to the concentrations of analytes in sediment.

$$\begin{aligned} C_{leafy} &= C_{sed} * CR_{veg} \\ C_{root} &= C_{sed} * CR_{veg} = C_{leafy} \\ C_{meat} &= C_{leafy} * TF_{deer} = C_{sed} * CR_{veg} * TF_{deer} \\ C_{bird} &= C_{leafy} * TF_{bird} = C_{sed} * CR_{veg} * TF_{bird} \end{aligned} \tag{5.8}$$

where

C_{bird} = analyte concentration in wild bird flesh (pCi or µg/kg)
C_{leafy} = analyte concentration in leafy vegetables (pCi or µg/kg)
C_{meat} = analyte concentration in animal protein (pCi or µg/kg)
C_{root} = analyte concentration in root vegetables (pCi or µg/kg)
C_{sed} = analyte concentration in sediment (pCi or µg/kg)
CR_{veg} = sediment-to-vegetation concentration ratio derived from ecosystem model
TF_{bird} = feed-to-wild-bird transfer factor derived from ecosystem model
TF_{deer} = feed-to-animal-protein transfer factor derived from ecosystem model

Native American Cultural Materials. The only unique Native American pathway defined in the CRCIA scenarios involves a sweat lodge. The assumption for the sweat lodge was that seep water would be collected and poured over hot rocks to create steam. Therefore,

$$C_{other} = C_{seep} \tag{5.9}$$

where

C_{other} = analyte concentration in cultural materials
C_{seep} = analyte concentration in seep/spring water (pCi/L or µg/L)

5.2.1.3 Human Exposure Equations Derived by Media

Later in Sections 5.2 and then in Section 6, the results of human exposure will be discussed in terms of risk from the various Columbia River media (for example, surface water, sediments, seep water). The equations used to quantify the results in that way are given here.

To provide the maximum amount of information to the CRCIA decision makers, the equations defined in Sections 5.2.1.1 and 5.2.1.2 were rearranged to provide risk as a function of exposure media (sediment, seep water, or surface water) or external radiation exposure. These equations used the same parameter definitions as in Section 5.2.1.1 but were broken out by contaminant type (radionuclide, carcinogenic chemical, or toxic chemical) and measured initiating medium. Note that groundwater, although used extensively as a surrogate measure for concentration as defined in Section 3.0, was not an initiating medium in the scenarios. Without repeating the same parameter definitions again, the equations used in the actual analysis are given here, with any new parameters defined.

Radionuclides

$$\begin{aligned} Risk(SD) = & [\{C_{sed} * (IR_{sedchild} * ED_{child} + IR_{sedadult} * ED_{adult}) * EF_{sed}\} \\ & + \{C_{leafy} * IR_{leafy} + C_{root} * IR_{root} + C_{meat} * IR_{meat} + C_{bird} * IR_{bird}\} \\ & * EF * ED] * CF5 * DF6 * DOSE2RISK \end{aligned} \tag{5.10}$$

where

Risk(SD) = risk from sediment
$IR_{sedchild}$ = ingestion rate of sediment by a child (kg/day)
ED_{child} = exposure duration of a child (year)
$IR_{sedadult}$ = ingestion rate of sediment by an adult (kg/day)
ED_{adult} = exposure duration of an adult (year)
DOSE2RISK = factor converting accumulated radiation dose to risk (risk/rem)

Note: C_{leafy}, C_{root}, C_{meat}, C_{bird} are all derived from C_{sed} as described in Section 5.2.1.2.

$$Risk(SW) = [C_{river} * ET_{swim} * EF_{swim} * ED * DF2 + C_{river} * ET_{boat} * EF_{boat} * ED * DF3 + C_{river} * VF * ET_{river} * EF_{river} * ED * BR * DF5/CF4 + (C_{fish} * IR_{fish} + C_{river} * IR_{river}) * EF * ED * CF5 * DF6] * DOSE2RISK \quad (5.11)$$

where

Risk(SW) = risk from surface water

Note: C_{fish} is derived from C_{river}.

$$Risk(SP) = [(C_{seep} * VF * ET_{seep} * EF_{seep} + C_{other} * CF_{other} * ET_{other} * EF_{other}) * ED * BR * DF5/CF4 + C_{seep} * IR_{seep} * EF_{seep} * ED * CF5 * DF6] * DOSE2RISK \quad (5.12)$$

where

Risk(SP) = risk from seeps

Two cases were evaluated for external irradiation: where direct thermoluminescent dosimetry measurements were available and where they were not. If measurements were available, they were used directly. To use the measurements, which record all radiation exposure including background and Hanford Site contribution, a background value was subtracted. For the region around the Hanford Site, a regional value of 0.2 mrad/day (8 µR/hour) was subtracted.

$$Risk(ER) = MAX[(ER-0.2),0] * ET_{sed} * EF_{sed} * ED * DOSE2RISK/(CF4 * CF6) \quad (5.13)$$

where

Risk(ER)	=	risk from external radiation
MAX	=	functional relationship, taking the larger of the measured exposure rate minus reference or zero
ER	=	measured exposure rate in a segment (mrad/day)
CF6	=	unit conversion factor (0.001 rem/mrad)

When measured values were not available, the dose rates were estimated from the sediment concentrations.

$$Risk(ER) = C_{sed} * ET_{sed} * EF_{sed} * RF_{sed} * ED * DF1 * DOSE2RISK \quad (5.14)$$

Carcinogenic Chemicals

$$Risk(SD) = [C_{sed} * AF_{sed} * ABS * SA_{sed} * EF_{sed} * CF1 * ED/(BW_{adult} * AT) + \{C_{sed} * (IR_{sedchild} * ED_{child}/BW_{child} + IR_{sedadult} * ED_{adult}/BW_{adult}) + C_{leafy} * IR_{leafy} * ED/BW_{adult} + C_{root} * IR_{root} * ED/BW_{adult} + C_{meat} * IR_{meat} * ED/BW_{adult} + C_{bird} * IR_{bird} * ED/BW_{adult}\} * EF/AT] * CPF_{ing} * CF7 \quad (5.15)$$

where

BW_{adult} = body weight of an adult (kg)
BW_{child} = body weight of a child (kg)
CPF_{ing} = cancer potency factor for ingestion, risk per mg/(kg/day)
CF7 = unit conversion factor (0.001 mg/µg)

Note: C_{leafy}, C_{root}, C_{meat}, C_{bird} are all derived from C_{sed} as described in Section 5.2.1.2.

$$Risk(SW) = [\{(C_{river} * IR_{river} + C_{fish} * IR_{fish}) * EF + (C_{river} * K_p * SA_{river} * ET_{swim} * EF_{swim} * CF3)\} * ED/(AT * BW_{adult}) * CPF_{ing} + C_{river} * VF * ET_{river} * EF_{river} * ED * BR/(BW_{adult} * AT * CF4) * CPF_{inh}] * CF7 \quad (5.16)$$

where

CPF_{inh} = cancer potency factor for inhalation, risk per mg/(kg/day)

Note: C_{fish} is derived from C_{river} as described in Section 5.2.1.2.

$$Risk(SP) = [(C_{seep} * K_p * SA_{seep} * ET_{seep} * EF_{seep} * CF3 + C_{other} * K_p * SA_{other} * ET_{other} * EF_{other} * CF3) * ED/(BW_{adult} * AT) * CPF_{ing} + (C_{seep} * VF * ET_{seep} * EF_{seep} + C_{other} * CF_{other} * ET_{other} * EF_{other}) * ED * BR/(BW_{adult} * AT * CF4) * CPF_{inh} + C_{seep} * IR_{seep} * EF * ED/(BW_{adult} * AT) * CPF_{ing}] * CF7 \quad (5.17)$$

Toxic Chemicals

The difference in the equations between those for carcinogenic chemicals and toxic chemicals was that CPF_{ing} and CPF_{inh} were replaced with $1/RfD_{ing}$ and $1/RfD_{inh}$, respectively.

$$Risk(SD) = [C_{sed} * AF_{sed} * ABS * SA_{sed} * EF_{sed} * CF1 * ED/(BW_{adult} * AT) + \{C_{sed} * (IR_{sedchild} * ED_{child}/BW_{child} + IR_{sedadult} * ED_{adult}/BW_{adult}) + C_{leafy} * IR_{leafy} * ED/BW_{adult} + C_{root} * IR_{root} * ED/BW_{adult} + C_{meat} * IR_{meat} * ED/BW_{adult} + C_{bird} * IR_{bird} * ED/BW_{adult}\} * EF/AT]/RfD_{ing} * CF7 \quad (5.18)$$

where

RfD_{ing} = reference dose for ingestion, mg/(kg day)

Note: C_{leafy}, C_{root}, C_{meat}, C_{bird} were all derived from C_{sed} as described in Section 5.2.1.2.

$$Risk(SW) = [\{(C_{river} * IR_{river} + C_{fish} * IR_{fish}) * EF + (C_{river} * K_p * SA_{river} * ET_{swim} * EF_{swim} * CF3)\} * ED/(AT * BW_{adult})/RfD_{ing} + C_{river} * VF * ET_{river} * EF_{river} * ED * BR/(BW_{adult} * AT * CF4)/RfD_{inh}] * CF7 \quad (5.19)$$

where

RfD_{inh} = reference dose for inhalation, mg/(kg day)

Note: C_{fish} was derived from C_{river} as described in Section 5.2.1.2.

$$\begin{aligned} Risk(SP) = {} & [(C_{seep} * K_p * SA_{seep} * ET_{seep} * EF_{seep} * CF3 + C_{other} * K_p * \\ & SA_{other} * ET_{other} * EF_{other} * CF3) * ED/(BW_{adult} * AT)/RfD_{ing} + \\ & (C_{seep} * VF * ET_{seep} * EF_{seep} + C_{other} * CF_{other} * ET_{other} * EF_{other}) * \\ & ED * BR/(BW_{adult} * AT * CF4)/RfD_{inh} + C_{seep} * IR_{seep} * EF * \\ & ED/(BW_{adult} * AT)/RfD_{ing}] * CF7 \end{aligned} \tag{5.20}$$

A series of equations was established to describe the individual exposure pathways for the Columbia River Island User. These equations differ from the more general ones presented in Sections 5.2.1.1 and 5.2.1.3, and therefore they are presented here.

For the likelihood of being subjected to a skin lesion/beta particle burn, the equation is

$$EX_{skin} = AF_{sed} * SA_{sed} * PD/\rho * EF_{sed} * PA * SR \tag{5.21}$$

where

ES_{skin}	=	skin exposure to a single hot particle (µCi - hour)
AF_{sed}	=	adherence factor for sediment (mg/cm^2 per day)
SA_{sed}	=	body surface area exposed to sediment (cm^2)
PD	=	particle density (particles/cm^3)
ρ	=	sediment density (mg/cm^3)
EF_{sed}	=	exposure frequency to sediment (days/year)
PA	=	particle activity (µCi/particle)
SR	=	sediment retention time on skin (hours)

For inhalation, the equation is based on risk of a skin lesion/beta particle burn from lodging of a discrete particle in the nose, as

$$ES_{nose} = BR * ML * PD/\rho * EF_{sed} * PA * SR \tag{5.22}$$

where

EX_{nose}	=	exposure of interior of nose to a single hot particle (µCi - hour)
BR	=	inhalation (breathing) rate (m^3/day)
ML	=	mass loading of soil in air (kg/m^3)
PD	=	particle density (particles/cm^3)
ρ	=	sediment density (mg/cm^3)
EF_{sed}	=	exposure frequency to sediment (days/year)
PA	=	particle activity (µCi/particle)
SR	=	sediment retention time on skin (hours)

For the possibility of ingestion of a particle, the equation is

$$RISK_{Co60\_ing} = EF_{sed} * IR_{sed} * PD * PA * DF_{Co60\_ing} * (1-e^{-\lambda * ED}) / \lambda * DOSE2RISK \quad (5.23)$$

where

EF_{sed}	=	exposure frequency to sediment (days/year)
IR_{sed}	=	ingestion rate of sediment (kg/day)
PD	=	particle density (particles/cm^3)
PA	=	particle activity (µCi/particle)
DF_{Co60_ing}	=	dose conversion factor for ingestion of cobalt-60 particles (rem/µCi)
λ	=	decay constant for cobalt-60 ($year^{-1}$)
ED	=	exposure duration (year)
DOSE2RISK	=	factor converting accumulated radiation dose to risk, risk/rem

The decay integral is required in this calculation because the scenario assumes repeated exposure over a lifetime. Thus, the scenario assumes that the individual is exposed every year of her/his life. Because cobalt-60 has a 5.27-year half-life, the exposures decrease rapidly. This must be accounted for in the exposure estimate

For external irradiation without direct contact, the equation is

$$RISK_{ext} = EF_{sed} * PD * PA * DF_{Co60\_ext} * (1-e^{-\lambda * ED}) / \lambda * DOSE2RISK \quad (5.24)$$

where

EF_{sed}	=	exposure frequency to sediment (days/year)
PD	=	particle density (particles/cm^3)
PA	=	particle activity (µCi/particle)
DF_{Co60_ext}	=	dose conversion factor for external exposure to cobalt-60 in sediment (rem/day per µCi/cm^3)
λ	=	decay constant for cobalt-60 ($year^{-1}$)
ED	=	exposure duration (year)
DOSE2RISK	=	factor converting accumulated radiation dose to risk, risk/rem

The scenario is established for a lifetime of exposure, so the annual exposures are multiplied by the integral of the activity over a 70-year lifetime.

The possibility of inhaling a discrete radioactive particle was addressed by Durham and Soldat in the appendix of Cooper and Woodruff (1993). They found the physical size of the particles was such that one could not be inhaled into the lungs. At worst, the particles would lodge in the anterior portion of the nose. Durham used the specific activity of hot particles commonly found in the commercial nuclear industry in his calculation (60,000 Ci/cm^3). This specific activity relates to relatively young particles. Those found in the Columbia River from plutonium production activities are at least 25 years old and therefore older than those studied by Durham. Thus, for the same particle activity, the particles would physically be much larger than assumed by Durham. He based his calculations on a 10-micron particle. The typical size found by Sula is

0.1 mm (100 microns). Therefore, the nasal retention used by Durham (1 to 2 days) is considerably longer than what would occur with this size particle. Nevertheless, a retention of up to 2 days has been used in this analysis. Durham's dose conversion parameter for cobalt-60 particles of 3.77 millirem/microcurie has also been used for this scenario.

5.2.2 Parameters

A large number of parameters were required by the equations defined in the preceding sections in addition to those describing the human activities in the scenarios (Section 5.1). The parameters fall into the categories of environmental transfer factors, radiation dose conversion factors, chemical risk and reference doses, dermal absorption rate constants, and miscellaneous other parameters. Each parameter used in the assessment is defined here and its source given. Most parameters were treated stochastically, which means they have a range of uncertainty. This uncertainty range is also provided here with notes as to how it was selected.

As you noticed in the previous section, each equation contains many parameters. Each parameter defines a particular aspect that affects risk to human health. For instance, one parameter is denoted as C_{leafy} in the equations. C_{leafy} is the amount of contaminant in leafy vegetables. We calculated C_{leafy} for each of the contaminants (28) in each of the areas (27 segments) along the Columbia River.

In this section, we describe the parameters used in the equations and where we obtained our information for each parameter. We organized the descriptions of the parameters according to type of parameter: environmental transfer factors, radiation dose conversion factors, chemical risk and reference dose factors, dermal absorption rate constants, or other types of parameters.

5.2.2.1 Common Parameters with the Ecological Model

The equations described in Section 5.2.1.2 for estimating potential contaminant concentrations in fish, birds, meat, and vegetation (plants consumed by humans or animals) require parameters that relate the ratios of a contaminant in one medium to that in another. The ratios used in the human health risk assessment were developed by running the ecological risk model described in Section 4.2. The ecological model was run in a deterministic fashion for each of the 27 river segments. The results of these runs were analyzed to develop the distributions of transfer functions needed for the human risk model. The results are presented in Table 5.14. Transfer functions are given for fish (averaged over several species of food fish), birds (an average of ducks), meat (defined as deer in the ecological model), and vegetation. The minima and maxima presented in Table 5.14 came from the 27 sements evaluated in the ecological model. The deterministic value is the average from that model's results.

An exception is the bioaccumulation factors for Columbia River fish. In several cases the ecological model was unable to provide information for several contaminants because the measurements of these contaminants in river water were not available. Therefore, to ensure completeness and consistency, bioaccumulation factors for fish were taken from a standard reference (IAEA1994). The minima and maxima presented in Table 5.14 came from the IAEA handbook. The deterministic value is the best estimate from the IAEA reference.

Table 5.14. Parameters in the Human Health Risk Assessment Coordinated with the Ecosystem Models

	BIO_{fish} [a] (pCi/kg per pCi/L) (µg/kg per µg/L)			Cr_{veg} (pCi/kg per pCi/kg) (µg/kg per µg/kg)			TF_{deer} (pCi/kg per pCi/kg) (µg/kg per µg/kg)			TF_{bird} (pCi/kg per pCi/kg) (µg/kg per µg/kg)		
Analyte	Deterministic	Minimum	Maximum	Deterministic	Minimum	Maximum	Deterministic	Minimum	Maximum	Deterministic	Minimum	Maximum
Ammonia	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	0	0	0	0	0	0	0	0	0	0	0	0
Carbon-14	0	0	0	0.18	0.18	0.18	0.9	0.9	0.9	0.9	0.9	0.9
Cesium-137	2000	30	3000	0.009	0.0006	0.102	2.8	2.5	3.6	8.4	4.5	19
Chromium	200	40	1000	0.0048	0.001	0.0288	0.058	0.056	0.1	0.024	0.014	0.25
Cobalt-60	300	10	300	0.009	0.0018	0.0664	0.22	0.13	0.58	48	0.76	246
Copper	200	50	200	0.045	0.006	1.13	1	1	1	16	10	21
Cyanide	0	0	0	0	0	0	0	0	0	0	0	0
Diesel	0	0	0	0	0	0	0	0	0	0	0	0
Europium-152	50	10	200	0.0006	0.0002	0.0014	1.8	1.6	2	40.5	37	44
Europium-154	50	10	200	0.0006	0.0002	0.0014	1.8	1.6	2	40.5	37	44
Iodine-129	40	20	600	0.046	0.0084	0.5952	0	0	0	0	0	0
Kerosene	0	0	0	0	0	0	0	0	0	0	0	0
Lead	300	100	300	0.0076	0.0006	0.0248	0.16	0.16	0.17	0.081	0.068	0.29
Mercury	1000	1000	1000	0.1454	0.0754	0.18	0.41	0.41	0.41	48	48	48
Neptunium-237	30	10	3000	0.004	0.0002	0.0322	0	0	0	0	0	0
Nickel	100	100	100	0.029	0.016	0.591	0.003	0.003	0.003	0.008	0.008	0.012
Nitrate	0	0	0	6	6	6	0	0	0	0	0	0
Nitrite	0	0	0	6	6	6	0	0	0	0	0	0
Phosphate	0	0	0	0.7	0.7	0.7	0	0	0	0	0	0
Strontium-90	60	1	1000	0.1488	0.0098	1.48	0.645	0.63	2.9	2.6	2.3	50
Sulfate	0	0	0	0.3	0.3	0.3	0	0	0	0	0	0
Technetium-99	20	2	80	1.1	0.3	1.9	0.1	0.095	0.1	0.16	0.14	0.23
Tritium (H-3)	1	1	1	0.8	0.8	0.8	0.43	0.43	0.43	0	0	0
Uranium-234	10	2	50	0.0034	8.82E-05	2.57	0.63	0.61	1	4.8	3.9	21
Uranium-238	10	2	50	0.0034	8.82E-05	2.57	0.63	0.61	1	4.8	3.9	21
Xylene	0	0	0	0	0	0	0	0	0	0	0	0
Zinc	1000	100	3000	0.066	0.0108	0.4064	0.23	0.23	0.23	1.7	0.92	3.7

(a) The minima and maxima came from IAEA (1994).

A number of transfer factors can be seen to be set to zero in Table 5.14. For most contaminants for which this is true, the ecological modeling indicated that plants or animals did not take up these chemical compounds without first breaking them down to other biological components (for example, nitrates are metabolized to other forms of nitrogen, sulfates to sulfur, etc.).

5.2.2.2 Radiation Dose Conversion Factors

The translation of radionuclide concentration in sediment, soil, or water to radiation dose rate was performed using dose rate conversion factors (see Table 5.15). Such factors are available from a number of sources and are very similar regardless of the source. The factors used in this analysis were taken from the Federal Guidance Report No. 12 (Eckerman and Ryman 1993).

Soil and sediment factors relate concentration in soil and sediment in picocuries/kilogram to the external dose rate above a large, flat contaminated area in rem/hour. These factors apply to very large sources; therefore, the geometry correction factor defined for each scenario is used to adjust these to fit the smaller geometry of the riparian zone. Uncertainties in these factors are fairly small. A range of one-half to twice the tabulated values was selected for all of these dose conversion factors in a uniform distribution following the logic of Snyder et al. (1994). Note that isotopes that emit no gamma rays and only low-energy beta particles, such as tritium (hydrogen-3), pose no hazard through external exposure.

Swimming dose factors relate the concentration of radionuclides in water in picocuries/liter to the dose rate in rem/hour. These were calculated using an assumption of immersion in what is effectively an infinite medium. This worked because the range of radiation in water is relatively short, on the order of a meter. The dose rate then was calculated by assuming that the energy emitted in a volume of water is equal to the energy absorbed in that same volume, and the presence of a person or a fish does not noticeably perturb the dose rate field. As with the soil dose rate factors, a narrow range of variability of one-half to two times the nominal value was used.

Dose conversion factors for boating were derived from those for swimming. The dose rate at the surface of a body of contaminated water can be shown to be exactly half that of a point immersed within the water (see, for example, Morgan and Turner 1973). For this analysis, that fact was used with no additional modifications (such as shielding from the boat or distance above the water line). A small range of a factor of 2 uniformly above and below the calculated dose rate conversion factor was also used.

Dose conversion factors for ingestion and inhalation were taken from Federal Guidance Report No. 11 (Eckerman et al. 1988). These factors relate the amount of a radionuclide in rem/picocurie taken into the body to the ultimate expressed dose over a period of 50 years following the intake. Internal doses such as these are more variable between individuals than are the external doses discussed above. Individual radiation doses depend on the amount of a radionuclide taken into the body and absorbed in the bloodstream, on the organs in which the contaminants accumulate and how long they remain there, and on the masses of the individual’s organs as well as the age and sex of the individual. These parameters vary

Table 5.15. Radiation Dose Conversion Factors

	Uniform Distributions								
	Soil & Sediment			**Swimming**			**Boating**		
	(rem/hr per pCi/kg)			(rem/hr per pCi/L)			(rem/hr per pCi/L)		
Analyte	Deterministic	Minimum	Maximum	Deterministic	Minimum	Maximum	Deterministic	Minimum	Maximum
Carbon-14	9.6E-16	4.8E-16	1.9E-15	5.8E-15	2.9E-15	1.2E-14	2.9E-15	1.5E-15	5.8E-15
Cesium-137	2.3E-10	1.2E-10	4.6E-10	8.3E-10	4.2E-10	1.7E-09	4.2E-10	2.1E-10	8.3E-10
Cobalt-60	9.7E-10	4.9E-10	1.9E-09	3.6E-09	1.8E-09	7.2E-09	1.8E-09	9.0E-10	3.6E-09
Europium-152	4.3E-10	2.2E-10	8.6E-10	1.6E-09	8.0E-10	3.2E-09	8.0E-10	4.0E-10	1.6E-09
Europium-154	4.7E-10	2.4E-10	9.4E-10	1.8E-09	9.0E-10	3.6E-09	9.0E-10	4.5E-10	1.8E-09
Iodine-129	9.2E-13	4.6E-13	1.8E-12	1.2E-11	6.0E-12	2.4E-11	6.0E-12	3.0E-12	1.2E-11
Neptunium-237	5.5E-09	2.7E-09	1.1E-08	3.1E-11	1.6E-11	6.2E-11	1.6E-11	7.9E-12	3.1E-11
Strontium-90	5.0E-14	2.5E-14	1.0E-13	1.9E-13	9.5E-14	3.8E-13	9.5E-14	4.8E-14	1.9E-13
Technetium-99	8.9E-15	4.5E-15	1.8E-14	4.2E-14	2.1E-14	8.4E-14	2.1E-14	1.1E-14	4.2E-14
Tritium (H-3)	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Uranium-234	2.8E-14	1.4E-14	5.6E-14	2.3E-13	1.2E-13	4.6E-13	1.2E-13	5.8E-14	2.3E-13
Uranium-238	7.4E-15	3.7E-15	1.5E-14	1.1E-13	5.5E-14	2.2E-13	5.5E-14	2.8E-14	1.1E-13
	Lognormal Distributions, GSD = 2.0								
	Ingestion			**Inhalation**			**Sweat Lodge Pathway = Inhalation**		
	(rem/pCi)			(rem/pCi)			(rem/pCi)		
Analyte	Deterministic	Minimum	Maximum	Deterministic	Minimum	Maximum	Deterministic	Minimum	Maximum
Carbon-14	2.1E-09	4.2E-10	1.1E-08	2.1E-09	4.2E-10	1.1E-08	2.1E-09	4.2E-10	1.1E-08
Cesium-137	5.0E-08	1.0E-08	2.5E-07	3.2E-08	6.4E-09	1.6E-07	3.2E-08	6.4E-09	1.6E-07
Cobalt-60	2.7E-08	5.4E-09	1.4E-07	3.3E-08	6.6E-09	1.7E-07	3.3E-08	6.6E-09	1.7E-07
Europium-152	6.5E-09	1.3E-09	3.3E-08	2.2E-07	4.4E-08	1.1E-06	2.2E-07	4.4E-08	1.1E-06
Europium-154	9.6E-09	1.9E-09	4.8E-08	2.9E-07	5.8E-08	1.5E-06	2.9E-07	5.8E-08	1.5E-06
Iodine-129	2.8E-07	5.6E-08	1.4E-06	1.7E-07	3.4E-08	8.5E-07	1.7E-07	3.4E-08	8.5E-07
Neptunium-237	2.4E-06	4.8E-07	1.2E-05	2.9E-04	5.8E-05	1.5E-03	2.9E-04	5.8E-05	1.5E-03
Strontium-90	1.4E-07	2.8E-08	7.0E-07	2.4E-07	4.8E-08	1.2E-06	2.4E-07	4.8E-08	1.2E-06
Technetium-99	1.5E-09	3.0E-10	7.5E-09	1.0E-09	2.0E-10	5.0E-09	1.0E-09	2.0E-10	5.0E-09
Tritium (H-3)	6.4E-11	1.3E-11	3.2E-10	6.4E-11	1.3E-11	3.2E-10	6.4E-11	1.3E-11	3.2E-10
Uranium-234	2.8E-07	5.6E-08	1.4E-06	2.7E-06	5.4E-07	1.4E-05	2.7E-06	5.4E-07	1.4E-05
Uranium-238	2.5E-07	5.0E-08	1.3E-06	2.4E-06	4.8E-07	1.2E-05	2.4E-06	4.8E-07	1.2E-05
References:	External dose factors from Eckerman and Ryan (1993).								
	Internal dose factors from Eckerman et al. (1988).								
Notes:	External Dose Factors are fairly well defined.								
	Following example of Snyder et al. (1994), external varied two times over tabulated values, uniform distribution.								
	Soil and sediment to account for surface roughness, shielding, and potentially closer exposures.								
	Swimming/boating to account for non-uniformities and potential lesser degrees of immersion.								
	Boating equals half of swimming.								
	Internal Dose Factors are more individual specific. Following the example of Snyder et al. (1994), the Geometric								
	Standard Deviation of 2.0 is assigned to all internal DFs. (e.g., Dunning and Schwarz 1981, Snyder et al. 1994).								
	This gives a range of a factor of 25 from 1st to 99th percentiles.								

in every person. Research on the variability of these parameters indicates that the resulting variability can be quite large (see, for example, Dunning and Schwarz 1981). Following the example of Snyder et al. (1994), a lognormal distribution was selected with a geometric standard deviation of 2. This provided an overall range of about a factor of 25 between the 1st and 99th percentiles of the distribution.

The exposure models were set up with separate pathways and parameters for the Native American cultural media exposures. In developing the scenarios, the sweat lodge was identified as a distinct Native American practice requiring analysis. The pathway of exposure in the sweat lodge is inhalation of contaminants volatilized from seep water in steam. This was represented in the model using the standard inhalation dose conversion factors.

5.2.2.3 Chemical Exposure Risk Factors

The calculations outlined in Sections 5.2.1.1 and 5.2.1.3 require a large number of input parameters for every chemical. Each parameter has a particular use and definition. The cancer potency factors relate the potential for causing cancer in an individual to the body burden of that material in the individual. A larger value for the cancer potency factor indicates a more potent, more dangerous, carcinogen. The reference doses relate a tolerable level of daily intake to an individual's body mass. A smaller value of reference dose indicates that less intake will be tolerated by the average person, and thus a more toxic material. The skin absorption factors relate the fraction of a contaminant, applied to the skin in a relatively dry mixture with dirt, that will be absorbed by the body. Similarly, the skin permeability coefficient relates the rate at which contaminants mixed with water will be absorbed through the skin. In each case, larger values indicate greater skin absorption.

Distributions of parameter values for the cancer potency factor, reference dose, skin absorption factor, and skin permeability coefficient are presented in Table 5.16 for the non-radioactive chemicals of interest in this scoping assessment. The information in Table 5.16 is derived from several sources. The preferred source is EPA's Integrated Risk Information System (IRIS) (EPA 1996, 1992b). IRIS is a database available through EPA's Environmental Criteria Assessment Office in Cincinnati, Ohio, and from various commercial electronic sources. The preferred secondary source is EPA's Health Effects Assessment Summary Tables (HEAST) (EPA 1995). HEAST, prepared by EPA's Office of Solid Waste and Emergency Response, is a compilation of toxicity values published in health effects documents issued by EPA. It is intended for use in CERCLA and RCRA programs.

Periodically, EPA announces changes in toxicity factors for individual chemicals as new information becomes available. In some instances, reference doses or other factors listed in IRIS or HEAST for some chemicals are withdrawn. For some of the chemicals in Table 5.16, older references were used to approximate the potential health risk because specific values are no longer included in IRIS or HEAST.

The range of uncertainty about the various health effect indicators or transfer factors can be quite large because the estimated values are often based on studies in animals or studies based on conditions quite unlike those typically encountered in routine human exposures. Many of the values include a safety factor used to account for uncertainty inherent in differences in response between humans and animals, variations in susceptibility among individuals in a human population, and use of data from a limited time to estimate chronic effects. In establishing the outer limits of the uncertainty bounds for this analysis, these safety factors have been considered.

Table 5.16. Chemical Exposure Risk Factors

	Carcinogenic Chemical					**Carcinogenic Chemical**				
	Inhalation Cancer Potency Factor					**Ingestion Cancer Potency Factor**				
	Risk/(mg/kg per day)					**Risk**/(mg/kg per day)				
	Deterministic	Minimum	Maximum	Distribution	Reference	Deterministic	Minimum	Maximum	Distribution	Reference
Benzene	0.029	0.009	0.09	lognormal	Heast 95	0.029	0.009	0.09	lognormal	IRIS 96
Chromium	42	4	400	lognormal	IRIS 96	42	4	400	lognormal	= inhalation
	Toxic Chemical					**Toxic Chemical**				
	Inhalation Reference Dose					**Ingestion Reference Dose**				
	(mg/kg per day)					(mg/kg per day)				
	Deterministic	Minimum	Maximum	Distribution	Reference	Deterministic	Minimum	Maximum	Distribution	Reference
Ammonia	0.029	0.01	0.87	triangular	EPA 1996	0.97	0.3	3	triangular	EPA 1995
Chromium	0.005	1.00E-03	0.015	triangular	= ingestion	0.005	0.002	2.5	triangular	EPA 1996
Copper	0.01	0.002	0.05	triangular	EPA 1984a	0.003	0.0006	0.015	triangular	EPA 1992b
Cyanide	0.02	0.004	2	triangular	= ingestion	0.02	0.007	2	triangular	EPA 1996
Diesel	0.36	0.06	1.8	triangular	= ingestion	0.36	0.07	1.8	triangular	NIOSH 1996
Kerosene	0.7	0.14	3.5	triangular	ACGIH 1987	0.7	0.14	3.5	triangular	= inhalation
Lead	0.00043	0.00008	0.002	triangular	EPA 1984b	0.0014	0.0003	0.007	triangular	EPA 1986
Mercury	0.000086	0.000028	0.0026	triangular	EPA 1996	0.0003	0.0000001	0.3	triangular	EPA 1995
Nickel	0.02	0.007	0.06	triangular	= ingestion	0.02	7.00E-03	6	triangular	EPA 1996
Nitrate	1.6	0.3	8	triangular	= ingestion	1.6	0.5	4.8	triangular	EPA 1996
Nitirite	0.1	0.02	0.5	triangular	= ingestion	0.1	0.03	0.3	triangular	EPA 1996
Phosphate	0.007	0.0014	0.035	triangular	NIOSH 1996	0.46	0.09	2.3	triangular	NIOSH 1996
Sulfate	71	14	350	triangular	= ingestion	71	14	350	triangular	40 CFR 143.3
Xylene	2	0.4	10	triangular	= ingestion	2	0.7	200	triangular	EPA 1996
Zinc	0.3	0.06	1.5	triangular	= ingestion	0.3	0.1	0.9	triangular	EPA 1996
NOTE: Distribution maxima based on safety factor where available.										
	ABS					**K_p**				
	Skin Absorption Factor					**Skin Permeability Cefficient**				
	(unitless)					(cm/hr)				
	Deterministic	Minimum	Maximum	Distribution	Reference	Deterministic	Minimum	Maximum	Distribution	Reference
Ammonia	0.01	0.03	0.3	loguniform	EPA 1992a	0.001	0.0001	0.01	loguniform	default
Benzene	0.01	0.03	0.3	loguniform	McKone 1990	0.11	0.05	0.2	loguniform	EPA 1992a
Chromium	0.001	0.0001	0.01	loguniform	default	0.001	0.0003	0.003	loguniform	EPA 1992a
Copper	0.001	0.0001	0.01	loguniform	default	0.001	0.0001	0.01	loguniform	default
Cyanide	0.001	0.0001	0.01	loguniform	default	0.001	0.0001	0.01	loguniform	default
Diesel	0.01	0.003	0.03	loguniform	bezene analogy	0.1	0.03	0.3	loguniform	bezene analogy
Kerosene	0.01	0.003	0.03	loguniform	bezene analogy	0.1	0.03	0.3	loguniform	bezene analogy
Lead	0.001	0.0001	0.01	loguniform	default	0.000004	0.000002	0.000008	loguniform	EPA 1992a
Mercury	0.001	0.0001	0.01	loguniform	default	0.001	0.0005	0.002	loguniform	EPA 1992a
Nickel	0.001	0.0001	0.01	loguniform	default	0.00003	0.00001	0.0001	loguniform	EPA 1992a
Nitrate	0.001	0.0001	0.01	loguniform	default	0.001	0.0001	0.01	loguniform	default
Nitirite	0.001	0.0001	0.01	loguniform	default	0.001	0.0001	0.01	loguniform	default
Phosphate	0.001	0.0001	0.01	loguniform	default	0.001	0.0001	0.01	loguniform	default
Sulfate	0.001	0.0001	0.01	loguniform	default	0.001	0.0001	0.01	loguniform	default
Xylene	0.05	0.017	0.15	loguniform	EPA 1992a	0.08	0.04	0.16	loguniform	EPA 1992a
Zinc	0.001	0.0001	0.01	loguniform	default	0.0006	0.0003	0.0012	loguniform	EPA 1992a

For benzene, the ingestion cancer potency factor was taken from IRIS (EPA 1996) and the inhalation cancer potency factor, which has the same numerical value, was taken from HEAST (EPA 1995). The cancer potency factor is described in IRIS as being the geometric mean of a series of well-defined measurements spanning about one order of magnitude. Therefore, the uncertainty assigned to these values is set to span a factor of 10 with a lognormal distribution.

The inhalation cancer potency factor for chromium is from HEAST. Neither HEAST nor IRIS provides an ingestion factor, so the ingestion factor is assumed to be the same as the inhalation factor. The studies that support this value have potentials for both over- and under-estimation; therefore, the uncertainty band could be a factor of 10 higher or lower on a lognormal scale.

The inhalation and ingestion reference doses for ammonia are the same from HEAST or IRIS. IRIS states that reference doses are generally certain to within a factor of about 3. The ammonia inhalation reference dose also includes a safety factor of 30. Therefore, the ingestion range is defined by a factor of 3 up or down, and the inhalation range is defined by a factor of 3 up and a factor of 30 down in triangular distributions.

IRIS provides an ingestion reference dose for chromium (assumed here to be soluble chromium VI). The inhalation value is assumed to be equal. The ingestion reference dose for chromium includes a safety factor of 500, which has been used to establish the upper bound for the ingestion uncertainty range.

The human toxicity of copper is equivocal. Recent versions of IRIS and HEAST have not provided values of reference dose. However, in 1992 IRIS did provide a value for ingestion, and EPA (1984a) has older documents that discuss the inhalation toxicity. Because these older references are under reevaluation, a wider range of a factor of 5 was used to set the uncertainty bounds for copper toxicity.

A reference dose value for oral uptake of cyanide is provided in IRIS. Because various forms of cyanide readily disassociate in body fluid to free cyanide, the ingestion value is used here for inhalation as well. A safety factor of 100 is included in the IRIS reference dose, which was accounted for in setting the upper value of the uncertainty range.

Reference doses are not provided by EPA for diesel fuel. An effective reference dose was estimated from the acute toxicity data available in the Registry of Toxic Effects of Chemical Substances (RTECS) published by the National Institute for Occupational Safety and Health (NIOSH 1996). An effective reference dose was evaluated using the equation (Strenge and Peterson 1989)

$$RfD = LD_{50} \times 4 \times 10^{-5} \qquad (5.25)$$

where

RfD = reference dose
LD_{50} = acute lethal dose to 50 percent of animals (mg/kg)
4×10^{-5} = empirical conversion factor (mg/kg/day per mg/kg)

This equation was based on a study by Layton et al. (1987) in which data for chemicals having known reference doses and LD_{50}s were compared. The conversion factor represents the median value of the reported ratios of reference dose to LD_{50} values. Because this approach was used, a range of a factor of 25 from low to high was used to bound the uncertainty.

A difficulty similar to that for diesel fuel was encountered for kerosene. A slightly different approach was used, based on the Threshold Limit Value (TLV) defined by the American Conference of Government Industrial Hygienists (ACGIH 1987) to estimate an effective reference dose for inhalation. The TLV values represent air concentrations that are not to be exceeded in the work environment. They represent concentrations that are assumed to be protective of workers exposed 8 hours/day, 5 days/week for a 50-year career. By adjusting for differences in exposure time, breathing rate, and a safety factor, the TLVs can be converted to a value representative of continuous exposure by a member of the public. This approach is preferable to that using the LD_{50} values because it is based on a reference directly relating to human exposures. This inhalation value was then also used for ingestion. Because of this approach, a range of a factor of 25 from low to high was used to bound the uncertainty.

Values of the reference dose for lead were taken from EPA documents (EPA 1986; EPA 1984b). Because these are older references, a range of a factor of 25 from low to high was used to bound the uncertainty.

The reference dose for inhalation of mercury is from IRIS, and the reference dose for ingestion of mercury is from HEAST. The IRIS reference dose for inhalation contains a safety factor of 30. The HEAST reference dose for ingestion contains a safety factor of 1000. These were used in defining the overall ranges of uncertainties.

For nickel, IRIS presents an ingestion reference dose associated with a safety factor of 300. The reference dose for inhalation is assumed to be the same as that for ingestion, but because of the pathway extrapolation, the safety factor was not used in defining the uncertainty range.

For nitrate and nitrite ions, reference doses are presented in IRIS for ingestion. In keeping with the general guidance that IRIS reference doses are accurate to within about a factor of 3, this was used to set the uncertainty bounds on the ingestion ranges. The same values were assumed for the inhalation route, but a factor of 5 was used to expand the range of uncertainty because of the pathway extrapolation.

Reference doses are not available for phosphate ion. The same technique based on Registry of Toxic Effects of Chemical Substances LD_{50} data as used for diesel fuel was used for phosphate.

The estimate for reference dose for sulfate inhalation is based on TLV using the same technique as described for diesel fuel. For ingestion, rather than assume the same value as derived for inhalation, an estimate was made using EPA's Secondary Drinking Water Standard (40 CFR 143). The drinking water standard for sulfates is 250 milligrams/liter. Because the secondary standards are based on aesthetics rather than human health risk, the value thus derived was increased by a factor of 10. A factor of 5 was included in the uncertainty range for this extrapolated set of estimates.

The IRIS database provides an ingestion reference dose for xylenes, which includes a safety factor of 100. The ingestion value was assumed to also apply to inhalation. An uncertainty range of 5 was used on the inhalation value to determine the uncertainty bounds.

Zinc is listed in the IRIS database for ingestion with a safety factor of 3. The ingestion value was assumed to also apply to inhalation. An uncertainty range of 5 was used on the inhalation value to determine the uncertainty bounds.

Values for the skin absorption coefficient ABS are difficult to obtain because very few measurements have been made. A metal, cadmium, has been evaluated (Wester et al. 1991), as have the organics—benzene (Skowronski et al. 1988) and xylene (Skowronski et al. 1990)—in experiments that are not completely consistent with exposure conditions in the environment. For cadmium applied at 20 and 40 mg/cm^2 to the skin of the abdomen for 16 hours, between 0.08 and 0.2 percent of the applied dose was absorbed. The average of twelve samples was 0.1 percent. EPA recommends an upper range of 0.1 to 1.0 percent (EPA 1992a).

The concentrations for dermal absorption of benzene (Skowronski et al.1988) were up to 21 percent of the soil mixture. In addition, the area of application was covered during the experiment, which prevented evaporation. A model based on fugacity was developed by McKone (1990) and applied by Burmaster and Maxwell (1991) for benzene, predicting 1 to 2 percent uptake for skin loadings of 0.1 to 10 mg/cm^2. McKone (1990) also made some generalizations for organics on the basis of Henry's Law constant and the octanol-water partition coefficient, K_{ow}, which indicated that the absorption for xylenes should be less than about 5 percent in 12 hours.

On the basis of the cadmium measurement, the default skin absorption factor for metals was established at 10^{-3}, and the default for other organics was set at 10^{-2}, with uncertainty ranges of one order of magnitude larger and smaller.

5.2.2.4 Miscellaneous Parameters

Additional parameters unrelated to the individual exposure scenarios used in the human health risk calculations are presented in Table 5.17. The risk from exposure to radiation and radioactive materials is estimated from the radiation doses, using a range of the dose-to-risk conversion factor. The dose-to-risk conversion is based on the accumulated evidence that radiation is carcinogenic, including studies of medical irradiation and the survivors of the bombings of Hiroshima and Nagasaki (NCRP 1993; ICRP 1991; NRC 1990; UNSCEAR 1988). Lifetime averaging time and body weights are standard values.

Organic chemicals are assumed to be volatile. For simplicity, the chemicals ammonia, benzene, diesel, kerosene, and xylene are assumed to be related to the volatilization of water as described in the individual exposure scenarios in Section 5.1. All others are assumed to be non-volatile.

Table 5.17. Miscellaneous Parameters

Dose-to-Risk Conversion (risk/rem)				
8.00E-04	Deterministic			
2.00E-04	Minimum			
1.00E-03	Maximum			
	Uniform distribution			
Irrigation Rate (L/m^2 per year)				
900	Deterministic			
500	Minimum			
1000	Maximum			
	Uniform distribution			
Body weights (kg)				
	Adult	70		
	Child	16		
Averaging Time				
	Days	25,550	(70 Years)	
Volatilization Factors (L/m3)				
	Analyte	**Deterministic**	**Range**	**Distribution**
	Ammonia	0.1	0.001-0.1	loguniform
	Benzene	0.1	0.001-0.1	loguniform
	Diesel	0.1	0.001-0.1	loguniform
	Kerosene	0.1	0.001-0.1	loguniform
	Xylene	0.1	0.001-0.1	loguniform
	All others	0		fixed

5.2.3 Overall Risk

In this section, we discuss the results of the screening assessment of human health. We present the highlights of the results for each scenario in Figures 5.1-5.4 and the full results in Figures E.1-E.9 in Appendix I-E. To show the risk for each scenario, we totalled the risk results for each contaminant according to the type of contaminant: carcinogenic chemical, toxic chemical, or radionuclide. Because the three types of contaminants result in different kinds of risk, the estimates for each type are reported differently:

- **Carcinogenic chemical results reflect the probability of the incidence of cancer.**
- **Toxic chemical results reflect the ratio between the dose determined by EPA to be safe (the reference dose) and the dose that has been estimated.**
- **Radionuclide results reflect the risk of cancer fatality.**

Each of the contaminants identified in Section 2.0 has been evaluated for each of the scenarios identified in Section 5.1. While the resulting number of calculations provides a detailed database from which to draw inferences, it also provides a voluminous amount of information. Therefore, the majority of the resulting information can be found in Appendix I-E. This section summarizes the nature of the results and provides an interpretation.

5.2.3.1 Risk by Scenario

The equations in Section 5.2.1 provide evaluations of potential human health risk from carcinogenic chemicals, toxic chemicals, and radionuclides. Each category is the linear sum of the risk estimates for all the contaminants in that category. This sum varies for each scenario in each river segment. The intent in using multiple scenarios was to provide insight to the range of risk associated with a wide range of possible activities. The range of human health risk associated with each scenario is shown for carcinogenic chemicals in Figure 5.1, for toxic chemicals in Figure 5.2, and for radionuclides in Figure 5.3. The figures also show the median estimated risk for each scenario. The figures show each scenario applied at the location of the N Reactor (Segment 6, see map in Figure 3.2) because it is one of the areas with higher Hanford-related contamination. (Additional locations will be discussed and shown later.)

In Figures 5.1-5-3, we present the range of results for each scenario. For example, our estimated risk from carcinogenic chemicals for fish hatchery workers shows a possible range of less than 1.00E-05 (0.00001) to more than 1.00E-03 (0.001) with the median just above 1.00E-04 (0.0001). The low ends of the range are the results for those fish hatchery workers who have less exposure, and the upper ends of the range are the results for those who have more exposure. The median is the value for which half the results are greater and half are less.

Figures 5.1 and 5.3 present the ranges of calculated risk to a single individual living according to each scenario at the N Reactor segment. A risk of 1.0×10^{-4} indicates a 1 in 10,000 chance that this individual would develop or die of cancer. Similarly, a 1.0×10^{-2} risk indicates a 1 in 100 chance that this individual would develop or die of cancer. For comparison, the naturally occurring incidence of cancer is about 2×10^{-1}, or about a 1 in 5 chance. Figure 5.2 presents the range of calculated hazard index for a single individual living according to each scenario at the N Reactor segment. A hazard index of 1.0 is the value at which some health impact might begin to be expected. A hazard index of 1.0×10^{-2} indicates that intake of potentially toxic materials is at 1 percent of the levels at which physical impacts might occur.

In the calculations, the uncertainties of the measurements, the health parameters, and the individual life styles were addressed; and the results are presented as a range of values. The range (from the lower bound for the scenarios of minimal exposure to the upper bound for the scenarios of extensive exposure) covers from 5 to 7 orders of magnitude (factors of 100,000 to 10,000,000) for the chemicals and radionuclides. As the following sections will discuss, the absolute risk illustrated in Figures 5.1-5.3 is somewhat misleading, but the wide range of different risk levels for the scenarios is very illuminating.

Generally, the scenarios for the Fish Hatchery Worker, Industrial Worker, and Ranger have the lowest exposures and therefore are lowest in terms of health risk. As defined in Section 5.1, none of the people involved in these scenarios consume foods grown in the Columbia River riparian zone or drink seep water. Therefore, the exposures are mostly incidental external exposures and inhalation of resuspended materials, although the Fish Hatchery and Industrial Workers also consume a moderate amount of Columbia River water. The risk to workers from these pathways is quite low compared with those projected for people potentially exposed in other ways. An initial result, then, is that consumption of Columbia River water is not the major pathway of exposure compared with other pathways.

At the other extreme, people assumed to live along the Columbia River, to eat substantial quantities of foods grown in the riparian zone, to eat fish and wildlife from the river, and to drink seep water have much larger potential exposures and, thus, larger estimated health risk. This category encompasses nearly all

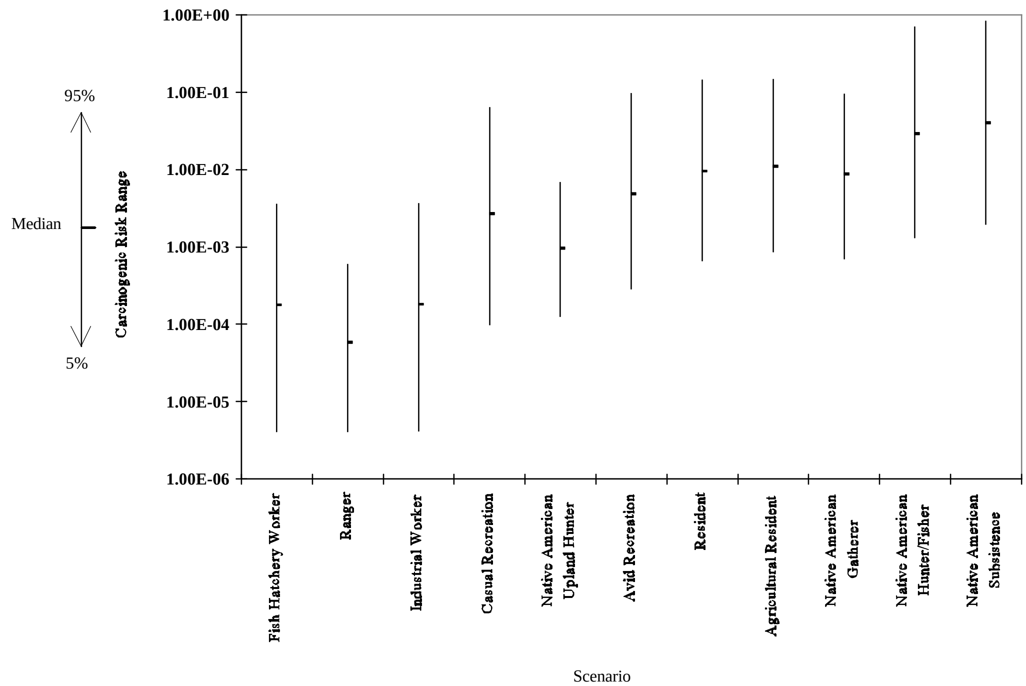


Figure 5.1. Range of Estimated Risk from Carcinogenic Chemicals (Segment 6 - N Reactor)

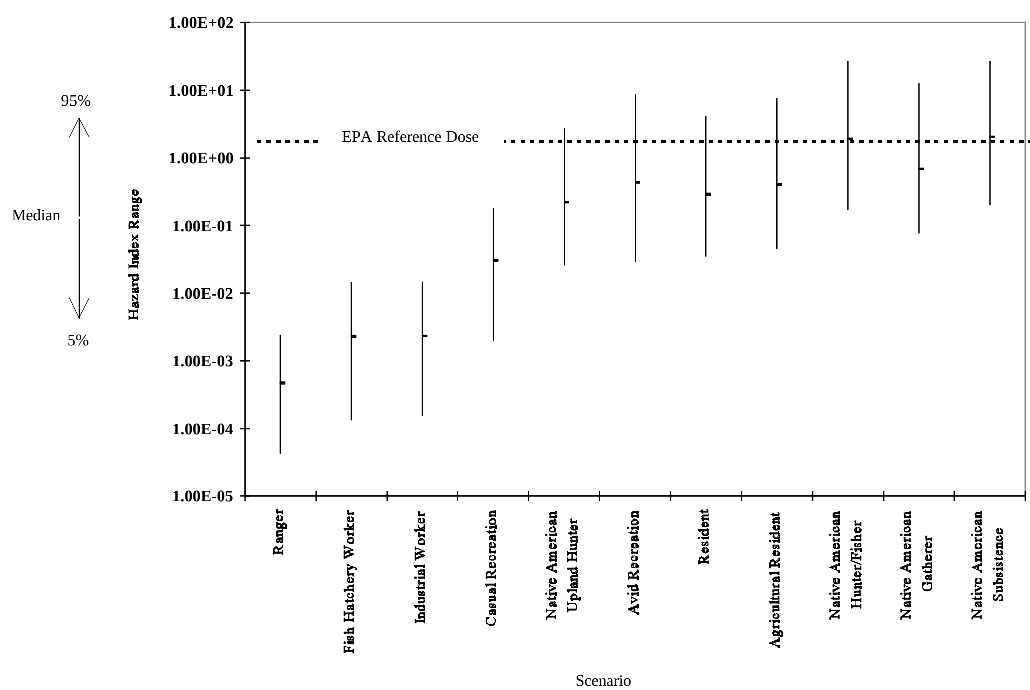


Figure 5.2. Range of Estimated Risk from Toxic Chemicals (Segment 6 - N Reactor)

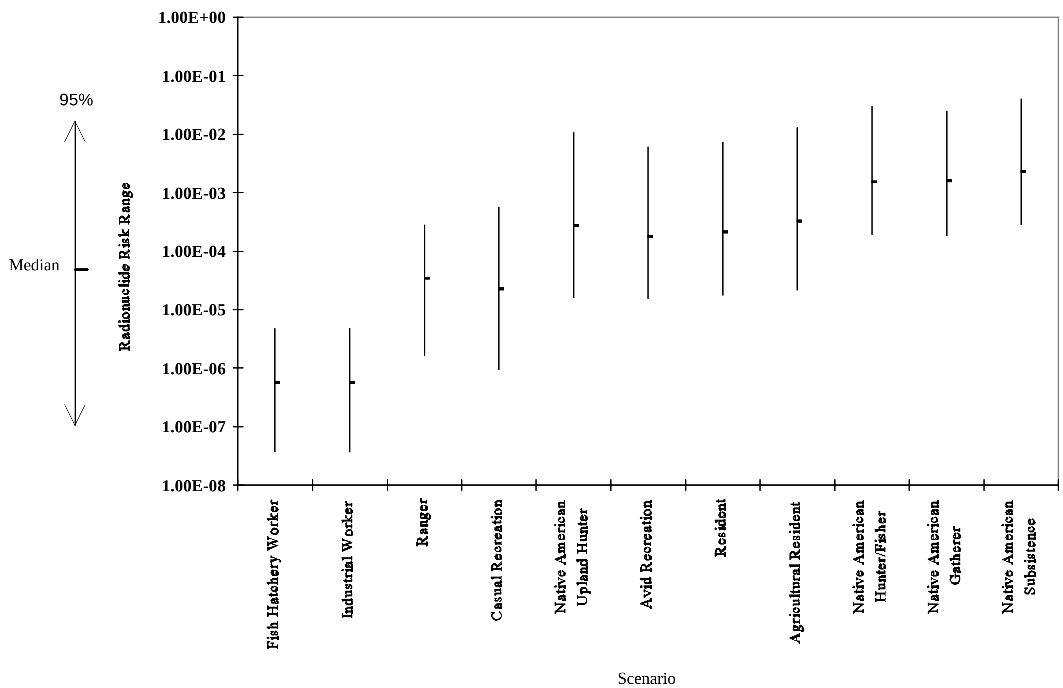


Figure 5.3. Range of Estimated Risk from Radionuclides (Segment 6 - N Reactor)

the rest of the scenarios described in Section 5.1. From a risk-assessment standpoint, very few differences appear between any of the Native American scenarios and recreational/residential scenarios: all assume individuals who spend the bulk of their time in the vicinity and consume riparian-zone foods and drink untreated water. The minor differences appear in quantities of each type of food assumed to be eaten.

The Casual Recreational Visitor Scenario appears to fall between these two sets. However, it actually has much more in common with the upper-end scenarios than with the worker scenarios. The main pathways of exposure for the Casual Recreational Visitor are consumption of food and seep water. The key difference between the Casual Recreational Visitor Scenario and the Native American or recreational/residential scenarios is in the number of exposure days per year. The Casual Recreational Visitor Scenario assumes that the individual visits the Hanford Reach of the Columbia River only 7 days per year. If the Casual Recreational Visitor were to increase the frequency of visits, ultimately the exposures and risk would parallel those of the residential scenarios. To a limited extent, this argument also applies to the Avid Recreational Visitor and, to a lesser extent, to Native American Upland Hunter scenarios. In the Avid Recreational Visitor Scenario, the individual visits less frequently but is assumed to consume foods associated with the Columbia River nearly to the extent a resident does.

Figures 5.1-5.3 show each scenario applied at the location of the N Reactor. While this is one of the river segments with higher Hanford-related contamination, it is not the highest for all contaminants. However, the statements made above regarding the scenarios are generally true, as Figure 5.4 illustrates.

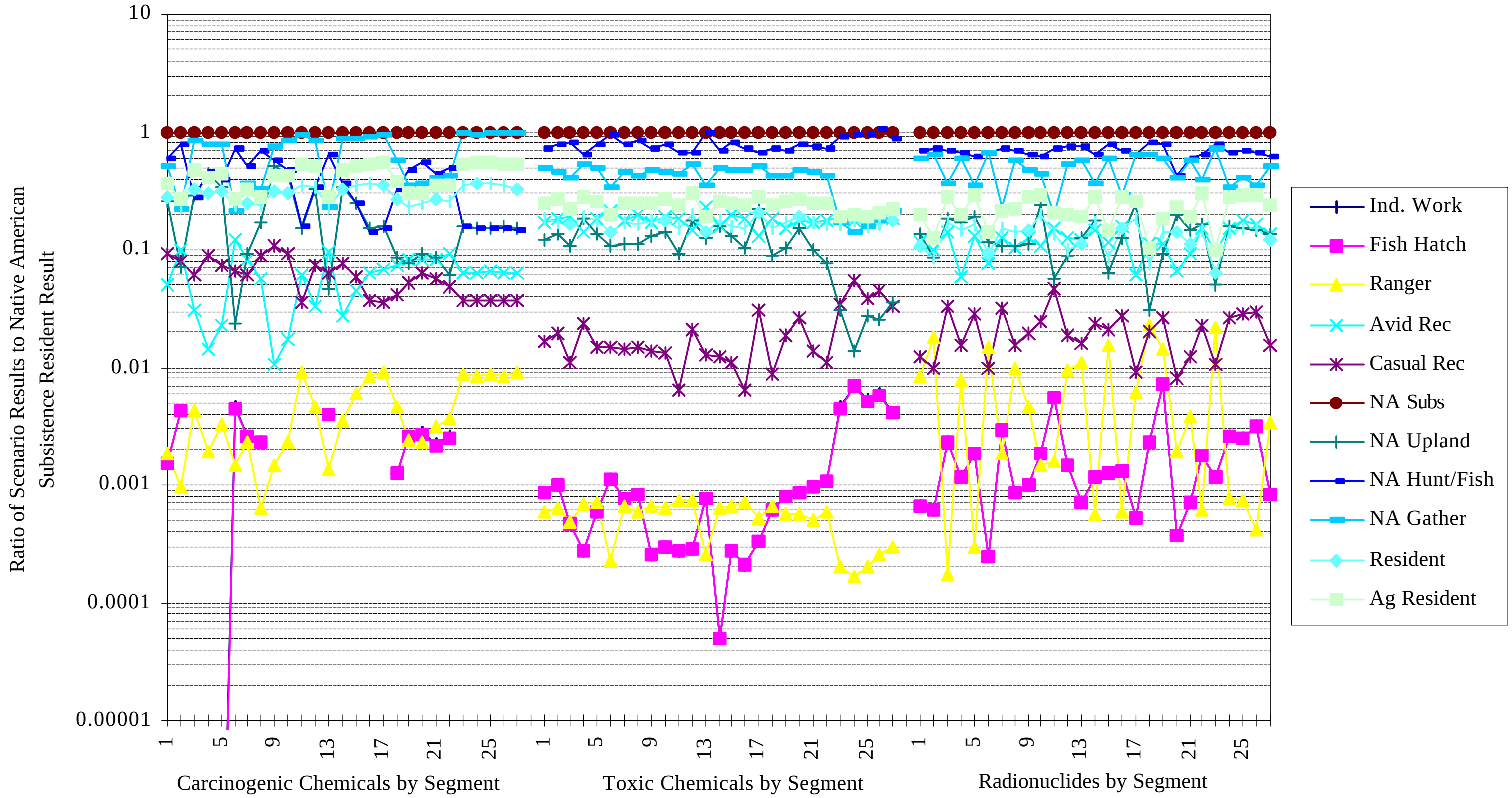


Figure 5.4. Comparison of Risk Results for All Scenarios

Figure 5.4 shows the relationship of each scenario normalized to the scenario of highest exposure, which is the Native American Subsistence Resident Scenario. In this figure, the ratio of the total carcinogenic, toxic, and radionuclide health risk at each segment for each scenario is shown relative to the estimated risk for the Native American Subsistence Resident Scenario. Thus, the Native American Subsistence Resident Scenario is always assigned a value of 1.0, and the other scenarios are plotted against it. In this figure, the Industrial Worker and Fish Hatchery Worker are indistinguishable (the Fish Hatchery Worker symbols cover up those of the Industrial Worker), and the Ranger is generally very close to these two. The remainder of the scenarios cluster together in a generally decreasing band, with the exception of the Casual Recreational Visitor Scenario, which lies between the two groups. As mentioned above, the Casual Recreational Visitor Scenario follows the patterns of the higher-exposure scenarios but at only a fraction of the total exposure because of the assumed limited duration.

Because the differences between the upper exposure scenarios and the lower exposure scenarios are distinct and the differences between scenarios within either group are less distinct, the Ranger Scenario has been selected as representative of the lower risk group and the Native American Subsistence Resident Scenario has been selected as representative of the higher group. These representative scenarios are used in the following detailed discussions of exposure pathways and contaminants.

5.2.3.2 Risk by River Segment

The calculations described in Section 5.2.1.3 provide total risk, that is, the sum of the potential carcinogenic chemical, toxic chemical, and radionuclide risk for each river segment. The risk is illustrated for Segment 6 for each scenario in Figures 5.1-5.3. The variability of total risk by segment of the Columbia River is illustrated in Figure 5.5 for the Ranger Scenario and in Figure 5.6 for the Native American Subsistence Resident Scenario.

The total risk from all contaminants combined is shown in Figures 5.5 and 5.6 for the Ranger and Native American subsistence scenarios. Similar figures for all other scenarios are provided in Appendix I-E. In each figure, the range of results— given as the 5th , 50th, and 95th percentiles of the calculated range—moves consistently up and down depending on contaminant concentration. The deterministic values follow a similar pattern, with some exaggeration of the extremes. Dramatic low spots in the curves frequently depict lack of measurement data.

The upper portion of Figure 5.5 shows the lifetime risk of cancer incidence from exposure to carcinogenic chemicals estimated for the Ranger Scenario in each of the 27 river segments. This particular calculation is dominated in all segments by the metal chromium in sediment, and the pathway is inadvertent ingestion of sediment. The deterministic calculations (performed as described in Section 5.2.2 with the highest measured contaminant concentrations in each segment and with reasonable maximum individual exposure parameters) can be seen to vary between an estimated lifetime risk of 10^{-4} to 10^{-3}. Overall, the deterministic values fall at about the 75th percentile of the stochastic range. For all segments, the estimated risk is within about a factor of 3 of the reference risk estimated for Segment 1.

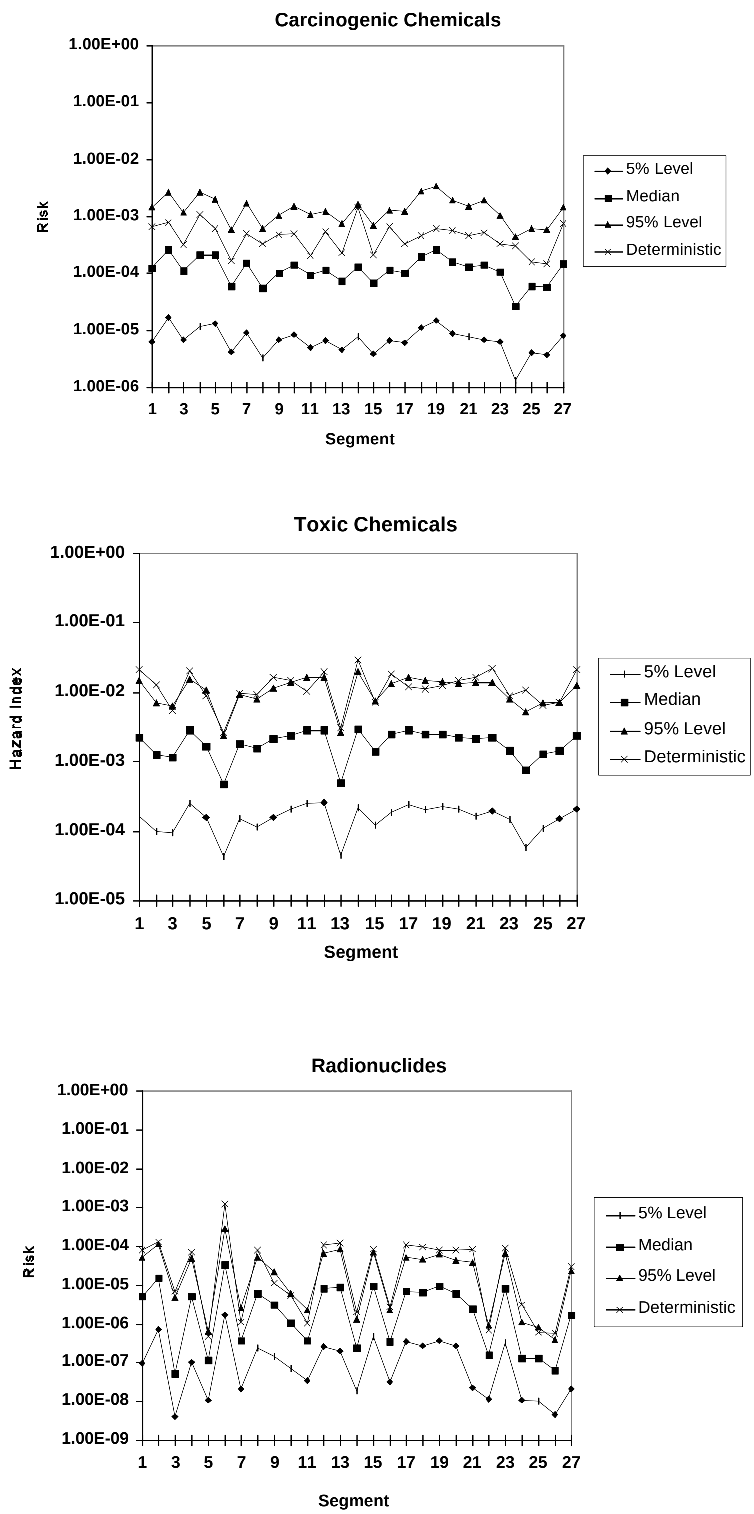


Figure 5.5. Human Health Risk Estimate for the Ranger Scenario

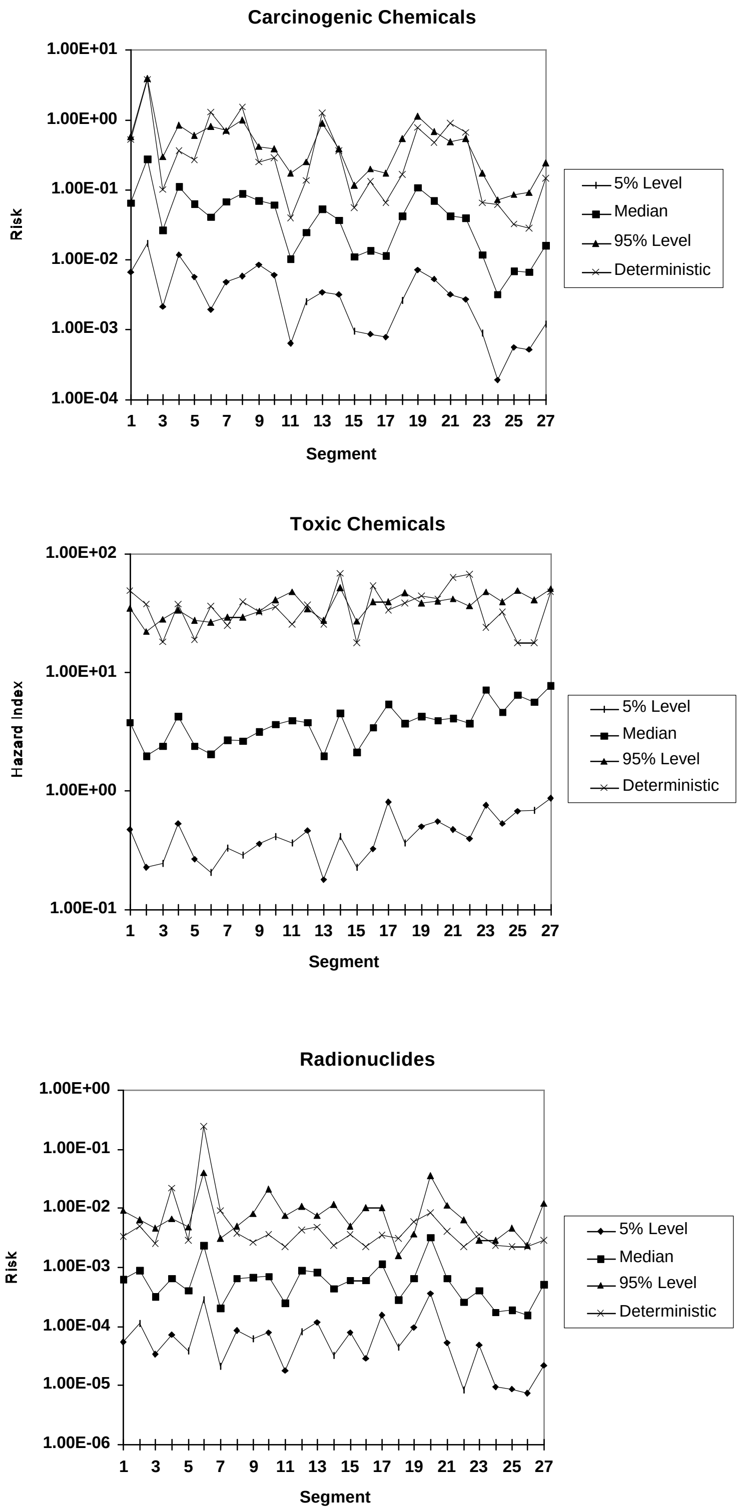


Figure 5.6. Human Health Risk Estimate for the Native American Subsistence Resident Scenario

The center portion of Figure 5.5 shows the hazard index value calculated for the Ranger Scenario at all river segments. The hazard index implies contaminant concentrations of potential risk when the hazard index value is greater than 1.0. The maximum values of hazard index for the Ranger Scenario are 1 to 3 percent of the indicator value of 1.0 with little discernable difference between the upstream reference in Segment 1 and any of the downstream segments. The risk reflected in this portion of the figure predominantly represents the presence of the metals (lead, copper, and chromium), which together make up over 90 percent of the total risk. The apparent dips in the curves at Segments 6 and 13 reflect the lack of measurements for lead at these locations.

The lower portion of Figure 5.5 shows the lifetime risk of death from cancer caused by radionuclides. The risk illustrated is largely from external irradiation. The somewhat jagged nature of the curve is the result of using two different approaches for this part of the calculation. The higher portions of the curve were calculated using radiation dose rates measured along the Columbia River shoreline with an approximate correction for background. The lower portions of the curve were calculated from the measured concentrations of radionuclides and dose conversion factors. In the calculations done with the measured dose rates, an attempt was made to correct for terrestrial and cosmic ray background by subtracting 0.2 mrem/day from the measured values. Because background has small local fluctuations, this is an imprecise approach; and because any measured dose rate in excess of 0.2 mrem/day was considered to be a result of Hanford contributions, some background values are probably reflected in the upper portions of the curve. The calculations based on the radionuclide concentration measurements in the environment are all lower than the background-corrected, measured dose rates by factors of greater than 10.

The bulk of the risk reported in this portion of the figure is probably attributable to natural sources. The peak at Segment 6, however, is from the documented increase in dose rate caused by radiation from facilities in the 100-N Area. In this case, using the measured dose rates has indicated a known problem, but one which would not have been evident from the samples of water or sediment because the source is the facilities themselves. The radionuclide average upper risk estimates of about 10^{-4} shown in Figure 5.5 correspond to a lifetime dose of about 125 millirem (about 2 millirem per year above the natural background rate of about 100 millirem/year).

The upper portion of Figure 5.6 shows the lifetime risk of cancer incidence from exposure to carcinogenic chemicals estimated for the Native American Subsistence Resident Scenario in each of the 27 river segments. This particular calculation is dominated in all segments by the metal chromium, but this scenario exemplifies the complexity of the contamination at Hanford. The primary medium causing exposure in Segments 1, 2, 6, 7, 13, 18, 19, 20, 21, and 22 is surface water, with the primary pathway being ingestion of fish. The primary medium in Segments 5, 8, 9, and 10 is seep water, with the primary pathway being ingestion of the seep water itself. For the remaining segments, the primary medium is sediment, and the primary pathway is consumption of food grown in sediment. Generally, if the chromium has been measured in the surface water (meaning in the river itself), the risk estimates are highest. If the main measurements are of seep water, the risk estimates are intermediate; and if the measurements are only of sediment, the risk estimates are lower. This result indicates that the estimated risk is highly dependent on what data are available and on how well the data actually characterize the environment.

The center portion of Figure 5.6 shows the hazard index value calculated for the Native American Subsistence Resident Scenario at all river segments. Recall that the definition of the hazard index implies contaminant concentrations of potential risk when the hazard index value is greater than 1.0. The deterministic and the median stochastic calculated hazard indices exceed the value of 1.0 at all segments. However, for only one-third of the 27 segments is the estimated median greater than that estimated for Segment 1 and for only 4 of the 27 segments for the deterministic calculation and never by more than a factor of two. The primary contributor to the high values of hazard index is copper. Over half the total hazard index is attributable to copper in nearly all segments. Other major contributors in Segment 1 are mercury (nearly 20 percent) and lead (over 15 percent). The primary medium is sediment with a large contribution also from surface water. As is discussed in subsequent sections, the high background of these metals makes discernment of a Hanford contribution to risk difficult to detect.

The lower portion of Figure 5.6 illustrates the lifetime risk of death from cancer caused by radionuclides. The median risk of about 10^{-3} results from estimated doses of about 20 millirem/year. The risk illustrated in this portion of the figure has a significant component from external irradiation, up to about half of the total in some segments. The external doses vary as described above for the Ranger Scenario. The second major contributor is ingestion of cesium-137 from surface water via fish. Eight segments have measurements of cesium-137 in surface water (see Table 3.9 in Section 3.0). The others are all surrogates. However, the measured concentrations are very similar in all measured segments. The concentrations in the river water are mostly attributable to global fallout. In certain segments, other sources stand out: strontium-90 in seeps and sediment in Segment 6, strontium-90 in surface water in Segment 7 (perhaps as a result of the releases in Segment 6), tritium (hydrogen-3) in seeps in Segments 4 and 17, and uranium in seeps in Segment 20.

Figures presenting the results of the other nine scenarios in the format of Figures 5.5 and 5.6 are presented Figures E.1-E.9 in the “Results of the Calculations” section of Appendix I-E.

Using the environmentally measured values of the contaminants of interest results in a total potential risk, not one that is solely attributable to Hanford operations. In some cases, the reference risk is greater than that estimated for the Hanford-related contaminants. This overshadowing of the Hanford contributions is evident in Figures 5.5 and 5.6 where, for example, the bulk of the hazard index is from metals such as copper and lead, or a substantial fraction of the radionuclide risk is from cesium-137. Without careful evaluation, this reference contribution to the results could be misunderstood as the Hanford Site contribution, and resources could be directed to mitigating problems that do not exist. Therefore, efforts were made to identify and compensate for contaminants that occur in the Hanford environs but that are not the result of Hanford past practices.

The reference values cannot simply be subtracted from the measurements. The reference concentration itself is a distribution that must be compared with the distributions of the measurements. Therefore, sophisticated statistical techniques are required. These are described in Section 5.2.4.

5.2.3.3 Uncertainties in the Risk Calculations

Figures 5.5 and 5.6 show the human health risk calculated for the Ranger and Native American Subsistence Resident scenarios using the available monitoring data and the other parameters described in Section 5.2.2. The results are presented as both the deterministic estimate and a stochastic range. The inputs to the model were selected to cover a wide range of possibilities. The various ranges consider the uncertainty of the measured data, the degree to which the data adequately characterize the real situation, the range of potential exposures within each scenario as defined, the uncertainties of the processes modeled, and the uncertainties of the response of humans to those exposures. Each range contributes to the overall uncertainty of the calculated answers.

The deterministic calculations use the largest measured environmental concentrations of each contaminant in each segment and reasonable maximum individual parameters to describe the behavior of the individual within the scenario. They also use regular defined values of the exposure-to-risk parameters (for example, the dose conversion factors, risk factors, and reference doses). The deterministic result, then, generally represents an exposure and risk as high as would be expected under most circumstances. However, because of the unpredictability of human behavior and the lack of knowledge of the true situation of the contaminant distribution in the environment and the way that real people would respond to it, there is uncertainty in this deterministic answer.

The stochastic calculations are an attempt to quantify these combined uncertainties. As Figures 5.5 and 5.6 show, there is some chance that the exposures and risk could actually be higher than the deterministic estimate. However, actual exposures are likely to be less because the deterministic input was designed to reflect a maximum but reasonable case. The median values of the stochastic results represent the central tendency of the risk, which is the value for which half the calculations are greater and half are less. In a sense, this represents a best estimate of what might happen if all of the parameter ranges are correct. Therefore, the median values are used extensively in the discussions in Sections 5.2.4, 5.2.5, and 5.2.7.

Also contributing to uncertainty is the limited amount of available data. For many of the contaminants of interest in many locations, measurements were not available for the time period of interest to provide a detailed characterization of the contaminant distributions in each of the river segments used in this screening assessment. For some segments, monitoring has focused on areas of known contamination. The resulting data may overestimate the actual levels of contaminants present within a segment. In other cases, monitoring may have missed hot spots of contamination in the environment. Estimating where and to what extent this may have happened is not possible. Therefore, this represents an uncertainty that was not modeled in this report. The result of this uncertainty is that the conclusions of this report can highlight areas where the problems are known, but it cannot rule out the possibility of similar problems where no measurements are available.

In a similar fashion, using the available data to represent large areas may have tended to artificially homogenize the results. Establishing an estimated risk for a segment does not mean that the risk is uniform within the segment. Some areas may be higher, and some may be lower.

The transfer factors used to relate concentrations of contaminants in water and sediment to those predicted for plant and animal products are also uncertain. As discussed in Section 4.2, many unknowns exist in the behavior of chemicals in the Hanford environment. Of key interest is the bioavailability of several of the background metals. If these metals are less bioavailable than assumed in the analysis, the results could mischaracterize the levels of total risk.

Although the individual scenarios include an apparently wide range of parameters, these actually contribute less to the overall uncertainty than do the other uncertainties. Generally, the ranges are narrower than those for the contaminant levels or the risk conversion factors because the scenarios are fairly narrowly defined. The scenarios define a certain set of activities that represent specific life styles or habits; and taken together, the suite of scenarios covers a wide range of possibilities, but each scenario itself is relatively fixed. In particular, the Native American scenarios defined for this report represent the input of only a few individuals and only include the most obvious pathways of exposure. While these pathways are expected to contribute the largest portion of the dose, the existence of other culturally specific pathways tends to increase the overall uncertainty.

The risk-response functions are as important in estimating actual risk as are the levels of contamination. The reference doses and cancer potency factors are quite uncertain, and the way that various compounds may interact is even more so. This analysis has attempted to consider the development of the risk factors, but because they are largely based on non-human experiments, the conversion from laboratory results to actual human risk introduces a large potential for error. The risk factors used range in uncertainty from factors of 10 to over factors of 1000.

All of these factors, taken together, explain the wide ranges of the results seen in Figures 5.5 and 5.6 and their companion Figures E.1-E.9 in Appendix I-E.

5.2.4 Evaluation of Reference Levels of Contaminants

Although an attempt was made in the scoping calculations of Section 2.0 to account for naturally

In the screening assessment, we estimated risk from contaminants originating at the Hanford Site. Of the contaminants we studied, some originate from other sources as well as the Hanford Site. Such sources might be those occurring naturally in the environment, from global fallout, or from an upstream source. We call the concentrations from such sources "reference levels." Because Segment 1 of the Columbia River is upstream from the Hanford Site, we assume the contaminants found in that segment have not originated from the Hanford Site and, therefore, reflect the reference levels. In this section, we compare the concentrations of the contaminants measured in Segment 1 against the concentrations of the contaminants measured in the other segments at and downstream from the Hanford Site to indicate what concentrations were contributed by the Site.

Figures 5.7-5.34 depict these comparisons for each contaminant for the two extreme scenarios: the Ranger Scenario with less risk and the Native American Subsistence Resident Scenario with more risk. Figures 5.36-5.37 and E.10-E.18 show for each scenario which contaminants have concentrations above reference levels, above risk thresholds of 10^{-6} and 10^{-4}, and above a hazard index of 0.01 and 1.0. Ratios significantly greater than 1.0 generally indicate the presence of a Hanford source of contamination.

occurring or globally enhanced levels of contaminants in the environment, even after the contaminants of interest were selected, the Hanford-related portion of the measured concentrations needed to be separated if possible from reference levels of the contaminants. For many of the metals, in particular, the abundance in the earth's crust is well within the range of the measurements used in the screening assessment. That means an uncorrected measurement could easily represent the background level rather than a level resulting from Hanford Site operations.

5.2.4.1 Point-by-Point Comparisons

One way to determine whether the estimated risk presented by a contaminant at a particular segment is an increase over the reference level is to compare the risk associated with that contaminant in the particular segment with the risk in a segment unaffected by Hanford Site operations. This comparison can be done with either the deterministic results or the stochastic median results. The deterministic comparison indicates whether the estimated risk at any point is greater than the maximum estimated for the unaffected segment. The stochastic comparison indicates whether the best estimate of the risk in the downstream segment is greater than that in the unaffected segment. Segment 1, the portion of the river upstream of the Hanford Site between Priest Rapids Dam and the Vernita Bridge, can be considered to be relatively unimpacted by Hanford operations. The estimated values of the risks for each scenario in Segment 1 are provided in Appendix I-F.

Although Segment 1 was not originally selected to be free of Hanford-related contamination (see Section 3.2.1), the bulk of Segment 1 is upstream of Hanford and is also generally upwind of Hanford atmospheric emissions. A small portion of Segment 1 is within the Hanford Site, but Segment 1 is upstream of all measured seeps. Two of the three groundwater wells used to characterize Segment 1 may be influenced by a plume of tritium (hydrogen-3) emanating from the 100 B/C Areas. However, of the other contaminants evaluated in the screening assessment, thirteen were undetected in Segment 1 groundwater (ammonia, benzene, cesium-137, cobalt-60, cyanide, europium-152, europium-154, mercury, neptunium-237, nitrite, phosphate, strontium-90, and xylenes). Most of the remaining contaminants are reasonably expected in reference samples, so Segment 1 appears to be suitable for this type of comparison. Therefore, an initial comparison of the upstream (Segment 1) and downstream (Segments 2-27) risk estimates was made using the deterministic and stochastic estimates from the various scenarios for each contaminant. The results for each contaminant are presented in Figures 5.7-5.34 as ratios with the one upstream segment (Segment 1). For perspective, the highest estimated values of human health risk in terms of risk from carcinogenic chemicals, hazard index for toxic chemicals, or risk from radioactive carcinogens are provided in Table 5.18. The table also identifies the segment of greatest risk for each contaminant and the primary contaminated medium.

Table 5.18. Maximum Median Human Health Risk Derived by Contaminant (stochastic median values)

		Ranger Scenario			Native American Subsistence Scenario		
Contaminant	**Type [(a)]**	**Value**	**Segment**	**Medium[(b)]**	**Value**	**Segment**	**Medium**
Ammonia	HI	6.6E-6	20	SW	3.6E-3	19	SP
Benzene	CC	1.5E-9	1	SW	2.6E-5	4	SP
Carbon-14	RC	-- [(c)]	--	--	2.9E-5	13	SP
Cesium-137	RC	9.6E-8	10	SD	3.1E-5	13	SW
Chromium	CC	2.6E-4	2	SD	2.7E-1	2	SW
Chromium	HI	8.9E-6	2	SD	3.3E-2	4	SW
Cobalt-60	HI	9.0E-9	6	SW	3.0E-6	6	SD
Copper	HI	9.6E-4	27	SD	6.8	27	SW
Cyanide	HI	--	--	--	5.5E-2	20	SP
Europium-152	RC	4.4E-9	12	SD	6.3E-5	13	SP
Europium-154	RC	3.3E-8	18	SW	1.5E-5	21	SP
Iodine-129	RC	6.9E-15	22	SW	2.2E-6	19	SP
Lead	HI	2.0E-3	4	SD	1.2	17	SP
Mercury	HI	3.2E-7	19	SD	8.3E-3	16	SW
Neptunium-237	RC	5.2E-7	9	SD	8.3E-5	9	SD
Nickel	HI	2.0E-6	19	SD	6.8E-3	17	SP
Nitrates	HI	2.2E-6	2	SW	2.4E-1	20	SP
Nitrites	HI	6.3E-7	21	SW	1.1E-2	19	SP
Phosphorus	HI	2.7E-6	18	SW	6.9E-1	21	SW
Strontium-90	RC	5.4E-8	6	SD	7.7E-4	6	SD
Sulfates	HI	1.0E-6	27	SW	1.2E-2	7	SP
Technetium-99	RC	6.3E-11	8	SD	3.1E-6	10	SP
Tritium (H-3)	RC	--	--	--	2.1E-4	17	SP
Uranium-234	RC	6.5E-8	20	SD	9.9E-4	20	SP
Uranium-238	RC	7.7E-8	20	SD	9.2E-4	20	SP
Xylenes	HI	2.7E-10	14	SD	1.8E-4	13	SP
Zinc	HI	1.1E-4	21	SD	3.7E-1	12	SP

(a) HI = hazard index of toxic chemicals; CC = lifetime risk of carcinogenic chemicals; RC = lifetime risk of radionuclides.
(b) SW = surface water; SD = sediment; and SP = seeps.
(c) A dash (--) indicates no exposure to this contaminant via this scenario.

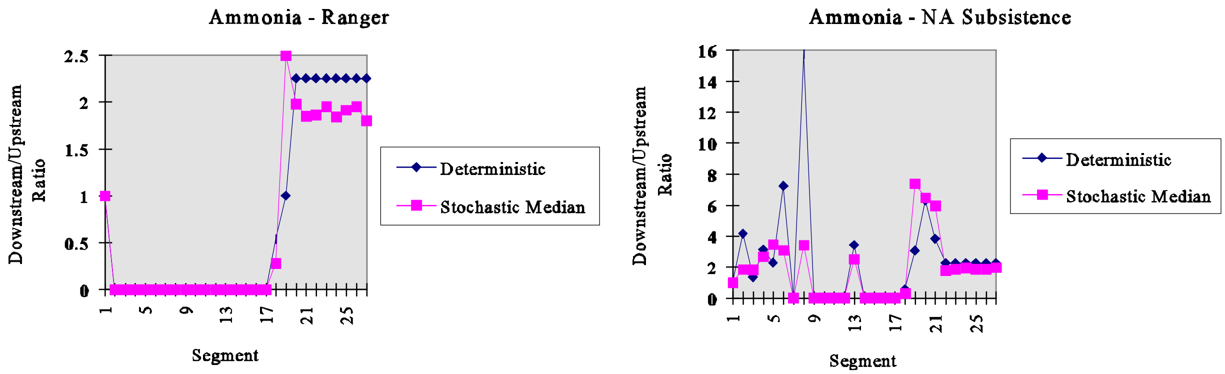


Figure 5.7. Downstream/Upstream Ratios of Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Ammonia

Ammonia. Figure 5.7 presents the ratios of the risk estimated for ammonia using the Ranger and Native American Subsistence Resident scenarios for each river segment compared with the risk estimated for Segment 1. The major differences in these scenarios are apparent in the two parts of this figure. The results for the Ranger Scenario are controlled by measurements in Columbia River water. As a result, the lack of detection of ammonia in most Hanford Site segments results in a low to zero estimated risk. Ammonia, however, is detected at downstream segments, but the amounts are not more than 2.5 times those detected upstream. The results for the Native American Subsistence Resident Scenario are largely controlled by the contribution of ammonia through seep water (frequently substituted by groundwater). The large risk ratios seen in Segments 2, 6, 8, 13, 18, 19, and 20 result from assumed exposures via seep water. These indicate definite points of Hanford Site contribution to the Columbia River via groundwater. The minor increases in Segments 22-27 are, as for the Ranger Scenario, the result of surface water detections. The highest risk from ammonia via the Ranger Scenario is from surface water in Segment 20, with a hazard index of 6.6×10^{-6}. The highest risk via the Native American Subsistence Resident Scenario is from seep water in Segment 20, with a hazard index of 3.6×10^{-3}.

In Figures 5.7 through 5.33, we present two figures for each contaminant—one for the low-exposure Ranger scenario and one for the high-exposure Native American Subsistence scenario. These figures illustrate the ratio of the downstream risks to the risk estimated for the reference section. River segments for which the estimated risks greatly exceed the upstream risk represent locations with a distinct Hanford contribution. Each figure has data for the reasonable maximum "deterministic" calculation and for the statistical "median" calculation.

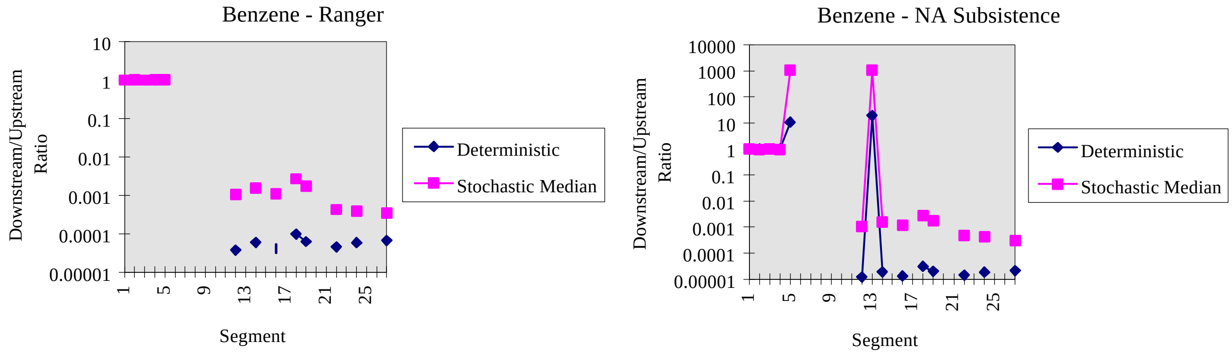


Figure 5.8. Downstream/Upstream Ratios of Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Benzene

Benzene. Figure 5.8 presents the ratios of the risk estimated for benzene using the Ranger and Native American Subsistence Resident scenarios for each river segment compared with the risk estimated for Segment 1. Benzene is assumed to be a tracer/analog (as is xylene, discussed below) for more complex hydrocarbon mixtures such as diesel fuel or other petroleum products. The key differences in the exposure scenario assumptions are also apparent in the two parts of this figure. The results for the Ranger Scenario are controlled by surface water measurements. For surface water, data for a segment are used if available, and if not, data from an upstream segment are substituted. This substitution is seen in the first five segments for the Ranger Scenario, where a measurement made in Segment 1 is repeated until a new measurement (which happened to be below detection) is applied at Segment 6. No downstream surface water measurements exceed the one made in Segment 1. The Native American Subsistence Resident Scenario, on the other hand, has components controlled by ingestion of seep water. River Segments 5 and 13 have higher inputs via seep water (substituted with groundwater), suggesting Hanford Site contributions from the groundwater to the Columbia River. The highest risk from benzene via the Ranger Scenario is from surface water in Segment 1, with a lifetime risk of 1.5×10^{-9}. The highest risk via the Native American Subsistence Resident Scenario is from seep water in Segment 13, with a risk of 2.6×10^{-5}.

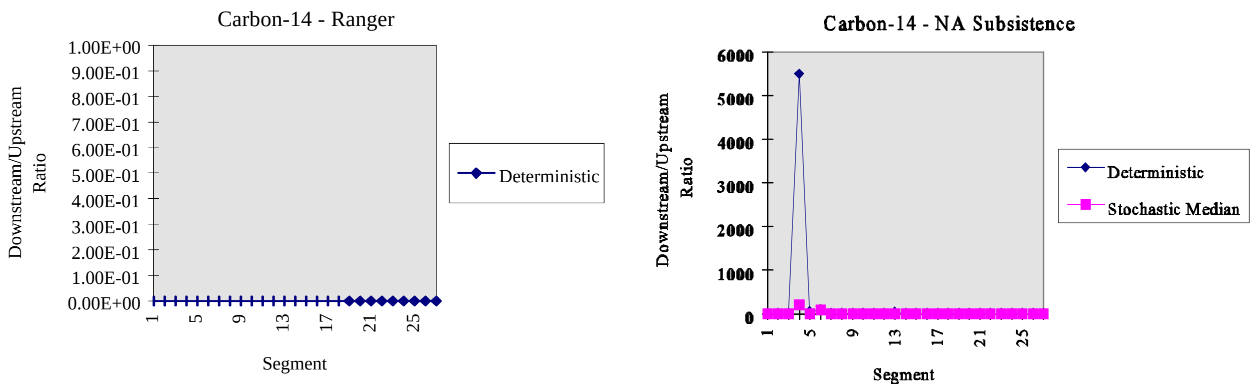


Figure 5.9.   Downstream/Upstream Ratios of Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Carbon-14

Carbon-14. Figure 5.9 presents the ratios of the risk estimated for carbon-14 using the Ranger and Native American Subsistence Resident scenarios for each river segment compared with the risk estimated for Segment 1. Carbon-14 is not detected in surface water, so it does not contribute to risk in the Ranger Scenario. The Native American Subsistence Resident Scenario is uniformly controlled by ingestion of carbon-14 derived from seep water. Seep water is surrogated with groundwater in almost all segments along the Hanford Site. A single particularly high value in Segment 4 is evident in the deterministic data. This point also influences the stochastic result in Segment 4. A lesser input is also evident in Segment 6. Carbon-14 poses no risk via the Ranger Scenario because the decay energy of carbon-14 is so low that external exposure is immaterial. The highest risk via the Native American Subsistence Resident Scenario is from seep water in Segment 4, with a lifetime risk of $2.9x10^{-5}$.

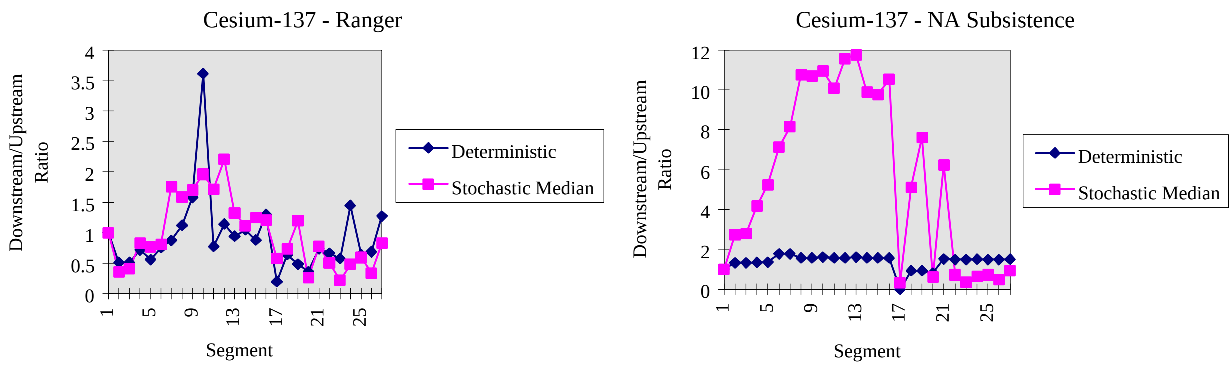


Figure 5.10. Downstream/Upstream Ratios of Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Cesium-137

Cesium-137. Figure 5.10 presents the ratios of the risk estimated for cesium-137 using the Ranger and Native American Subsistence Resident scenarios for each river segment compared with the risk estimated for Segment 1. Cesium-137 is present in the world environment from global fallout, making its Hanford-related detection difficult. The deterministic Ranger Scenario implies a somewhat higher than normal concentration in sediment in Segment 10. The Native American Subsistence Resident Scenario peak concentration (deterministic) calculations do not indicate any enhancement downstream, but the stochastic calculations do because they compare the median upstream value, rather than the peak, with those estimated for downstream locations. The results for Segments 4-20 are controlled by surface water concentrations, but most of these are surrogates taken primarily from Segment 8. Cesium-137 in surface water was not detected in Segment 17, resulting in the dip in the figure. The highest risk from cesium-137 via the Ranger Scenario is from sediment in Segment 10, with a lifetime risk of 9.6×10^{-8}. The highest risk via the Native American Subsistence Resident Scenario is from surface water in Segment 13, with a risk of 3.1×10^{-5}.

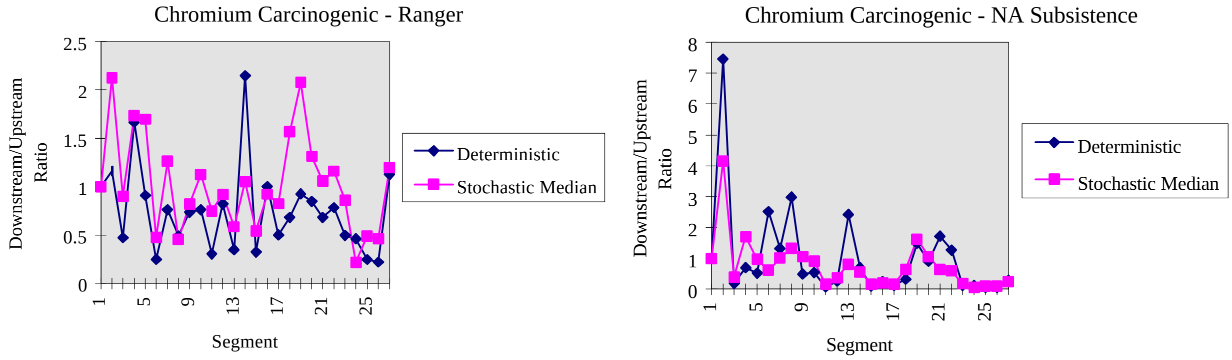


Figure 5.11. Downstream/Upstream Ratios of Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Chromium Treated as a Carcinogenic Chemical-137

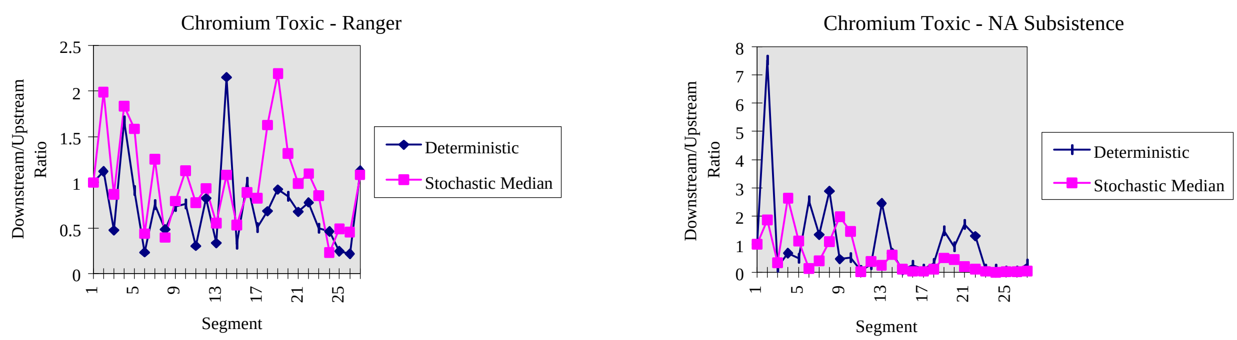


Figure 5.12. Downstream/Upstream Ratios of Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Chromium Treated as a Toxic Chemical

Chromium. Figures 5.11 and 5.12 present the ratios of the risk estimated for chromium, as both a carcinogenic and toxic chemical, using the Ranger and Native American Subsistence Resident scenarios for each river segment compared with the risk estimated for Segment 1. The ratios in these two figures are essentially identical, as would be expected since both sets of calculations use the same monitoring data. Generally, the results indicate fluctuations around the reference value. The highest values indicated by the Ranger Scenario are caused by sediment at Segments 2, 14, and 19. The highest indicated by the Native American Subsistence Resident Scenario is at Segment 2, although here it is in surface water. The highest risk from chromium via the Ranger Scenario is from sediment in Segment 2, with a lifetime risk of 2.6×10^{-4} and a hazard index of 8.9×10^{-6}. The highest risk via the Native American Subsistence Resident Scenario is from surface water in Segments 2 and 4, with a lifetime risk of 0.27 and a hazard index of 3.3×10^{-2}.

Chromium exemplifies the difficulty of determining the Hanford Site contribution above reference. Chromium is known to enter the Columbia River via groundwater at several Hanford Site locations, yet the results do not show dramatic increases in human risk at these known locations. Condensing data from several locations to represent an entire river segment results in some dilution of the contaminant level from selected hot spots. The results do represent some reality of potential human exposures since people would not be expected to continually remain at one point. Because of this difficulty, a more detailed statistical technique was developed to evaluate whether contaminants are present in elevated concentrations. It is presented in the subsequent section. In addition, the EPA does not provide an ingestion cancer potency factor for chromium; the value used in this assessment is equal to that for inhalation. This assumption may significantly misrepresent the risk from chromium.

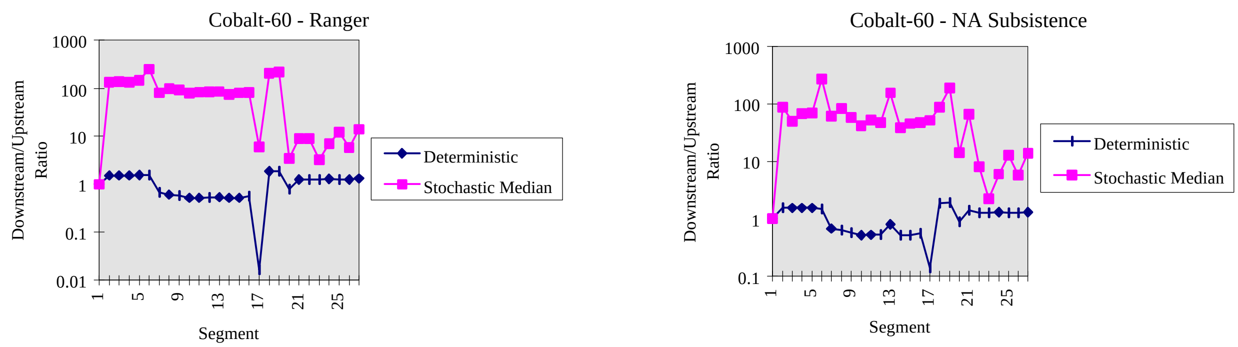


Figure 5.13. Downstream/Upstream Ratios of Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Cobalt-60

Cobalt-60. Figure 5.13 presents the ratios of the risk estimated for cobalt-60 using the Ranger and Native American Subsistence Resident scenarios for each river segment compared with the risk estimated for Segment 1. Cobalt-60 has an obvious Hanford Site origin and is present in elevated quantities throughout the Hanford Reach. In the Ranger Scenario, the primary exposure media is surface water. In the Native American Subsistence Resident Scenario, the dominant medium varies between surface water, sediment, and seep water in various segments. The noticeable drop in the ratio in the downstream Segments 21-27 is the result of a single surface water measurement in Segment 21 being used as a surrogate in subsequent downstream segments. The highest risk from cobalt-60 via the Ranger Scenario is from surface water in Segment 6, with a lifetime risk of 9.0×10^{-9}. The highest risk via the Native American Subsistence Resident Scenario is from sediment in Segment 6, with a risk of 3.0×10^{-6}.

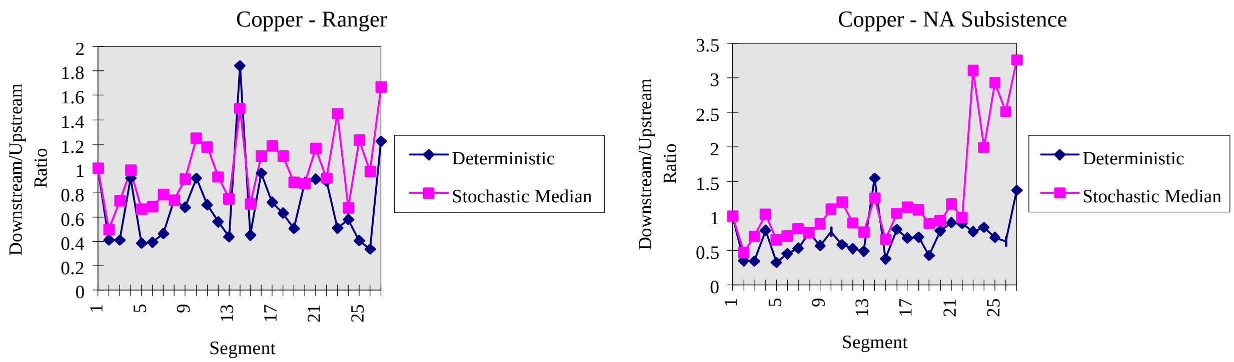


Figure 5.14. Downstream/Upstream Ratios of Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Copper

Copper. Figure 5.14 presents the ratios of the risk estimated for copper using the Ranger and Native American Subsistence Resident scenarios for each river segment compared with the risk estimated for Segment 1. The controlling media vary with location between sediment (for example, Segment 14) and surface water (for example, Segments 23-27). Generally, the variations appear to be minor fluctuations around the reference concentration. An apparent increase in copper concentration in surface water in Segments 23-27 may be related to the influx of Yakima River water or may result from accumulation of fine grained sediment in the slower moving water behind McNary Dam. Concentrations in surface water throughout the Hanford Reach are much lower than below the influx of the Yakima River. The highest risk from copper via the Ranger Scenario is from surface water in Segment 27, with a hazard index of $9.6x10^{-4}$. The highest risk via the Native American Subsistence Resident scenario is from surface water in Segment 27, with a hazard index of 6.8. Copper has the largest hazard index of any contaminant evaluated.

The large hazard index for copper may result from a combination of three factors. First, copper appears to be enhanced throughout the study domain as a result of upstream human activities such as mining. Second, copper has been assumed to be in a bioavailable form, which may magnify its impacts. Finally, the human reference dose for copper used in this assessment is based on older EPA sources; the current versions of HEAST and IRIS do not provide values for the copper reference dose (RfD).

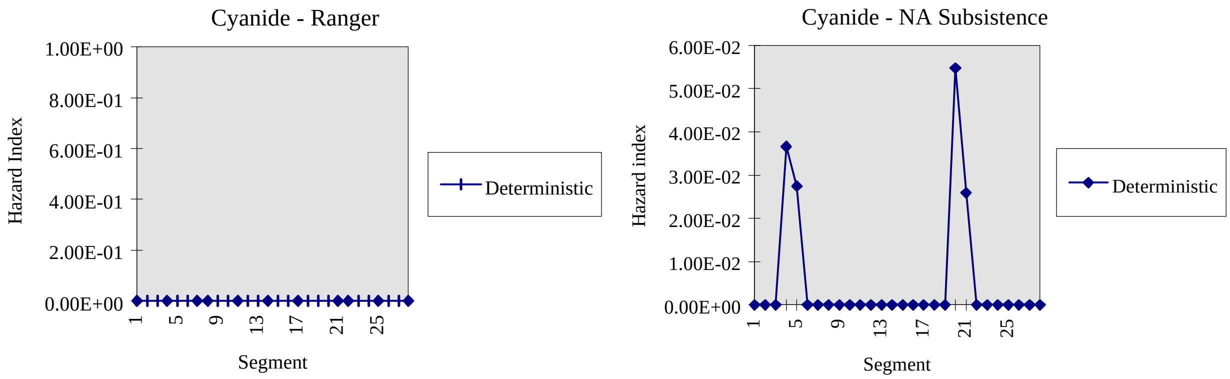


Figure 5.15. Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Cyanide

Cyanide. Figure 5.15 presents the risk estimated for cyanide using the Ranger and Native American Subsistence Resident scenarios for each river segment compared with the risk estimated for Segment 1. Cyanide measurements for Segment 1 are all below detection limits, making it impossible to prepare downstream/upstream ratios. Therefore, the absolute value of the estimated hazard index is plotted in this figure. For the four segments where data are available, all are controlled by seep water data derived from groundwater measurements. The absolute values of the hazard indexes are well below 1.0, so cyanide at the Hanford Site does not appear to be a contaminant of potential toxicity. Cyanide does not pose a risk via the Ranger Scenario because this scenario has no assumed exposures to seep water. The highest risk via the Native American Subsistence Resident Scenario is from seep water in Segment 20, with a hazard index of 5.5×10^{-2}.

Diesel Fuel. This potential contaminant was not detected in any of the media sampled during the time frame of the database. Therefore, it was not analyzed in the screening assessment.

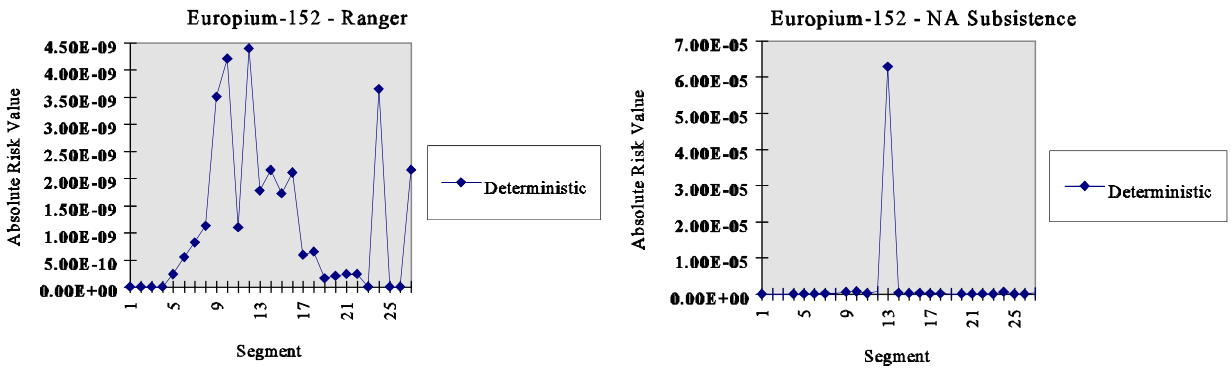


Figure 5.16. Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Europium-152

Europium-152. Figure 5.16 presents the risk estimated for europium-152 using the Ranger and Native American Subsistence Resident scenarios for each river segment compared with the risk estimated for Segment 1. Europium-152 measurements for Segment 1 are all below detection limits, making it impossible to prepare downstream/upstream ratios. Therefore, the absolute value of the estimated radionuclide risk is plotted in this figure. The peaks in the Ranger Scenario results are all controlled by europium-152 measured in sediment. The Native American Subsistence Resident Scenario results generally are well below a risk of 10^{-6}, with the exception of a large spike in Segment 13. This spike is caused by a measurement of europium-152 in groundwater that has been used as a surrogate for seep water at this location. The highest risk from europium-152 via the Ranger Scenario is from sediment in Segment 12, with a lifetime risk of 4.4×10^{-9}. The highest risk via the Native American Subsistence Resident scenario is from seep water in Segment 13, with a risk of 6.3×10^{-5}.

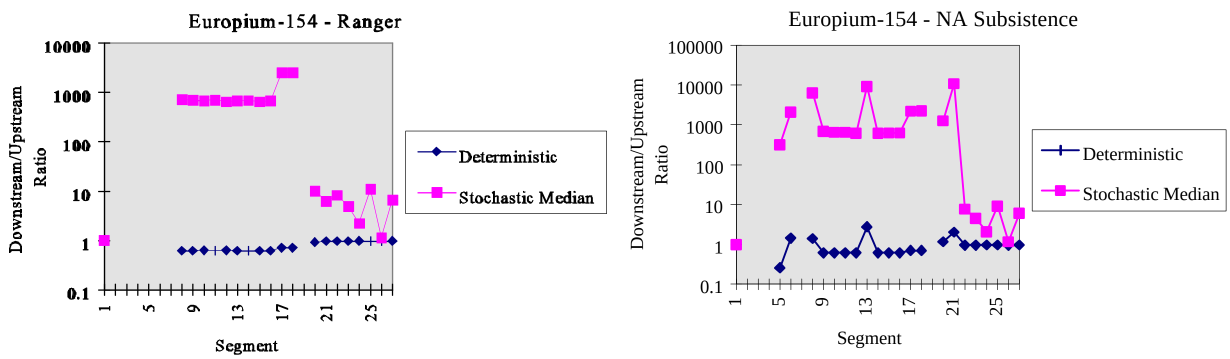


Figure 5.17. Downstream/Upstream Ratios of Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Europium-154

Europium-154. Figure 5.17 presents the ratios of the risk estimated for europium-154 using the Ranger and Native American Subsistence Resident scenarios for each river segment compared with the risk estimated for Segment 1. Europium-154 is generally considered to be an activation product, and relatively little of it is present in global fallout. Distinctly elevated levels appear in the stochastic calculations for both the Ranger and Native American Subsistence Resident scenarios between Segments 8 and 18. The highest risk from europium-154 via the Ranger Scenario is from surface water in Segment 18, with a lifetime risk of $3.3x10^{-8}$. The highest risk via the Native American Subsistence Resident Scenario is from seep water in Segment 21, with a risk of $1.5x10^{-5}$. Of note is that the surface water measurement for Segment 8 is used as a surrogate through Segment 16. Thus, actual measurements of elevated europium-154 in surface water currently exist only for Segments 8 and 17. The values for the Native American Subsistence Resident Scenario in Segments 20 and 21 result from using groundwater as a surrogate for seep water in these locations.

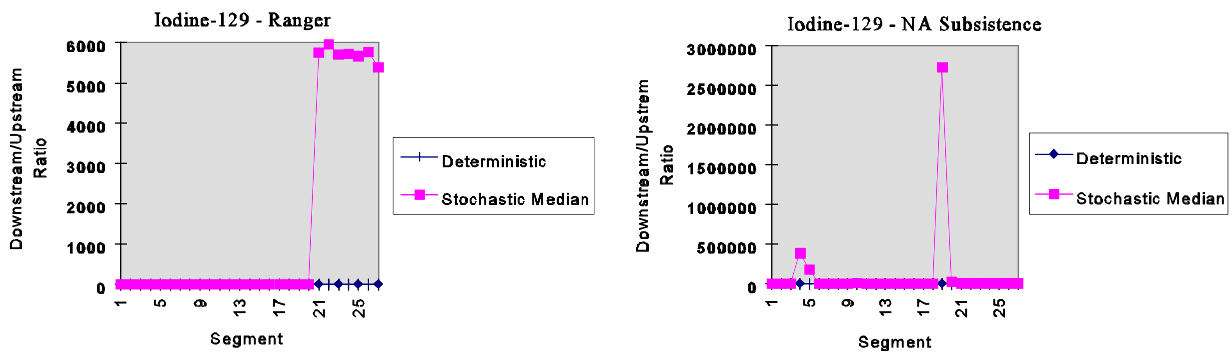


Figure 5.18. Absolute and Downstream/Upstream Ratios of Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Iodine-129

Iodine-129. Figure 5.18 presents the ratios of the risk estimated for iodine-129 using the Ranger and Native American Subsistence scenarios for each river segment compared with the risk estimated for Segment 1. For the Ranger Scenario, the risk directly depends on the concentration measured in surface water. Only two such measurements are available, in Segments 1 and 21. The maxima in these two segments are very similar, and the median measured value in Segment 1 is much less than that in Segment 21. Both measured concentration values are very small. External exposure to iodine-129 poses essentially no risk, so the Ranger Scenario is not a good measure of risk from this radionuclide because it assumes only external and dermal exposures. The Native American Subsistence Resident Scenario indicates much higher concentrations of iodine-129 in the seep water of Segments 4, 5, 10, and 19 (each of these were surrogated with groundwater data). These segments correspond to the locations of groundwater monitoring wells that are sampled for iodine-129 (Dirkes and Hanf 1996, p. 205). The highest risk from iodine-129 via the Ranger Scenario is from surface water in Segment 22, with a lifetime risk of 6.9×10^{-15}. The highest risk via the Native American Subsistence Resident Scenario is from seep water in Segment 19, with a risk of 2.2×10^{-6}.

Kerosene. This potential contaminant was not detected in any of the media sampled during the time frame of the database. Therefore, it was not analyzed in the screening assessment.

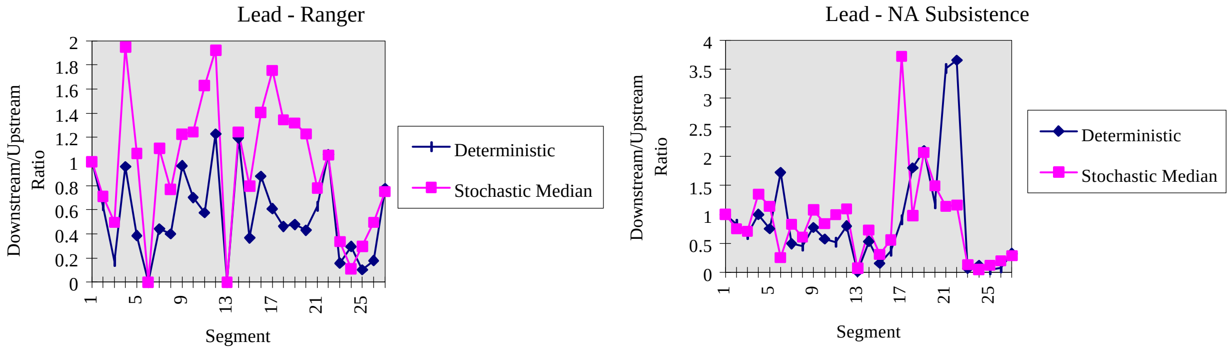
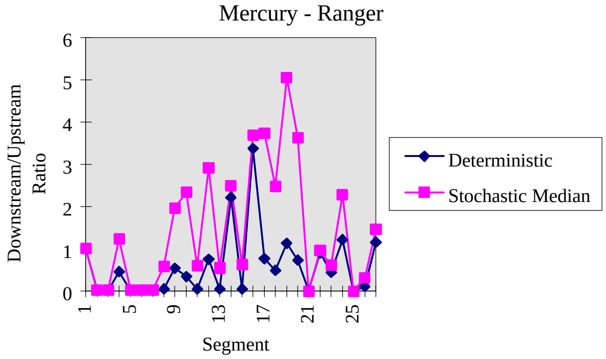


Figure 5.19. Downstream/Upstream Ratios of Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Lead

Lead. Figure 5.19 presents the ratios of the risk estimated for lead using the Ranger and Native American Subsistence Resident scenarios for each river segment compared with the risk estimated for Segment 1. The deterministic results for neither the Ranger nor Native American Subsistence Resident scenarios indicate deviations much above reference, but the stochastic calculations indicate that Segments 4, 12, and 17 may be elevated. In these and the other segments, the controlling medium is sediment. In all cases, the concentrations of lead in sediment are within about a factor of 2 of the upstream value. The highest risk from lead via the Ranger Scenario is in Segment 4, with a hazard index of 2.0×10^{-3}. The highest risk via the Native American Subsistence Resident Scenario is from sediment and seep water together in Segment 17, with a risk of 1.2. Lead has the second highest hazard index calculated. Note that the reference dose for lead in this assessment is taken from older references because EPA does not currently provide a reference dose for lead. Future re-evaluations of lead toxicity may impact the magnitude of the calculated risk.



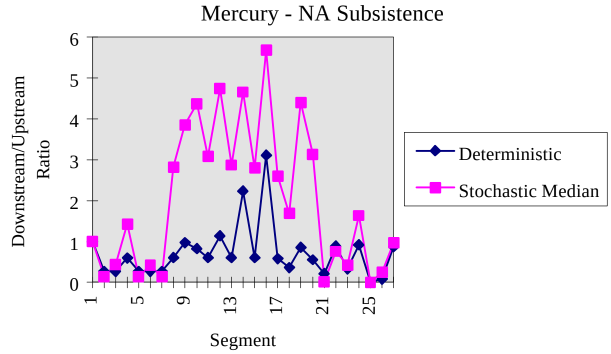


Figure 5.20. Downstream/Upstream Ratios of Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Mercury

Mercury. Figure 5.20 presents the ratios of the risk estimated for mercury using the Ranger and Native American Subsistence Resident scenarios for each river segment compared with the risk estimated for Segment 1. The Ranger Scenario results are driven by a combination of surface water and sediment measurements. The Native American Subsistence Resident Scenario results also are a mix of these two sources. For both, the surface water measurement in Segment 8 is a surrogate through Segment 16. A minor increase in risk from mercury appears throughout the Hanford Reach. However, the source is indeterminate because the surface water value for mercury in Segment 1 is used to estimate its concentration in Segments 2-7, and the higher value from Segment 8 is used in Segments 9-16. Fluctuations in the overall risk in the intervening segments result from the presence or absence of measurements of mercury in sediment. Also, the sediment in Segment 1 has no measurement of mercury. The highest risk from mercury via the Ranger Scenario is from sediment in Segment 19, with a hazard index of 3.2×10^{-7}. The highest risk via the Native American Subsistence Resident scenario is from surface water in Segment 16, with a hazard index of 8.3×10^{-3}.

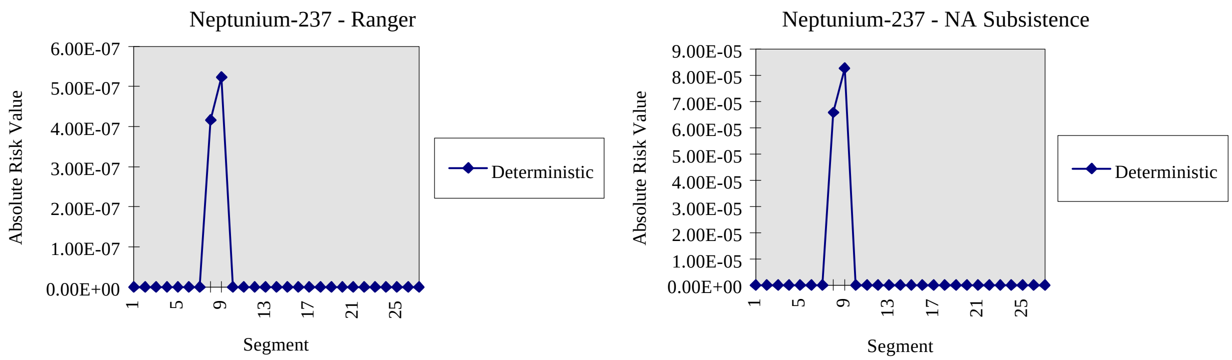


Figure 5.21. Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Neptunium-237

Neptunium-237. Figure 5.21 presents the risk estimated for neptunium-237 using the Ranger and Native American Subsistence Resident scenarios for each river segment compared with the risk estimated for Segment 1. Neptunium-237 measurements are not available for Segment 1, making downstream/upstream ratios impossible to prepare. The only positive measurements for neptunium-237 occur in sediment in Segments 8 and 9. The differences in the magnitude of the estimated risk between the Ranger and Native American Subsistence Resident scenarios result from the differences between the external pathway in the Ranger Scenario and the sum of the external and internal exposure pathways in the Native American Subsistence Resident Scenario. The highest risk from neptunium-237 via the Ranger Scenario is from sediment in Segment 9, with a lifetime risk of $5.2x10^{-7}$. The highest risk via the Native American Subsistence Resident scenario is from sediment in Segment 9, with a risk of $8.3x10^{-5}$.

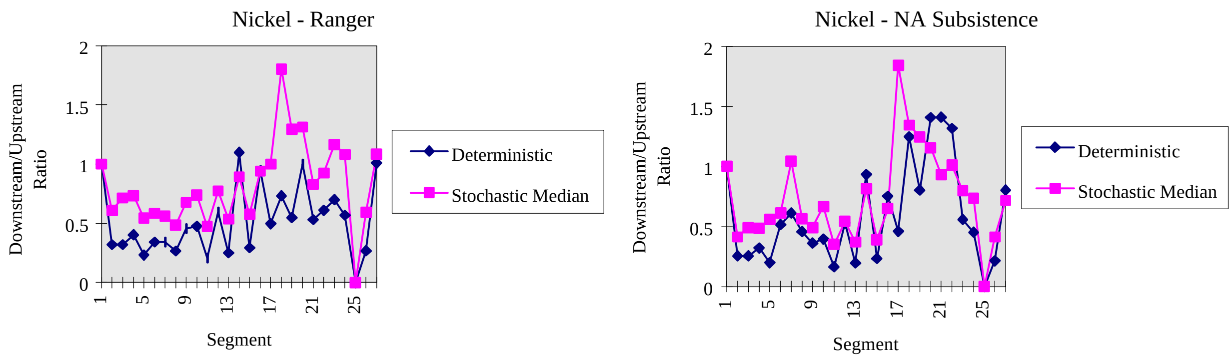


Figure 5.22. Downstream/Upstream Ratios of Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Nickel

Nickel. Figure 5.22 presents the ratios of the risk estimated for nickel using the Ranger and Native American Subsistence Resident scenarios for each river segment compared with the risk estimated for Segment 1. For both sets of scenarios, the maximum downstream risk estimates are always within 50 percent of the upstream estimates.   The highest risk from nickel via the Ranger Scenario is from sediment in Segment 19, with a hazard index of $2.0x10^{-6}$. The highest risk via the Native American Subsistence Resident scenario is from seep water in Segment 17, with a hazard index of $6.8x10^{-3}$. The upstream and downstream estimates are controlled by measurements in sediment at the respective locations. The dip in the results in Segment 25 is because no sediment measurements are available for this location. Nickel does not appear to be related to releases from the Hanford Site.

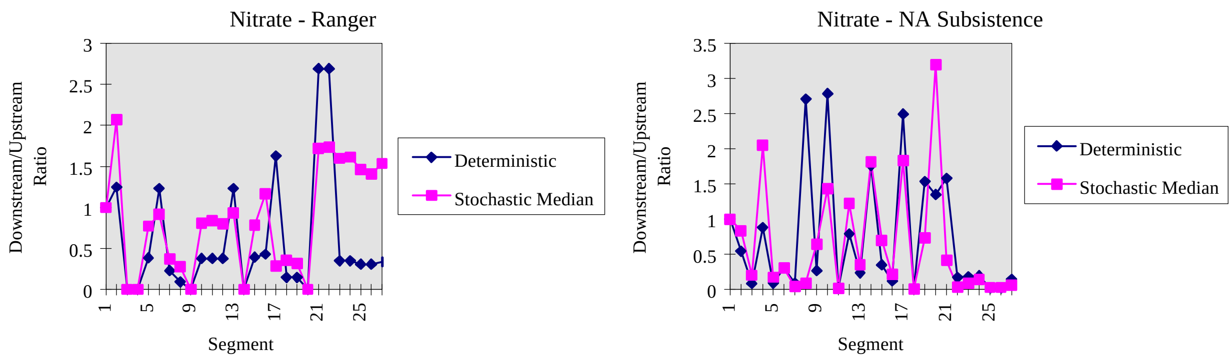


Figure 5.23. Downstream/Upstream Ratios of Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Nitrates

Nitrates. Figure 5.23 presents the ratios of the risk estimated for nitrates using the Ranger and Native American Subsistence Resident scenarios for each river segment compared with the risk estimated for Segment 1. The bulk of the downstream Ranger Scenario results is equal to or less than the upstream result, but the risk driven by surface water in Segments 2, 21 and 22 is somewhat higher (surface water in Segment 22 is a surrogate based on Segment 21). The Native American Subsistence Resident Scenario results are increased in Segments 4, 8, 10, 14, 17, and 20, all from the influence of nitrates in seep water measurements. Nitrates are a well known and documented Hanford Site contaminant and are known to discharge to the Columbia River. The highest risk via the Native American Subsistence Resident scenario is from seep water in Segment 20, with a hazard index of 0.24. The highest risk via the Ranger Scenario is from surface water in Segment 2, with a hazard index of $2.2x10^{-6}$.