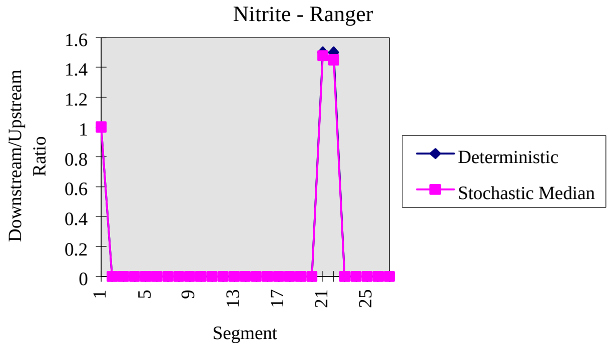


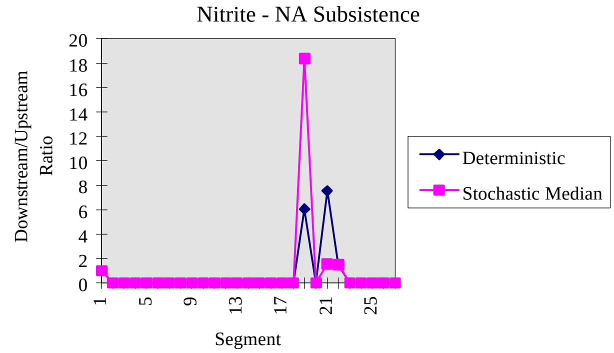


Figure 5.24. Downstream/Upstream Ratios of Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Nitrites

Nitrites. Figure 5.24 presents the ratios of the risk estimated for nitrites using the Ranger and Native American Subsistence Resident scenarios for each river segment compared with the risk estimated for Segment 1. Nitrite measurements are available for most segments, but the concentration of nitrites is generally below detection. Nitrites have been detected in small amounts in surface water in Segments 1 and 21. The figure shows the use of surrogate surface water, in that Segment 22 uses surface water measurements from Segment 21. For the Native American Subsistence Resident Scenario, nitrite are also present in modeled seep water (surrogated by groundwater) in Segments 19 and 21. No other locations have measurements above the detection level for nitrites. The highest risk from nitrites via the Ranger Scenario is from surface water in Segment 21, with a hazard index of 6.3×10^{-7}. The highest risk via the Native American Subsistence Resident Scenario is from seep water in Segment 19, with a hazard index of 0.011.

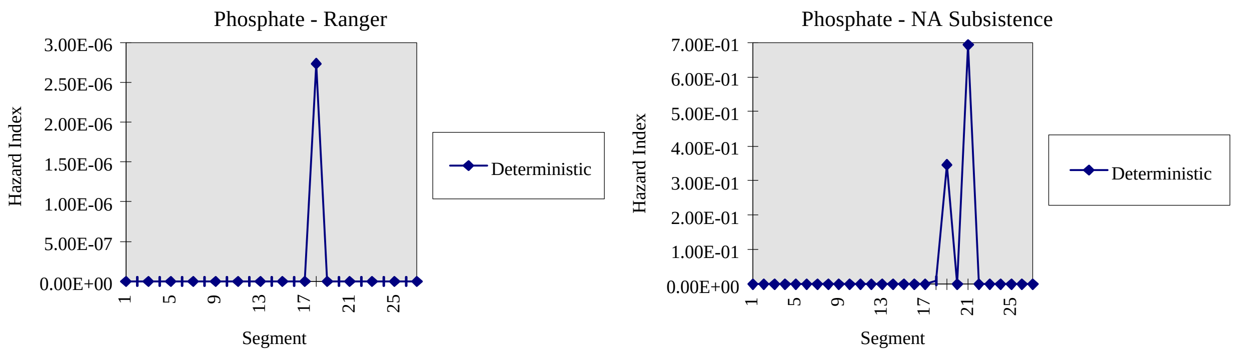
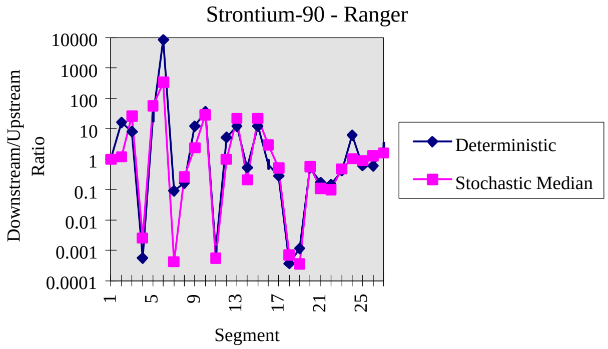


Figure 5.25. Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Phosphates

Phosphates. Figure 5.25 presents the risk estimated for phosphates using the Ranger and Native American Subsistence Resident scenarios for each river segment compared with the risk estimated for Segment 1. Phosphate measurements for Segment 1 are all below detection levels, making it impossible to prepare downstream/upstream ratios. Surface water in Segment 18 for the Ranger Scenario illustrates the only positive measurement for phosphate. This is repeated in the Native American Subsistence Resident Scenario, and two instances of phosphate detection in groundwater used as a surrogate for seep water are shown in Segments 19 and 21. The highest risk from phosphates via the Ranger Scenario is from surface water in Segment 18, with a hazard index of 2.7×10^{-6}. The highest risk via the Native American Subsistence Resident Scenario is from seep water in Segment 19, with a deterministic hazard index of 0.69. Because the reference phosphate dose used in this assessment has been approximated (see Section 5.2.2.3), this may not be an accurate assessment of the phosphate risk.



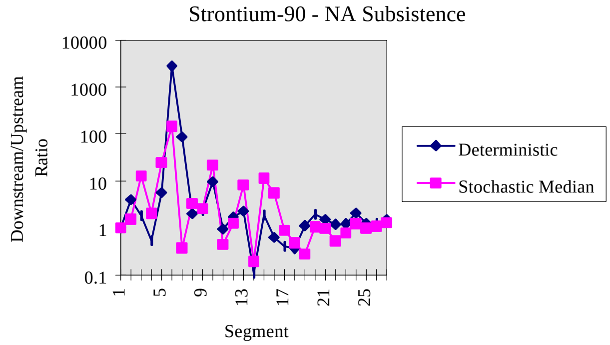


Figure 5.26. Downstream/Upstream Ratios of Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Strontium-90

Strontium-90. Figure 5.26 presents the ratios of the risk estimated for strontium-90 using the Ranger and Native American Subsistence Resident scenarios for each river segment compared with the risk estimated for Segment 1. Strontium-90 is a component of global radioactive fallout. Results of both the Ranger and Native American Subsistence Resident scenarios indicate that concentrations of strontium-90 are significantly higher in the water and sediment of some segments of the Hanford Reach than elsewhere. For the Ranger Scenario, the increases are the result of strontium-90 concentrations in sediment in the Hanford Reach segments, and below Segment 21 is the result of strontium-90 in surface water. Segments downstream from Segment 21 are modeled using the Segment 21 surface water measurement. For the Native American Subsistence Resident Scenario, the primary medium in the Hanford Reach is sediment with a secondary contribution from strontium-90 in seep water (either directly measured or using groundwater as a surrogate). The highest risk from strontium-90 via the Ranger Scenario is from sediment in Segment 6, with a lifetime risk of 5.4×10^{-8}. The highest risk via the Native American Subsistence Resident Scenario is also from sediment in Segment 6, with a risk of 7.7×10^{-4}. It is apparent that strontium-90 is enhanced as a result of Hanford Site operations.

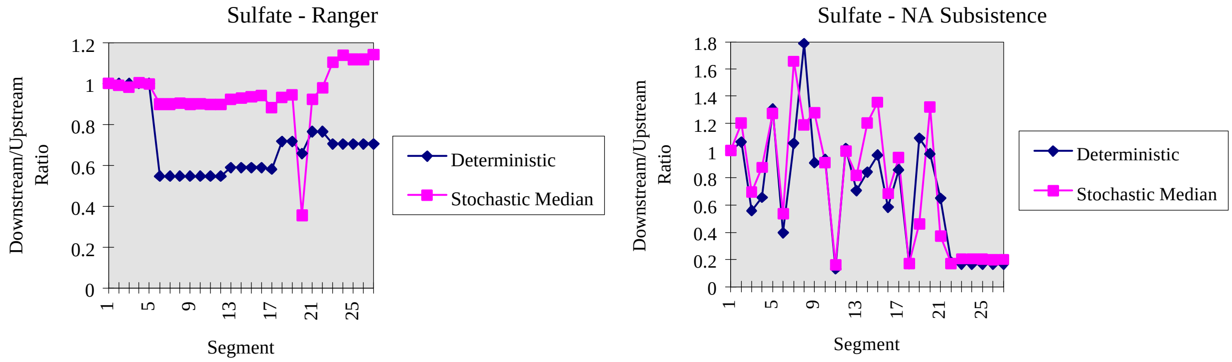


Figure 5.27. Downstream/Upstream Ratios of Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Sulfates

Sulfates. Figure 5.27 presents the ratios of the risk estimated for sulfates using the Ranger and Native American Subsistence Resident scenarios for each river segment compared with the risk estimated for Segment 1. The Ranger Scenario is controlled by a few measurements in surface water. Measurements made in Segments 1, 6, 13, 17, 18, 20, and 21 are used in the segments that are respectively downstream of these. No noticeable difference exists in surface water concentration throughout the region. The Native American Subsistence Resident Scenario includes the influence of seep water. Minor increases in the estimated risk from sulfates are apparent in Segments such as 7, 8, 15, and 20. The largest is almost a doubling of risk in Segment 8 as a result of inflowing sulfates from Hanford groundwater. The highest risk from sulfates via the Ranger Scenario is from surface water in Segment 27, with a hazard index of 1.0×10^{-6}. The highest risk via the Native American Subsistence Resident Scenario is from seep water in Segment 7, with a hazard index of 0.012. The reference dose for sulfates used in this assessment is based on the Secondary Drinking Water Standard (see Section 5.2.2.3), which may result in an overstatement of the risk from sulfates.

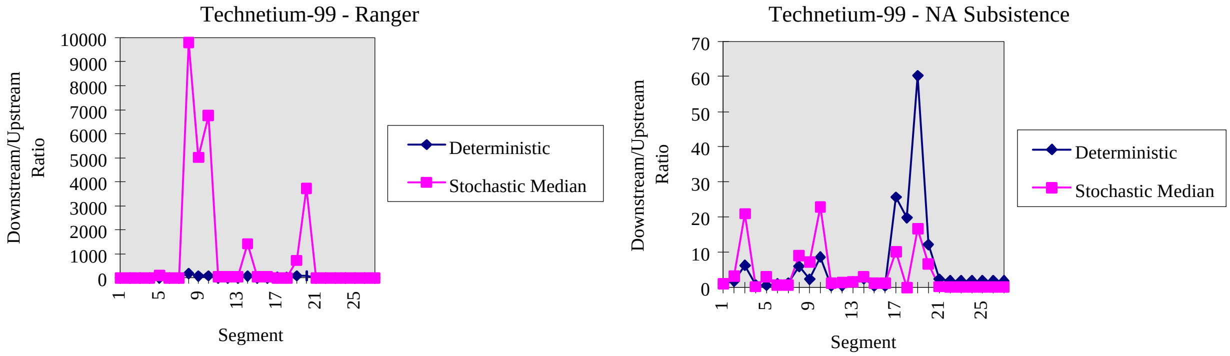


Figure 5.28. Downstream/Upstream Ratios of Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Technetium-99

Technetium-99. Figure 5.28 presents the ratios of the risk estimated for technetium-99 using the Ranger and Native American Subsistence Resident scenarios for each river segment compared with the risk estimated for Segment 1. The radionuclide technetium-99 is generally of low concentration in global fallout. The patterns in both parts of Figure 5.26 reflect the availability of sediment measurements for technetium-99. The highest risk from technetium-99 via the Ranger Scenario is from sediment in Segment 8, with a lifetime risk of $6.3x10^{-11}$. The highest risk via the Native American Subsistence Resident Scenario is from seep water in Segment 10, with a risk of $3.1x10^{-6}$. Because technetium has a very high bioaccumulation factor, it tends to accumulate in plants. The model used to estimate risk uses a bioaccumulation factor based on the sediment measurements. When measurements are available, the accumulation in plants is very apparent. Technetium-99 is known to contaminate the groundwater at some Hanford Site locations, one being in the 100-H Area represented by Segment 10. Although technetium-99 has been measured in sediment in the 100-H and other areas, it is not known whether the technetium-99 in the sediment is of Hanford Site origin because no sediment sample measurements for technetium-99 are available upstream of Segment 8 (100-D Area). More sediment samples would be required to unequivocally identify the source of the technetium-99.

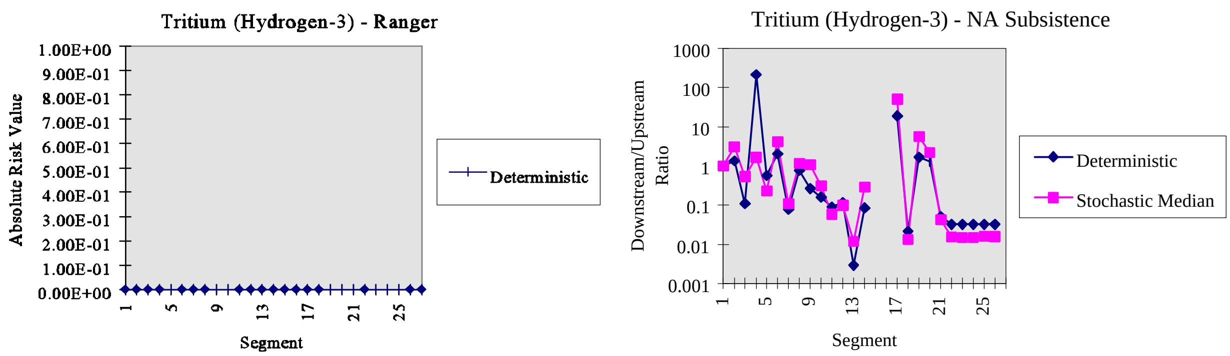


Figure 5.29. Absolute and Downstream/Upstream Ratios of Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Tritium (Hydrogen-3)

Tritium (Hydrogen-3). Figure 5.29 presents the risk estimated for tritium (hydrogen-3) using the Ranger Scenario for each river segment and the ratios of the risk estimated using the Native American Subsistence Resident Scenario for each river segment compared with the risk estimated for Segment 1. Tritium (hydrogen-3) measurements in sediment are not available for Segment 1, making it impossible to prepare downstream/upstream ratios for the Ranger Scenario. External exposure to tritium (hydrogen-3) 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 that exposures to seep water in Segments 4 and 17 result in risk from tritium (hydrogen-3) that is distinctly elevated above reference. No risk occurs from tritium (hydrogen-3) via the Ranger Scenario because the low decay energy provides no external exposure. The highest risk via the Native American Subsistence Resident Scenario is from seep water in Segment 17, with a lifetime risk of 2.1×10^{-4}.

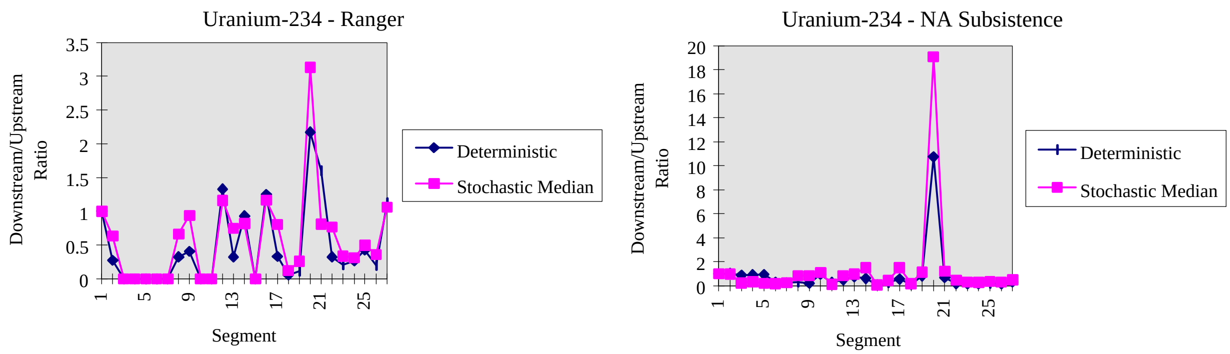


Figure 5.30. Downstream/Upstream Ratios of Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Uranium-234

Uranium-234. Figure 5.30 presents the ratios of the risk estimated for uranium-234 using the Ranger and Native American Subsistence Resident scenarios for each river segment compared with the risk estimated for Segment 1. Uranium-234 is a naturally occurring decay product of uranium-238, the form most prevalent in nature. However, in operations involving reactor fuel made of enriched uranium, uranium-234 can also be enhanced in concentration. The results for both the Ranger and Native American Subsistence Resident scenarios indicate that uranium-234 is enhanced in Segment 20 (300 Area), quite likely because the 300 Area was used for uranium fuel fabrication. The Ranger Scenario indicates that uranium-234 concentrations are elevated in sediment. The Native American Subsistence Resident Scenario indicates that seep water in the 300 Area also contains elevated concentrations of uranium-234. The highest risk from uranium-234 via the Ranger Scenario is from sediment in Segment 20, with a lifetime risk of 6.5×10^{-8}. The highest risk via the Native American Subsistence Resident Scenario is from seep water in Segment 20, with a risk of 9.9×10^{-4}.

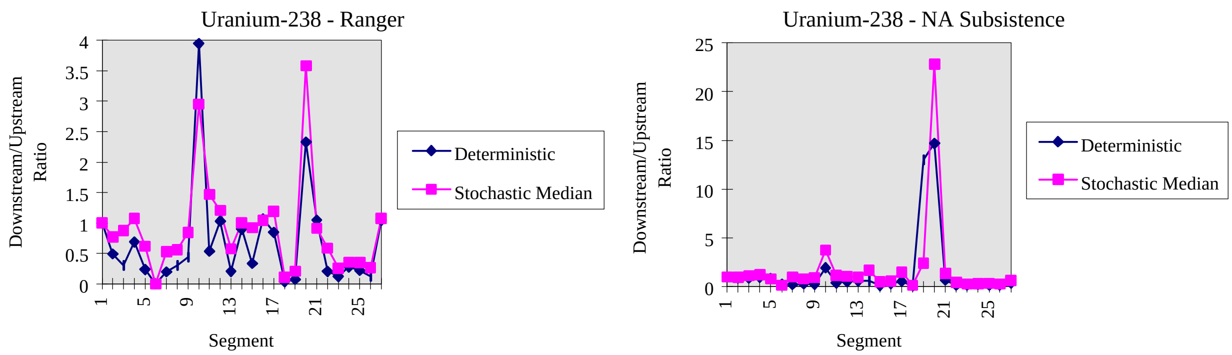


Figure 5.31. Downstream/Upstream Ratios of Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Uranium-238

Uranium-238. Figure 5.31 presents the ratios of the risk estimated for uranium-238 using the Ranger and Native American Subsistence Resident scenarios for each river segment compared with the risk estimated for Segment 1. Uranium is a naturally occurring radionuclide, appearing in concentrations of about 1 part per million in igneous rocks (NCRP 1987). As with uranium-234, a peak is apparent in the 300 Area (Segment 20), and a separate peak appears at Segment 10 (100-H Area). The dominant medium in both locations is sediment. The highest risk from uranium-238 via the Ranger Scenario is in Segment 20, with a lifetime risk of $7.7x10^{-8}$. The highest risk via the Native American Subsistence Resident Scenario is from sediment and seep water in Segment 20, with a risk of $9.2x10^{-4}$.

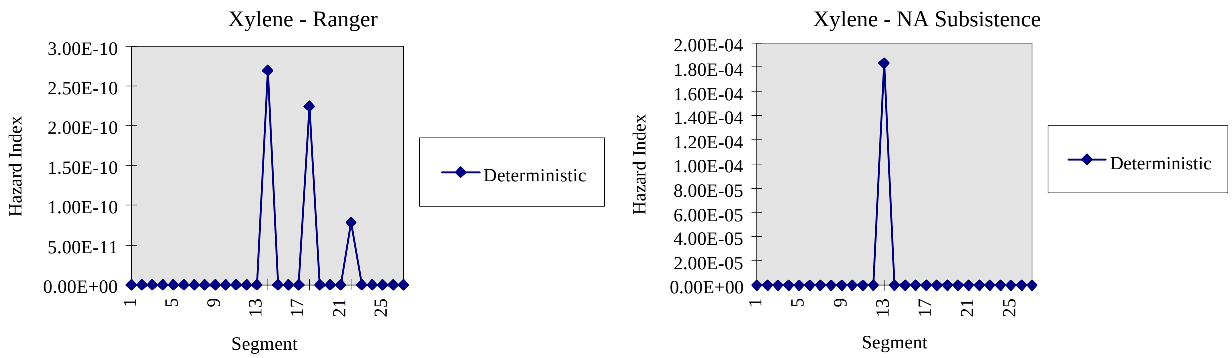


Figure 5.32. Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Xylenes

Xylenes. Figure 5.32 presents the risk estimated for xylenes using the Ranger and Native American Subsistence Resident scenarios for each river segment compared with the risk estimated for Segment 1. Xylene measurements for Segment 1 are all below detection limits, making it impossible to prepare downstream/upstream ratios. The peaks in the graph for the Ranger Scenario correspond to measurements of xylenes in sediment in Segments 14, 18, and 22. The graph for the Native American Subsistence Resident Scenario has similar peaks, but they are lost in the scale because of a single measurement of xylenes in groundwater (substituted for seep water) in Segment 13. This large peak in Segment 13 is most likely correlated with the benzene peak in this segment and both probably represent a petroleum hydrocarbon source. The highest risk from xylenes via the Ranger Scenario is from sediment in Segment 14, with a hazard index of 2.7×10^{-10}. The highest risk via the Native American Subsistence Resident Scenario is from seep water in Segment 13, with a hazard index of 1.8×10^{-4}.

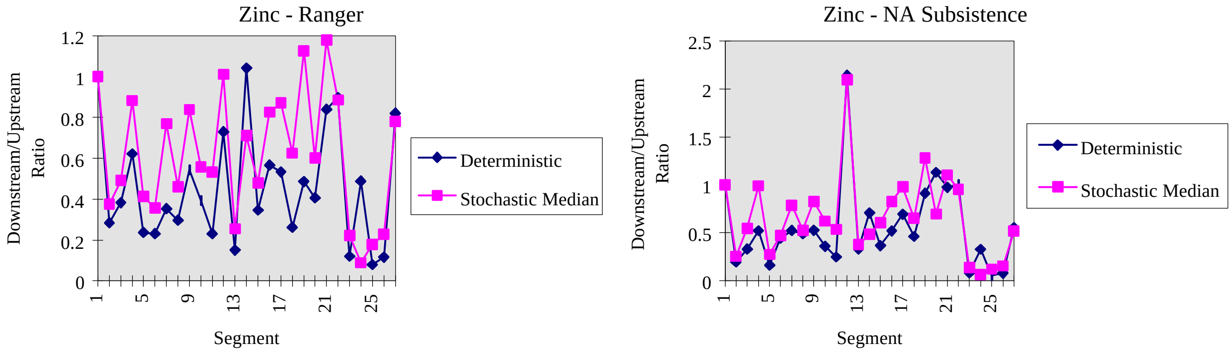


Figure 5.33. Downstream/Upstream Ratios of Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Zinc

Zinc. Figure 5.33 presents the ratios of the risk estimated for zinc using the Ranger and Native American Subsistence Resident scenarios for each river segment compared with the risk estimated for Segment 1. The highest risk from zinc via the Ranger Scenario is from sediment in Segment 21, with a hazard index of $1.1x10^{-4}$. The highest risk via the Native American Subsistence Resident Scenario is from seep water in Segment 12, with a hazard index of 0.37. None of the downstream results differ greatly from the upstream result in Segment 1 for either the Ranger or Native American Subsistence Resident scenarios. Zinc in the environment is not likely to be the result of releases from the Hanford Site.

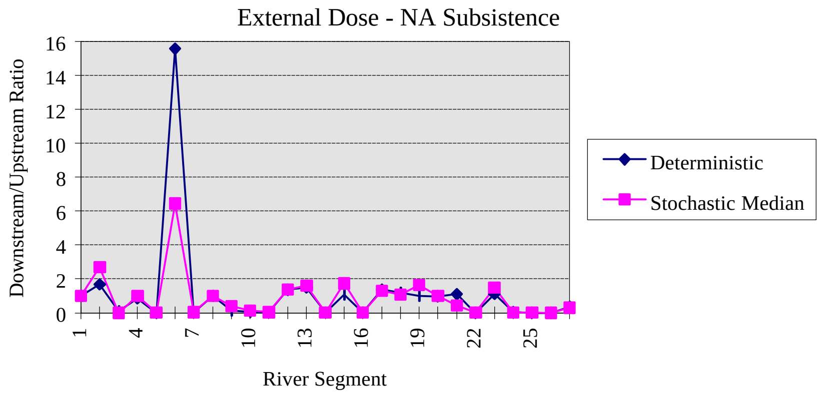


Figure 5.34. Downstream/Upstream Ratios of Estimated Risk Results for External Doses

External Doses. Figure 5.34 presents the ratios of the risk estimated from external radiation compared with the risk estimated for Segment 1. The ratios were calculated using either thermoluminescent dosimeter data from each river segment or dose rate calculations based on radionuclide concentrations. The largest deviation from reference is apparent in Segment 6, the N Reactor Area, a dose rate of about 12 millirem/year, which corresponds to a lifetime risk of $6.8x10^{-4}$. As discussed above, some of these estimates are based on measurements with a constant background subtracted, and the rest are based on concentrations of radionuclides in soils, sediment, and water.

5.2.4.2 Statistical Evaluation

The comparison of upstream to downstream risk on the basis of the deterministic or median stochastic value does not incorporate all of the information available in the distributions of the measured data. An example of distributions for a contaminant is illustrated in Figure 5.35. In this figure, the distribution of estimated human risk from the radionuclide tritium (hydrogen-3) for the Native American Subsistence Resident Scenario in Segment 1 (the upstream segment) is compared with that for Segment 17 (the old Hanford townsite). In Segment 1, all environmental measurements are below the EPA drinking water standard for tritium (hydrogen-3) of 20,000 picocuries/liter. However, Segment 17 has shown measurements of seeps and groundwater as high as 169,000 picocuries/liter. Consumption of groundwater with concentrations of tritium (hydrogen-3) of this magnitude would result in annual doses greater than 4 millirem and lifetime risk of up to 10^{-3}. The distinct shift of the distributions is indicative of an increase in individual risk that can be attributed to Hanford operations.

Because the distributions hold more information than can be easily used, methods were developed to compare the entire upstream and downstream distributions. These techniques are based on detailed statistical approaches called the Mann-Whitney U Test and the Kruskal-Wallis One-Way Anova Test.

The Mann-Whitney U Test (Gibbons 1971, p. 140) was developed to test whether two independent sets of sample values, called X and Y, were drawn from the same statistical distribution. In this application,

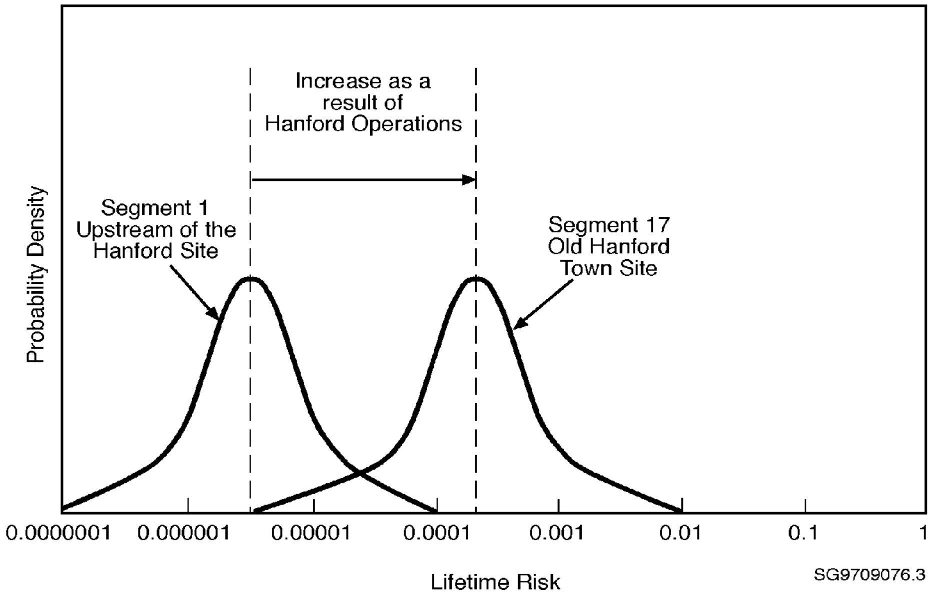


Figure 5.35. Comparison of Reference and Elevated Distribution of Estimated Lifetime Risk for the Native American Subsistence Resident Scenario for Tritium (Hydrogen-3)

both sets of samples come from a two-parameter lognormal distribution by construction. The test then addresses whether the two lognormal distributions have the same parameters, that is, $F_Y(t)=F_X(t)$ for all t, where F denotes a cumulative distribution function.

The test procedure combines the two sets of sampled data and then sorts the combined values into increasing order. The Mann-Whitney U statistic is defined as the number of times a Y_i precedes an X_j in the set of combined, sorted values. The rejection region for the one-sided alternative is $F_Y(t) \leq F_X(t)$ with strict inequality for some t.

If the two sets of values come from the same distribution, they should be randomly interspersed in the combined sorted set. Similarly, if one distribution lies to the left of the other one, the sampled values should be segregated into different areas. Using combinatorial arguments, one can derive the statistical distribution of the U statistic under the assumption of equal distributions. Assume that X contains m values and Y contains n values, then the large sample test statistic

$$Z = \frac{U - mn/2}{\sqrt{mn(m + n + 1)/12}} \tag{5.26}$$

has a distribution that is approximately standard normal. The approximation is reasonably accurate for equal sample sizes as small as 6. In the context of this screening assessment, both sets of samples have the same number of values: m = n = 1,000.

The Mann-Whitney U Test was developed to check for differences between two sets of sampled values. The test can be extended to multiple sets of sampled values (an arbitrarily large number, represented by k), in which case it is then known as the Kruskal-Wallis One-Way Anova Test (Gibbons 1971, p. 198). The null hypothesis for the test is that all of the sets of samples come from the same statistical distribution.

Assume that the ith sample contains n_i values and that the sum of all the n_i is N. The test procedure is to combine all N observations into a single ordered sequence from smallest to largest, keeping track of which observation is from what sample and assign the ranks 1, 2, …, N to the sequence. Let R_i denote the sum of the ranks associated with the ith sample. The test statistic, K_w, is computed as

$$K_w = \frac{12}{N(N+1)} \sum_{i=1}^{k} \frac{R_i^2}{n_i} - 3(N+1) \qquad (5.27)$$

The large-sample rejection region for the test is $K_w \geq \chi^2_{\alpha,k-1}$ where $\chi^2_{\alpha,k-1}$ denotes a Chi-squared statistic with k-1 degrees of freedom. Unfortunately, the form of the test statistic does not yield information as to the nature of differences between the statistical distributions of the sets of sampled values when the null hypothesis is rejected. The only conclusion that can be drawn is that not all of the distributions were the same.

Multiple applications of the Mann-Whitney U Test are not equivalent in a statistical sense to a single application of the Kruskal-Wallis One-Way Anova Test. However, once the Kruskal-Wallis Test has found a difference, multiple applications of the U Test may yield some practical, although not statistically rigorous, insights into the nature of the data. With repeated applications of the U Test, “false positives” are likely to be identified; that is, segments may be identified as containing elevated concentrations when they actually do not. The additional conservatism this implies has been accepted for this analysis.

As with the risk calculations themselves, these statistical tests produce a great deal of numerical output because information for each scenario and each location is provided. The results of the statistical evaluation are summarized in Figures 5.36 and 5.37 for the Ranger and Native American Subsistence Resident scenarios, respectively. Summaries for the other scenarios (Figures E.10-E.18) are provided in the “Computer Code for the Statistical Analysis of Downstream/Upstream Comparisons and the Results” section of Appendix I-E.

The statistical techniques are very sensitive. They can distinguish very small differences in the shape of the output distributions. In some cases, the difference in shape may be real but not of importance if the absolute magnitude of the estimated risk is very small. This is illustrated using Figures 5.38 and 5.39. Figure 5.38 shows the distributions of estimated human risk from the radionuclide strontium-90 for the Native American Subsistence Resident Scenario in Segment 1 (the upstream segment) as compared with that for Segment 6 (the N Reactor). As in Figure 5.35 for tritium (hydrogen-3), a clear Hanford-related increase in risk is evident, resulting largely in this case from strontium-90 in sediment. Figure 5.39 shows the distributions of estimated human risk from the metal lead for the Native American Subsistence

Figure 5.36. Statistical Evaluation of the Differences between a Segment Not Affected by Hanford Site Operations and Downstream Segments Affected by Hanford Site Operations for the Ranger Scenario (Under the analytes, chromium has two entries: “chromium/car” indicates chromium treated as a carcinogenic chemical and “chromium/tox” indicates chromium treated as a non-carcinogenic toxic chemical.)

At or below reference

Reference

Above reference, insignificantly

Human risk greater than 1 in 1,000,000 or Hazard Index of 0.01

Human risk greater than 1 in 10,000 or Hazard Index of 1.0

Based on stochastic output of Ranger Scenario

Results identified using "RISKS" program, implementing Kruskal-Wallis Test (2-sided) and Mann-Whitney U Test (1-sided) (Gibbons 1971)

The statistical tests use a tail probability of 5%, yielding a 1-in-20 chance of false positives

	Segment																										
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
	Priest	B/C		KE/KW	K-	N		D		H		White	F	F		Hanf.	Hanf.	Supp.		300	1100		Yakima	Snake	Boise	Walla	McNary
Analyte	Rapids	Area		Area	Trench	Area		Area	Horn	Area		Bluffs	Area	Slough		Slough	Town.	Sys.		Area	Area	Richland	Riv.	Riv.	Casc.	Walla R.	Res.
Ammonia																											
Benzene																											
Carbon-14																											
Cesium-137																											
Chromium/Car																											
Chromium/Tox																											
Cobalt-60																											
Copper																											
Cyanide																											
Diesel																											
Europium-152																											
Europium-154																											
Iodine-129																											
Kerosene																											
Lead																											
Mercury																											
Neptunium-237																											
Nickel																											
Nitrate																											
Nitrite																											
Phosphate																											
Strontium-90																											
Sulfate																											
Technetium-99																											
Tritium																											
Uranium-234																											
Uranium-238																											
Xylene																											
Zinc																											

Figure 5.37. Statistical Evaluation of the Differences between a Segment Not Affected by Hanford Site Operations and Downstream Segments Affected by Hanford Site Operations for the Native American Subsistence Resident Scenario (Under the analytes, chromium has two entries: "chromium/car" indicates chromium treated as a carcinogenic chemical and "chromium/tox" indicates chromium treated as a non-carcinogenic toxic chemical.)

	Legend
(blank)	At or below reference
░	Reference
▓	Above reference, insignificantly
■	Human risk greater than 1 in 1,000,000 or Hazard Index of 0.01
■	Human risk greater than 1 in 10,000 or Hazard Index of 1.0

Based on stochastic output of Native American Subsistence Resident Scenario

Results identified using "RISKS" program, implementing Kruskal-Wallis Test (2-sided) and Mann-Whitney U Test (1-sided) (Gibbons 1971)

The statistical tests use a tail probability of 5%, yielding a 1-in-20 chance of false positives

	Segment																										
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
	Priest	B/C		KE/KW	K-	N		D		H		White	F	F		Hanf.	Hanf.	Supp.		300	1100		Yakima	Snake	Boise	Walla	McNary
Analyte	Rapids	Area		Area	Trench	Area		Area	Horn	Area		Bluffs	Area	Slough		Slough	Town.	Sys.		Area	Area	Richland	Riv.	Riv.	Casc.	Walla R.	Res.
Ammonia	░	▓	▓	▓	▓	▓		▓					▓						▓	▓	▓	▓	▓	▓	▓	▓	▓
Benzene	░				■								■														
Carbon-14	░			■	░	■	▓			▓																	
Cesium-137	░	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		■	■		■						
Chromium/Car	░	■		■				■											■								
Chromium/Tox	░	■		■	■			■	■	■									■								
Cobalt-60	░	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	▓	■	▓	▓	▓	▓	▓	▓
Copper	░													■									■	■	■	■	■
Cyanide	░																										
Diesel	░																										
Europium-152	░																										
Europium-154	░				▓	■		■	▓	▓	▓	▓	■	▓	▓	▓	■	■		■	■	▓	▓	▓	▓	▓	▓
Iodine-129	░				▓	▓				▓									■	▓	▓	▓	▓	▓	▓	▓	▓
Kerosene	░																										
Lead	░			■	■												■		■	■		■					
Mercury	░			▓				▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓				▓			
Neptunium-237	░																										
Nickel	░																▓	▓	▓								
Nitrate	░			■						■		■		■			■			■							
Nitrite	░																		■		▓	▓					
Phosphate	░																										
Strontium-90	░	■	■	■	■	■		■	■	■		■	■		■	■				■							■
Sulfate	░	▓			▓		■	▓	▓					▓	▓					▓							
Technetium-99	░	▓	■		▓			■	▓	■	▓	▓	▓	▓	▓	▓	■		■	▓							
Tritium	░	■		■		■		■									■		■	■							
Uranium-234	░													■			■			■							
Uranium-238	░			▓						■				▓			▓		■	■							
Xylene	░																										
Zinc	░											■							■								

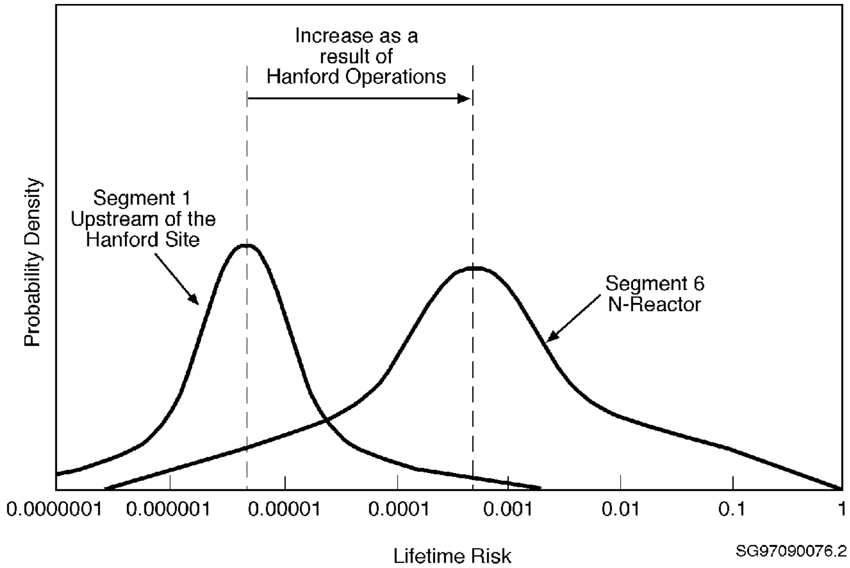


Figure 5.38. Comparison of Reference and Elevated Distribution of Estimated Lifetime Risk for the Native American Subsistence Resident Scenario for Strontium-90

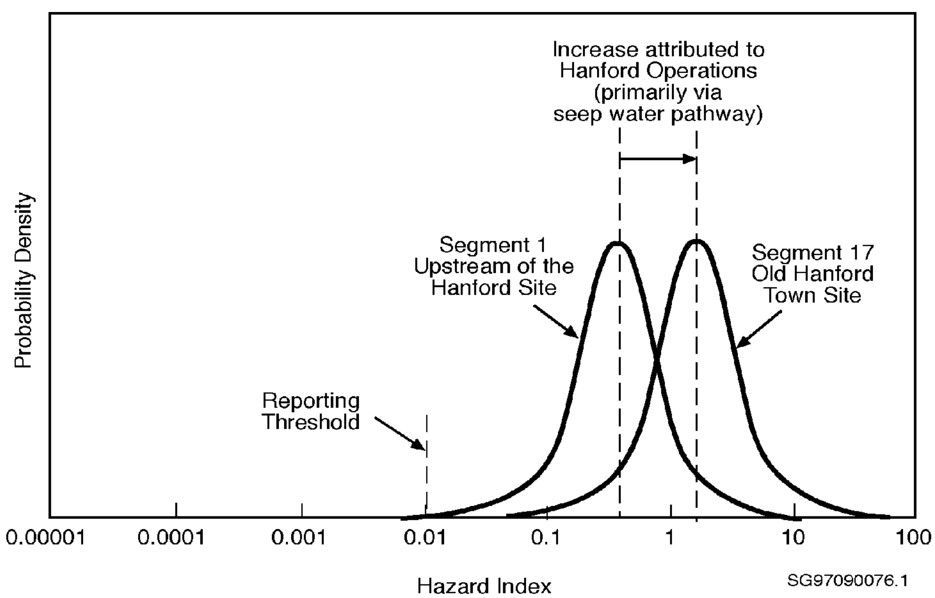


Figure 5.39. Comparison of Reference and Elevated Distribution of Estimated Hazard Index for the Native American Subsistence Resident Scenario for Lead

Resident Scenario in Segment 1 (the upstream segment) as compared with that for Segment 17 (the old Hanford townsite). This figure shows the largest downstream/upstream difference for lead and illustrates the difficulty of comparing either the deterministic or median values. The deterministic value for lead in Segment 17 is actually lower than that in Segment 1, and the medians differ by less than a factor of 4. The two distributions significantly overlap. However, this location appears to have an increase in the risk resulting from the Hanford Site, caused by increased concentrations of lead in seep water. The subtle difference between these two distributions is captured by the statistical tests.

Because the statistical tests are so sensitive, a second screen has been superimposed on the results of the statistical screening. This second screen is based on the size of the estimated risk. To differentiate Hanford-derived contaminants in the Columbia River, a set of risk thresholds has been selected. These risk thresholds are only used in the following discussion to simplify the explanation of the results of the analysis and are not intended to imply definitive levels of importance or neglect. The thresholds are set equal to other accepted regulatory levels to distinguish the differences in the estimated results.

For carcinogenic chemicals and radionuclides, the lower threshold is set at a lifetime risk of 10^{-6}. For toxic chemicals, the lower threshold is set at a hazard index of 0.01 (1 percent of the estimated toxic response level). The upper threshold is set at a lifetime risk of greater than 10^{-4} or a hazard index of 1.0. These values are represented on Figures 5.36 and 5.37 as shadings. Any results greater than the upper threshold are shaded black, and results greater than the lower threshold are shaded medium grey. A lighter grey is used to indicate the other segments in which the contaminants were identified as above reference but below the lower threshold.

The results illustrated in Figures 5.36 and 5.37 correspond well with the results described in the preceding section. The Columbia River segments identified by the statistical tests as having potential risk results that exceed those of the upstream segment are essentially the same as those identified in Section 5.2.4.1, with several additions. The two techniques complement each other because the statistical comparison cannot be used if upstream data are missing (for example, as is the case for cyanide and europium-152), and the statistical technique is more sensitive to small variations, for example, tritium (hydrogen-3). Using the observational technique described in Section 5.2.4.1 provides insight to the magnitude of the potential risk for some of the segments identified as being different (for example, nickel in Segments 18, 19, and 20 for the Ranger Scenario).

The superposition of the risk threshold levels (Section 5.2.4.2) on the results of the comparison (Section 5.2.4.1) also provides insight into the most significant potential contaminants. For instance, it indicates that chromium is the largest potential contributor to risk to individuals represented by the Ranger Scenario. It also indicates that while several contaminants of Hanford Site origin, such as europium-154 or cobalt-60, are present in elevated quantities throughout the Hanford Reach, they are of lesser risk than other such distributed contaminants as strontium-90 or nitrates.

The combination of observational and statistical techniques identifies the same contaminants in the same locations, and the results are generally quite consistent across the numerous exposure scenarios as well.

Although diesel and kerosene were not analyzed because no environmental measurements of their presence are available, benzene and xylene are reasonable surrogates for these. The contaminants identified as probably not of Hanford Site origin include copper, nickel, and zinc. Those contaminants of probable Hanford Site origin with potential risk in at least one river segment are presented in Table 5.19.

Table 5.19. Maximum Risk Levels in the Native American Subsistence Scenario for Contaminants

Lifetime Risk Levels			Hazard Indices		
>1E-6	>1E-5	>1E-4	>0.01	>0.1	>1.0
Benzene	Benzene		Chromium		
Carbon-14	Carbon-14		Lead	Lead	Lead
Cesium-137	Cesium-137		Nitrate		
Chromium	Chromium	Chromium	Nitrite		
Cobalt-60			Phosphate		
Europium-152			Sulfate		
Europium-154	Europium-154				
Iodine-129					
Neptunium-237	Neptunium-237				
Strontium-90	Strontium-90	Strontium-90			
Technetium-99					
Tritium (H-3)	Tritium (H-3)	Tritium (H-3)			
Uranium-234	Uranium-234	Uranium-234			
Uranium-238	Uranium-238	Uranium-238			

5.2.5 Evaluation of Hanford-Related Contaminants by Scenario

In this section, we describe which contaminants, media, and pathways contribute most to the potential risk for each scenario. For the contaminants of potential risk, we also indicate when a contaminant does not appear to be of Hanford origin.

This section describes the key pathways of human exposure for each of the contaminants of probable Hanford Site origin for each of the exposure scenarios. This discussion is intended to provide insight to the nature of human exposures, so that plans for possible intervention can be based on appropriate knowledge of the important contaminant mechanisms. The discussion is based on the scenario specific information in Appendix I-E and the results of Figures 5.5, 5.6, 5.36, 5.37, and E.10-E.18.

5.2.5.1 Industrial Worker, Fish Hatchery Worker, and Ranger Scenarios

The key contaminant for these three scenarios is chromium. The key pathway for the Industrial Worker and Fish Hatchery Worker scenarios is direct consumption of Columbia River water. The key pathway for the Ranger Scenario is incidental consumption of river sediment because the scenario does not assume the person drinks the water. Although copper appears to be somewhat elevated in the downstream Segments 23-27, this is entirely due to surface water measurements in Segment 23 (influenced by the influx of the Yakima River) and seems to be unrelated to releases from the Hanford Site. The Fish Hatchery Worker and Industrial Worker scenarios also exhibit a small influence of uranium-238 from consumption of surface water in Segment 19.

5.2.5.2 Avid Recreational Visitor and Casual Recreational Visitor Scenarios

Key contaminants for these two scenarios are chromium, lead, and strontium-90, and also uranium for the Avid Recreational Visitor Scenario. Cesium-137 and nitrates are also present at levels just above the lower thresholds. The appearance of zinc in Segment 12 for the Casual Recreation Visitor Scenario results from input via seep water surrogated using groundwater. No significant difference exists in the results for zinc in Segment 12 or for the results for zinc in upstream segments in the other media. Although copper appears to be somewhat elevated in the downstream Segments 23-27, this is entirely due to surface water measurements in Segment 23 (influenced by the influx of the Yakima River) and seems to be unrelated to releases from the Hanford Site.

The controlling medium for chromium is surface water. The controlling pathway is consumption of fish caught in the Columbia River. These scenarios do not include any ingestion of native plants, and because the bioaccumulation factor for chromium is around 200, the fish ingestion outweighs the direct ingestion of drinking water from the river.

The controlling medium for lead is also surface water, and the controlling pathway for lead is also consumption of fish. The controlling medium for strontium-90 for the casual recreational visitor is seep water, and the controlling pathway is direct consumption. The controlling medium for strontium-90 in the Avid Recreational Visitor Scenario is sediment. The structure of the model is such that the controlling medium becomes consumption of wild birds. The model relates concentrations of strontium-90 in biota to the concentrations in sediment. The transfer factor is large enough that uptake from consumption of resident birds is much higher than that via incidental intake of sediment directly.

For uranium for the Casual Recreational Visitor Scenario, the intake is split between consumption of surface water and seep water. For the Avid Recreational Visitor Scenario, the controlling medium is sediment for modeling reasons similar to those for strontium-90.

5.2.5.3 Native American Scenarios

The four Native American scenarios are all essentially variants on the most complete scenario, that of the Native American Subsistence Resident. The Native American Upland Hunter Scenario includes animal products but omits the vegetable products and surface water exposures, including that of fish consumption. The Native American Hunter/Fisher Scenario uses the same parameters but omits fruit, vegetables, and terrestrial animal products. The Native American Gatherer Scenario includes the vegetable products but omits birds, fish, and animal products. Because they are all similar, the pathways of exposure are similar for the various contaminants of interest with minor variations discussed below.

The key contaminants for the Native American scenarios are chromium, lead, nitrates, strontium-90, tritium (hydrogen-3), uranium-234, and uranium-238. Benzene, carbon-14, cesium-137, cobalt-60, europium-154, iodine-129, nitrites, sulfates, and technetium-99 also appear at levels somewhat above the lower thresholds.

For chromium, two media contribute sizable fractions of the total potential exposures: surface water and sediment. When surface water dominates, the key pathway is consumption of fish. When sediment dominates, the key pathway is consumption of crop plants grown in the riparian zone. Thus, for the Gatherer Scenario, the crops always control, and for the Hunter/Fisher Scenario, the fish always controls. Because the Upland Hunter Scenario is assumed to eat neither of these foods, the pathway of highest exposure for that scenario is the consumption of seep water. All of these pathways contribute to the Native American Subsistence Resident Scenario.

For lead, exposures are primarily dominated by consumption of vegetation grown in sediment (for example in Segments 4, 11, 12, and 17). Significant fractions of exposure also result from consumption of fish caught in surface water (Segments 19 and 20). Of course, fish is not a pathway for the Upland Hunter and Gatherer scenarios, and vegetation is not a pathway for the Upland Hunter and Hunter/Fisher scenarios. For the Upland Hunter, the key pathway (less in magnitude than the others) is the consumption of meat from game animals that are themselves eating food grown in the riparian sediment. As Figure 5.39 shows, although the absolute magnitude of the hazard index for lead is relatively large, it is never elevated by more than about a factor of 2 from the upstream segment.

For nitrates, the key medium and pathway for all scenarios is consumption of seep water. The key medium for strontium-90 is sediment, and the key pathway for scenarios using it is consumption of riparian vegetation. A significant secondary pathway is consumption of wild birds that feed on the riparian vegetation. For the scenarios with no consumption of vegetation (Upland Hunter and Hunter/Fisher), the consumption of the wild birds is the controlling pathway.

Tritium (hydrogen-3) is a proven Hanford Site contaminant. It is routinely monitored in surface water, groundwater, and seep water. It is highly ranked in Columbia River Segment 17 in all four of the Native American scenarios and in Segment 4 in the deterministic analyses. The medium causing this high ranking is seep water (surrogated by groundwater), and the pathway is direct ingestion of seep water.

Uranium has more varied exposure routes than the other contaminants. For the two scenarios with substantial intake of crop plants, the Subsistence Resident and Gatherer scenarios, concentrations in sediment in Segment 10 result in exposures. For the scenarios with substantial intake of fish, the Subsistence Resident and Hunter/Fisher scenarios, surface water concentrations in Segment 19 lead to large estimated exposures via fish consumption. For all scenarios, direct ingestion of seep water in Segment 20 is important.

5.2.5.4 Resident and Agricultural Resident Scenarios

These two scenarios differ only by the addition of animal products in the Agricultural Resident Scenario. The key contaminants are chromium, lead, nitrates, strontium-90, and uranium-234 and -238. Other contaminants above the lower threshold include benzene, carbon-14, cesium-137, cobalt-60, and tritium (hydrogen-3).

The controlling medium for chromium is surface water. The controlling pathway is consumption of fish caught in the river. The controlling medium for lead, unlike the recreational scenarios, is sediment. The difference between these scenarios and those of recreational activities is the addition of vegetation consumption pathways. These pathways result in the potential intake of lead via consumption of food crops grown in the riparian zone.

The controlling medium for nitrates in these scenarios is seep water, and the controlling pathway is direct consumption. Nitrates are not usually detected in sediment; and when they are, they typically act as fertilizers. Therefore, the addition of the crop consumption pathways does not change the results from the recreational scenarios.

The controlling medium for strontium-90 is sediment. The controlling pathway is ingestion of crop plants. Consumption of meat adds a fraction to the resulting exposure, but it is not as large as the intake from plants directly and it is modeled as being a secondary pathway to the plant uptake. (The animals eat the plants that are grown in the sediment.) These two scenarios do not have a component for ingestion of wild birds as modeled in the recreational scenarios. Wild birds would add to the exposure via the meat pathways and would also be related to the sediment concentrations.

For the segments where the uranium exposures are above the threshold, the controlling medium for uranium-234 and -238 is seep water, and the controlling pathway is direct consumption. There is also a component via consumption of vegetation grown in the riparian zone sediment, but it never results in exposures greater than the upper threshold.

5.2.6 Radioactive Particles

Surveys of Columbia River islands and shoreline have shown the existence of small, discrete metallic radioactive particles containing microcurie quantities of cobalt-60 (Sula 1980; Cooper and Woodruff 1993; Wade and Wending 1994) beginning in Segment 8 and continuing downstream. This section evaluates the potential risk to members of the public resulting from these particles based on the scenario developed in Section 5.1.

5.2.6.1 Particle Activity Distribution

Various researchers have found particles containing small quantities of cobalt-60 on some of the Columbia River islands and shoreline. D Island has been found to have the highest concentration of these particles. In this section, we evaluate the potential risk from these particles to members of the public. Our evaluation shows that the estimated risk for these cobalt-60 particles is low for D Island. None of the known results are near an integrated exposure of 75 microcurie-hour that would indicate initial harmful effects. The 75 microcurie-hour exposure is a reference dose level set by the National Council on Radiation Protection and Measurements (NCRP 1989).

The particles were first found by Sula in 1978, who detected 188 particles over a large portion of the Columbia River shoreline. He collected and determined the activity of 14 particles, 7 of which were collected from D Island (Sula 1980, p. 37). These particles were barely visible to the naked eye (diameter about 0.1 mm) and contained cobalt-60 activities ranging from 1.7-24 microcuries at that time. The next survey was by Cooper and Woodruff (1993), who also detected particles in the Hanford Reach. Ten of eleven were found on D Island. Two particles were recovered, with activities of 1.7 and 16 microcuries. In 1993, the upstream end of the island was extensively surveyed, and 103 particles were found and recovered, of which activities were determined for 47 (Wade and Wending 1994).

To obtain a statistical description of the likely distribution of particle activities, the activities of the particles found by Sula, Cooper, and Woodruff were decayed to 1996, and the total set analyzed. Table 5.20 lists the 1996 cobalt-60 activities of the 61 particles and shows that the activities are lognormally distributed with a mean value of about 1.9 microcuries, a median value of 1.1 microcuries, and a geometric standard deviation of about 2.4-2.6. This indicates a 95 percent probability that any additional particles found should be from 0.2 to 20 microcuries.

5.2.6.2 Areal Density of Particles

Sula (1980) performed a detailed survey to obtain information on the distribution and density of the radioactive particles on D Island. From this data, Wells (appendix to letter from J.L. Erickson, Washington State Department of Health, to L.E. Gadbois, EPA, January 3, 1995) derived a density of particles in rocky surfaces of 0.037 particles/m^3. In Sula's survey, fourteen 100-square-foot areas were selected at random along the north shore of the island, some near the water line and some 20-30 feet inland. Each plot was carefully surveyed. A total of seven particles was located in the fourteen areas, yielding a density of 0.054 particles per square meter (0.005 particles per square foot). Since all of these particles were found within the top 15 centimeters (6 inches), this provides a volume density estimate of 0.36 particles/m^3 in 1978/1979.

The survey documented by Wade and Wending (1994) on D Island may also be used to estimate the density of particles in sediment. For this survey, thirteen areas of approximately 65 meters by 65 meters (200 feet by 200 feet) were established, and transects were made every 3 meters (10 feet) in two perpendicular directions. The survey thus covered approximately 30 kilometers (nearly 20 miles). If a detector window about one-third of a meter wide (1 foot) is assumed to a depth of 15 centimeters (6 inches), then a total of 1470 m^3 (52,000 ft^3) was surveyed in which 103 particles were found. This provides a particle density estimate of 0.07 particles/m^3. It is notable in this survey that Sula's assumption the particles would be within 6-9 meters (20-30 feet) of the waterline was not confirmed. The particles were distributed across the entire island.

The particles are located in the sediment between the rocks on the island. If the rocks were spheres, the smallest volume that could be occupied by sediment would be 26 percent. Hexagonal close-packed spheres occupy 74 percent of the available volume (Rosenbaum 1970). For non-spherical rocks, the solid fraction may be even higher. Values as high as 90 percent could be conceivable. Thus, the density of particles in sediment (as opposed to in the mixture of rocks and sediment) could approach or exceed 1.0 particle/m^3 in the rocky areas.

The sandier, downstream end of the island has not received a detailed survey for discrete radioactive particles. However, Cooper and Woodruff (1993) describe a survey track consisting of two survey lines 20 meters (approximately 20 yards) apart, walked on the island in 1993. In that survey eight particles on the upstream end and three particles on the downstream end were found. This information is insufficient to defensibly conclude particle densities on the downstream end of the island. However, many measurements of the direct gamma ray exposure rates have been performed and provide sufficient information to set an upper bound on the number of particles that may exist there. Sula (1980) describes the particles as approximately 0.1 millimeter (0.04 inch) in diameter with a composition similar to the metal alloy stellite. Stellite has a density of about 8 grams/cm^3, making the particles considerably denser than the other sands in the area. This could partially explain the observed behavior of the particles, which are like gold flakes trapped in cracks and settling into low spots rather than distributing uniformly throughout the sediment or accumulating in sandy spots.

An early aerial radiological survey was performed in 1973-1974 soon after the last once-through cooled production reactor was shut down. This survey could

Table 5.20. Measured Cobalt-60 Particle Activities in 1996 (μCi)

Number	Sula 1980	Cooper and Woodruff 1993	Wade and Wendling 1994	Decay to 1996
1	16			1.71
2	14			1.50
3	1.7			0.18
4	6.6			0.71
5	23			2.46
6	21			2.25
7	9.9			1.06
8	13			1.39
9	12			1.28
10	6.5			0.70
11	2.5			0.27
12	9.7			1.04
13	1.7			0.18
14	24			2.57
15		16		9.46
16		1.7		1.00
17			2.3	1.77
18			2.3	1.77
19			4	3.08
20			1.3	1.00
21			1.2	0.92
22			22	16.91
23			2.2	1.69
24			2.4	1.85
25			0.28	0.22
26			1.7	1.31
27			1.9	1.46
28			3.4	2.61
29			4.1	3.15
30			0.13	0.10
31			0.66	0.51
32			3.9	3.00
33			2.7	2.08
34			0.45	0.35
35			1.9	1.46
36			1.7	1.31
37			1.1	0.85
38			0.52	0.40
39			0.98	0.75
40			0.99	0.76
41			1.5	1.15
42			1.5	1.15
43			1.2	0.92
44			1.5	1.15
45			1.7	1.31
46			18.6	14.30
47			3.3	2.54
48			0.58	0.45
49			1.1	0.85
50			0.59	0.45
51			2.6	2.00
52			0.67	0.52
53			2.6	2.00
54			0.96	0.74
55			0.41	0.32
56			1.5	1.15
57			4.04	3.11
58			0.8	0.62
59			0.78	0.60
60			2.36	1.81
61			0.5	0.38
			Average	1.88
			Geo.Mean	1.12
			Median	1.15
	Sula age	17	yr	
	Cooper age	4	yr	
	Wendling age	2	yr	

clearly distinguish radioactive contamination on the banks, islands, and sloughs of the Columbia River far downstream from the reactors (EG&G 1975). During the fly-overs of D Island, this survey found the highest exposure rates near the middle of the island (approximately 5.6 to 8.8 microroentgen/hour above reference) and the lower exposure rates at each end (less than 1 microroentgen/hour). The background rate was about 10 microroentgen/hour.

A repeat aerial survey in 1988 during low water in April/May found the highest radiation near the upstream end of the island. The measurements were near the limit of detection of the instrumentation, and no exposure rates are provided (EG&G 1990). During the 1978 survey, Sula et al. (1980, Appendix D) found an average exposure rate on the island of 9 microroentgen/hour, with a maximum of 125 microroentgen/hour near the vent pipes. No particular elevation in exposure rates was noted at the downstream end. Cooper and Woodruff (1993) also walked the upstream and downstream ends of the island. For the upstream end, the maximum, average, and median exposure rate was 10 microroentgen/ hour. For the downstream end, the maximum was 11, average 10.1, and median 10.0 microroentgen/ hour. In addition, the average soil concentration of cobalt-60 in sediment was determined to be 0.91 picocuries/gram on the upstream end and 0.36 picocuries/gram on the downstream end of the island (Cooper and Woodruff 1993, p. B.4 and Figure 4.19). Cooper (1995, p. 3.2) states that the normal background exposure rate in the Hanford Reach is 9.8 microroentgen/hour.

The 1993 Hanford Site annual report provides the exposure rate at the site of the single thermoluminescent dosimeter permanently located on the island near the vent pipes at 10.8 microroentgen/ hour (Bisping 1994, p. 205). Finally, a recent survey to determine gamma ray spectra performed in June of 1995 found a hint of cobalt-60 spectra on the downstream end of Island but no noticeably elevated exposure rates (personal communication between E.J. Antonio and B.A. Napier, June 1995).

A distributed source of cobalt-60 in soil to an infinite depth has a dose rate conversion factor of about 1 microroentgen/hour per microcurie/m^3 (Eckerman and Ryman 1993). In the rocky areas, the particle densities of 0.1 to 0.3 particle/m^3 of rocky soil, with average particle activities of about 1.9 microcuries, would lead to exposure rates of 0.2 to 0.7 microroentgen/hour, which would be essentially undetectable above background. If the exposure rate is assumed to have to be as high as 10 microroentgen/hour above reference to be reliably detected, then the soil would have to contain 4 particles/m^3. This is a potential increase of factors of about 10 to 50 above what is seen in the rocky areas, although only about 4 times what is found in the sediment of the rocky areas.

5.2.6.3 Effects of Particles

The possibility of inhaling a discrete radioactive particle was addressed by Durham and Soldat in the appendix of Cooper and Woodruff (1993). They found that the physical size of the particles prevented a person from inhaling one into the lungs, but that they would at worst 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 curies/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. Thus, for the same particle activity, the particles would be physically much larger than assumed by Durham. (He based his calculations on a 10-micron particle.) The typical size found by Sula (1980) is 0.1 millimeter (100 microns).

Thus, the nasal retention used by Durham (1 to 2 days) is considerably longer than what would occur with this size particle. (However, a retention of up to 2 days has been used in this analysis.)

For direct contact with the particles, no effect is seen below a limit of 75 microcurie-hours (NCRP 1989).

5.2.6.4 Results for Cobalt-60 Particles

The detailed stochastic calculations for the four pathways in each of the rocky and sandy areas are summarized in Table 5.21. From the differences between the median and 99.9 percentile values shown in Table 5.21, a wide difference is apparent between the expected and most extreme exposures that could occur. The worst-case exposures are factors of up to 100 times greater than the median exposures, indicating that the exposure distributions are generally lognormally distributed.

The pathway of highest risk is lifetime cancer risk from external exposure to cobalt-60 radiations in the sandy areas. Exposures of this magnitude are unlikely to occur (besides being at the 99.9% of the distribution) because the calculation is based on an assumed upper level of contamination that could exist without having been detected via aerial and foot surveys.

Table 5.21. Summary of Cobalt-60 Calculation Results

Exposure Pathway	Units	Median in Rocky Area	Median in Sandy Area	99.9% in Rocky Area	99.9% in Sandy Area
Skin exposure	µCi-hr	$1.2x10^{-4}$	$2.1x10^{-4}$	$9.9x10^{-3}$	$1.8x10^{-2}$
Direct external	Risk	$1.6x10^{-7}$	$3.2x10^{-6}$	$1.2x10^{-6}$	$2.4x10^{-5}$
Ingestion	Risk	$4.9x10^{-11}$	$1.8x10^{-10}$	$2.7x10^{-9}$	$9.8x10^{-9}$
Inhalation	µCi-hr	$1.6x10^{-7}$	$4.3x10^{-7}$	$2.0x10^{-5}$	$4.0x10^{-5}$

The table shows that the estimated risk for cobalt-60 particles is low for D Island, the point of highest known concentration of particles. None of the risk approaches the 75 microcurie-hour value for which the NCRP (1989) indicates initial harmful effects could occur. The risk is assumed to be lower at other downstream locations. This conclusion is supported by a recent re-survey and risk analysis of D Island by the Washington State Department of Health (Danielson and Jaquish 1996).

5.2.7 Evaluation of Hanford-Related Contaminants by Segment

The Hanford Site is very large, and many different operations occurred at various places during its history. The distribution of possible contaminants is not uniform and varies in the surface water, sediment, and groundwater. In addition, not all possible contaminants have been measured for in each location.

For readers more interested in the risk at a particular location rather than risk for a particular scenario, we discuss the estimated risk for each segment of the Columbia River in this section. Where possible, we have indicated the Hanford operations in the segment that contributed the contaminants found.

The following sections discuss the nature and extent of possible contamination in each segment of the Columbia River. The discussions relate the key contaminants identified as possibly important in each of the human exposure scenarios developed for this assessment to those identified as possibly important in each segment.

5.2.7.1 Segment 1: Priest Rapids Dam

This river segment is upstream of the Hanford Site reactors and generally upgradient for groundwater movement. For this assessment, the concentrations of contaminants measured in this segment have been considered to represent natural or reference levels. In this segment the reference risk to humans ranges from a stochastic median low for the Ranger Scenario of $1x10^{-4}$ lifetime risk and $2.2x10^{-3}$ hazard index to a median high for the Native American Subsistence Resident Scenario of $6.6x10^{-2}$ lifetime risk and 3.8 hazard index. The cancer risk values are dominated by chromium, and the hazard index is primarily driven by copper. While the upper reference risk seems large in absolute terms, the various limitations of the modeling must be kept in mind (discussed more extensively in Section 6.0). The values are best considered to be screening indicators of the various potential problems that may exist along the Columbia River today.

5.2.7.2 Segment 2: 100-B/C Area

This first river segment within the bounds of the Hanford Site initiated many of the contaminants that are associated with past Hanford operations. Distinctly identified above reference in this segment are ammonia, cesium-137, chromium, cobalt-60 (diffuse), strontium-90, sulfates, technetium-99, and tritium (hydrogen-3). The radionuclides are easily attributed to past reactor operations. Sodium dichromate was used in large amounts for decades as a water conditioner for the reactor cooling water. The ammonia and sulfates could be associated with other process chemicals (for example, sulfuric acid).

The contaminant that stands out as being significant in this segment is chromium in almost all scenarios. Chromium is present in sediment and surface water. The risk from several other contaminants falls in the range between the lower and upper reporting threshold. These include cesium-137, cobalt-60, and strontium-90 in surface water and tritium (hydrogen-3) in seep water.

In this segment the total risk to humans ranges from a stochastic median low for the Ranger Scenario of $2.7x10^{-4}$ lifetime risk and $1.2x10^{-3}$ hazard index to a median high for the Native American Subsistence Resident Scenario of 0.27 lifetime risk and 1.9 hazard index. These results are controlled by chromium and copper, respectively.

5.2.7.3 Segment 3: Between 100-B/C and K Areas

As might be expected for a river segment not adjacent to a Hanford Site operating area, fewer contaminants are identified in Segment 3. Ammonia, cesium-137, cobalt-60, strontium-90, technetium-99, and tritium (hydrogen-3) are present in concentrations above the upstream reference. The risk from several contaminants falls in the range between the lower and upper reporting threshold. These include cesium-137 and cobalt-60 in surface water (extrapolated from upstream), strontium-90 in sediment, and technetium-99 in seep water.

In this segment the total risk to humans ranges from a stochastic median low for the Ranger Scenario of $1.1x10^{-4}$ lifetime risk and $1.1x10^{-3}$ hazard index to a median high for the Native American Subsistence Resident Scenario of 0.026 lifetime risk and 2.4 hazard index. These results are controlled by chromium and copper, respectively.

5.2.7.4 Segment 4: K Reactor Area

Segment 4 represents the next Hanford Site operating area downstream. The number of contaminants identified increases, and the relative risk is also higher here than in Segment 3. The contaminants identified as present above reference levels include ammonia, carbon-14, cesium-137, chromium, cobalt-60 (diffuse), cyanide, lead, mercury, nitrates, strontium-90, tritium (hydrogen-3), and uranium-238. Chromium risk exceeds the upper threshold value. In this segment chromium is elevated in the seeps and sediment with which they are associated. The risk from several other contaminants falls in the range between the lower and upper reporting threshold. These include carbon-14, nitrates, and tritium (hydrogen-3) in seep water; cesium-137, cobalt-60, and strontium-90 in surface water (extrapolated from upstream); and lead and uranium-238 in sediment.

In this segment the total risk to humans ranges from a stochastic median low for the Ranger Scenario of $2.1x10^{-4}$ lifetime risk and $2.9x10^{-3}$ hazard index to a median high for the Native American Subsistence Resident Scenario of 0.11 lifetime risk and 4.2 hazard index. These results are controlled by chromium and copper, respectively.

5.2.7.5 Segment 5: K Reactor (Mile-Long Trench)

The region between the 100-K Area and the 100-N Area is outside the official boundaries of these operating areas, but it did contain a large crib for disposal of waste water from the 100-K reactors. Thus, contaminants identified in this segment are similar to those in Segment 4, although generally in slightly lower concentrations. Those contaminants identified as existing above upstream reference levels are ammonia, benzene, carbon-14, cesium-137, chromium, cobalt-60 (diffuse), cyanide, europium-152 and -154, iodine-129, lead, strontium-90, sulfates, and technetium-99. Those sufficiently elevated to be above the upper threshold are chromium and strontium-90. Those above the lower threshold include benzene in seep water (surrogated by groundwater), cesium-137 and cobalt-60 in surface water (extrapolated from upstream), and lead in sediment. Chromium is present in sediment and the associated seeps. Strontium-90 is present in sediment.

In this segment the total risk to humans ranges from a stochastic median low for the Ranger Scenario of $2.1x10^{-4}$ lifetime risk and $2.9x10^{-3}$ hazard index to a median high for the Native American Subsistence Resident Scenario of 0.11 lifetime risk and 4.2 hazard index. These results are controlled by chromium and copper, respectively.

5.2.7.6 Segment 6: N Area

The 100-N Area is the location of the most recently operating Hanford Site reactor, the N Reactor, which was shut down in 1987. This area contains not only environmentally dispersed contaminants but also a large concentration of recently operating facilities. This is apparent in the large component of external radiation risk estimated for scenarios in this location. The source of the majority of the radiation is the 1325-N and 1301-N Liquid Waste Disposal Facilities, and the 1304-N Emergency Dump Tank (Thatcher 1995). Each of these facilities contains substantial inventories of gamma-emitting radionuclides. As stated by the Washington State Department of Health, “free release scenarios involving access to the 100-N Area could not occur without a remediation of the highly contaminated areas” (Thatcher 1995, p. 23).

Other contaminants identified as being in the environment in the 100-N Area include ammonia, carbon-14, cesium-137, chromium, cobalt-60 (diffuse), europium-152 and -154, iodine-129, strontium-90, and tritium (hydrogen-3). The contaminants above the upper threshold, along with the direct radiation, are chromium and strontium-90. The chromium is indicated as being in surface water by the Industrial Worker, Fish Hatchery Worker, and Avid Recreational Visitor scenarios. It is not indicated as being elevated for the other scenarios. The strontium-90 exposure primarily results from sediment, although it is likely that the sediment is associated with riverside seeps. The risk from several other contaminants falls in the range between the lower and upper reporting threshold. These contaminants include carbon-14, europium-154, and tritium (hydrogen-3) in seep water; cesium-137 in surface water; and cobalt-60 in sediment.

In this segment the total risk to humans ranges from a stochastic median low for the Ranger Scenario of $4x10^{-4}$ lifetime risk and $4.7x10^{-4}$ hazard index to a median high for the Native American Subsistence Resident Scenario of 0.042 lifetime risk and 2.0 hazard index. These results are controlled by chromium and copper, respectively.

5.2.7.7 Segment 7: Upstream of D Area

This segment is also between operating areas, and the levels of the various contaminants of interest are lower than in the preceding segment. Contaminants noted to statistically be elevated above the reference level include carbon-14, cesium-137, chromium, cobalt-60 (diffuse), europium-152, sulfates, and tritium (hydrogen-3). The chromium and sulfates are sufficiently elevated to be above the upper threshold. Chromium is elevated in surface water for the Industrial Worker and Fish Hatchery Worker scenarios and in sediment for the Ranger and Native American Subsistence Resident scenarios. Sulfates are present in groundwater (substituted for seep water) and contribute to risk primarily via the direct ingestion portions of the scenarios. The risk from several other contaminants falls in the range between the lower and upper reporting threshold. These contaminants include cesium-137 in surface water (extrapolated from upstream), cobalt-60 and europium-152 in sediment, and sulfates in seep water (surrogated with groundwater).

In this segment the total risk to humans ranges from a stochastic median low for the Ranger Scenario of $1.6x10^{-4}$ lifetime risk and $1.8x10^{-3}$ hazard index to a median high for the Native American Subsistence Resident Scenario of 0.066 lifetime risk and 2.7 hazard index. These results are controlled by chromium and copper, respectively.

5.2.7.8 Segment 8: D Area

Segment 8 houses the D and DR Reactors in the 100-D Area. This area is the apparent source of the discrete radioactive particles discussed in Section 5.2.6. Based on that discussion, these particles do not present a major human health risk; and although they have been detected downstream of this location, they are not discussed further. Other contaminants identified as existing in concentrations elevated above the upstream reference are ammonia, cesium-137, chromium, cobalt-60 (diffuse), europium-152 and -154, mercury, strontium-90, sulfates, technetium-99, and tritium (hydrogen-3). Chromium is elevated sufficiently to be above the upper threshold. Chromium is present in surface water, seeps, and sediment at this location. This condition has been reported regularly (for example, Dirkes and Hanf 1996). The risk from several other contaminants falls in the range between the lower and upper reporting threshold. These contaminants include cesium-137 and cobalt-60 in surface water; europium-154, strontium-90, and tritium (hydrogen-3) in seep water; and technetium-99 in sediment.

In this segment the total risk to humans ranges from a stochastic median low for the Ranger Scenario of 6.2×10^{-5} lifetime risk and 1.6×10^{-3} hazard index to a median high for the Native American Subsistence Resident Scenario of 0.087 lifetime risk and 2.7 hazard index. These results are controlled by chromium and copper, respectively.

5.2.7.9 Segment 9: The Horn

This segment is relatively far from the upstream operating reactors and relatively distant from the direction of groundwater flow common to the remainder of the Hanford Site, but some contaminants still are statistically evident above reference levels. These contaminants include cesium-137, chromium, cobalt-60, europium-152 and -154, mercury, neptunium-237, strontium-90, sulfates, technetium-99, and tritium (hydrogen-3). Present in sufficiently high concentrations to exceed the upper reporting threshold is chromium, which is found in seeps and sediment in Segment 9. The risk from several other contaminants falls in the range between the lower and upper reporting threshold. These include cesium-137 (extrapolated from upstream), cobalt-60 (extrapolated from upstream), and strontium-90 in surface water; neptunium-237 in sediment; and tritium (hydrogen-3) in seep water.

In this segment the total risk to humans ranges from a stochastic median low for the Ranger Scenario of 1.0×10^{-4} lifetime risk and 2.1×10^{-3} hazard index to a median high for the Native American Subsistence Resident Scenario of 0.069 lifetime risk and 3.2 hazard index. These results are controlled by chromium and copper, respectively.

5.2.7.10 Segment 10: H Area

Reactor operations in the 100-H Area ceased over 30 years ago, in 1965. However, the 100-H Area was subsequently used for other waste handling operations, some of which resulted in a substantial legacy of soil and groundwater contamination in the vicinity. Contaminants potentially relating to human health risk discerned to be above reference levels in or near the Columbia River in this area include carbon-14, cesium-137, chromium, cobalt-60 (diffuse), europium-152 and -154, iodine-129, mercury, neptunium-237, nitrates, strontium-90, technetium-99, uranium-234, and uranium-238. Those resulting in risk above the upper threshold values in at least one of the scenarios are chromium, strontium-90, and uranium-238. Chromium is elevated in seep water and sediment. The primary medium for strontium-90 and uranium-238 is sediment. The risk from several other contaminants falls in the range between the lower and upper reporting threshold. These contaminants include cesium-137 and cobalt-60 in surface water (extrapolated from upstream), neptunium-237 in sediment, and nitrate and technetium-99 in sediment.

In this segment the total risk to humans ranges from a stochastic median low for the Ranger Scenario of $1.4x10^{-4}$ lifetime risk and $2.4x10^{-3}$ hazard index to a median high for the Native American Subsistence Resident Scenario of 0.061 lifetime risk and 3.7 hazard index. These results are controlled by chromium and copper, respectively.

5.2.7.11 Segment 11: Between the H Area and White Bluffs Slough

Relatively few measurements are available for this segment, and it is difficult to state which contaminants are not present in this segment. The limited information available does indicate that Hanford-related contaminants common in the other areas are also present in concentrations above reference. These contaminants include cesium-137, cobalt-60 (diffuse), europium-152 and -154, mercury, technetium-99, tritium (hydrogen-3), and uranium-234 and -238. Through agreement with the CRCIA Team, only minimal analyses were performed for this river segment.

5.2.7.12 Segment 12: White Bluffs Slough

The sloughs are backwater areas, relatively distant from the operating areas and presumed release points, where fine-grained sediment and whatever is attracted to sediment can settle. The detected Hanford-related contaminants are fewer here, and the concentrations are generally also lower. However, benzene, cesium-137, cobalt-60, europium-152 and -154, mercury, nitrates, strontium-90, technetium-99, uranium-234, and uranium-238 are identified as present in concentrations above reference. None of the estimated risk exceeds the upper reporting threshold. The risk from several contaminants falls in the range between the lower and upper reporting threshold. These contaminants include cesium-137, cobalt-60, and strontium-90 in surface water (extrapolated from upstream); strontium-90 in sediment; and uranium-234 and -238 in sediment.

In this segment the total risk to humans ranges from a stochastic median low for the Ranger Scenario of $1.1x10^{-4}$ lifetime risk and $2.9x10^{-3}$ hazard index to a median high for the Native American Subsistence Resident Scenario of 0.025 lifetime risk and 3.8 hazard index. These results are controlled by chromium and copper, respectively.

5.2.7.13 Segment 13: F Area

The reactor in the 100-F Area was also shut down in 1965. Although some biological research continued in that area for several years, almost all of the facilities have been removed and the waste sites stabilized. Concentrations of Hanford-related contaminants are relatively low. Contaminants identified as remaining above the reference levels include ammonia, benzene (an indicator of petroleum hydrocarbons), cesium-137, chromium, diffuse cobalt-60, europium-152 and -154, mercury, strontium-90, technetium-99, and xylenes (probably also indicators of petroleum). Chromium remains in sufficient concentrations to exceed the upper risk threshold. Chromium appears in measurements of surface water. The risk from several other contaminants falls in the range between the lower and upper reporting threshold. These contaminants include cesium-137 in surface water (extrapolated from upstream); strontium-90 in sediment; and cobalt-60, europium-152 and -154, benzene, and xylene in seep water. Benzene and xylene are both surrogated using groundwater measurements, strengthening their probable association.

In this segment the total risk to humans ranges from a stochastic median low for the Ranger Scenario of 8.0×10^{-5} lifetime risk and 4.9×10^{-4} hazard index to a median high for the Native American Subsistence Resident Scenario of 0.054 lifetime risk and 2.0 hazard index. These results are controlled by chromium and copper, respectively.

5.2.7.14 Segment 14: F Slough

The sloughs are backwater areas, relatively distant from the operating areas and presumed release points, where fine-grained sediment and whatever is attracted to them can settle. The detected Hanford-related contaminants are fewer here, and the concentrations are generally also lower. However, benzene, cesium-137, cobalt-60, europium-152 and -154, mercury, nitrates, strontium-90, sulfates, technetium-99, tritium (hydrogen-3), uranium-234, and uranium-238 are identified as being present in concentrations above reference levels. No contaminants are present in concentrations sufficient to exceed the upper risk threshold. The risk from several other contaminants falls in the range between the lower and upper reporting threshold. These contaminants include cesium-137 and cobalt-60 in surface water (extrapolated from upstream), and nitrates, uranium-234, and -238 in seep water. Nitrates are present in groundwater and provide a potential risk through drinking of seep water.

In this segment the total risk to humans ranges from a stochastic median low for the Ranger Scenario of 1.3×10^{-4} lifetime risk and 2.9×10^{-3} hazard index to a median high for the Native American Subsistence Resident Scenario of 0.037 lifetime risk and 4.5 hazard index. These results are controlled by chromium and copper, respectively.

5.2.7.15 Segment 15: Between the F Area and Hanford Sloughs

This river segment is downstream of all the reactor areas and behind Gable Mountain in relation to the operations in the 200 Areas. Contaminants identified as above the reference levels are cesium-137, cobalt-60, europium-152 and -154, mercury, strontium-90, sulfates, and technetium-99. None of the contaminants is present in concentrations sufficient to exceed the upper threshold. The risk from several other contaminants falls in the ranges between the lower and upper reporting threshold. These contaminants include cesium-137 and cobalt-60 in surface water (extrapolated from upstream). Strontium-90 is somewhat elevated in sediment in this segment.

In this segment the total risk to humans ranges from a stochastic median low for the Ranger Scenario of 7.6×10^{-5} lifetime risk and 1.4×10^{-3} hazard index to a median high for the Native American Subsistence Resident Scenario of 0.011 lifetime risk and 2.1 hazard index. These results are controlled by chromium and copper, respectively.

5.2.7.16 Segment 16: Hanford Slough

The sloughs are backwater areas, relatively distant from the operating areas and presumed release points, where fine-grained sediment and whatever is attracted to them can settle. The detected Hanford-related contaminants are fewer here, and the concentrations are generally also lower. However, benzene, cesium-137, cobalt-60, europium-152 and -154, mercury, strontium-90, and technetium-99 are identified as being present in concentrations above reference. None of the contaminants are present in concentrations resulting in estimated risk above the upper threshold. The risk from several other contaminants falls in the range between the lower and upper reporting threshold. These contaminants include cesium-137 and cobalt-60 in surface water extrapolated from upstream, and strontium-90 in surface water measured in this location.

In this segment the total risk to humans ranges from a stochastic median low for the Ranger Scenario of 1.1×10^{-4} lifetime risk and 2.4×10^{-3} hazard index to a median high for the Native American Subsistence Resident Scenario of 0.013 lifetime risk and 3.4 hazard index. These results are controlled by chromium and copper, respectively.

5.2.7.17 Segment 17: Old Hanford Townsite

Although no nuclear production operations occurred in this segment, it is the original site of the town of Hanford, which began as a farming community and was later taken over as temporary housing for thousands of Hanford construction workers. Groundwater contaminated with contaminants from the 200 Areas is known to discharge into the Columbia River in this region. Contaminants identified as being above reference levels in this segment are diffuse cobalt-60, europium-152 and -154, lead, mercury, nitrates, strontium-90, technetium-99, tritium (hydrogen-3), uranium-234, and uranium-238. The lead and tritium (hydrogen-3) are present in concentrations resulting in estimated risk above the upper threshold. Lead is present in sediment at this location at levels about twice as high as reference. The primary increase is in groundwater, which may be due to historical releases in this region or may be the result of natural fluctuations. Tritium (hydrogen-3) is present in groundwater and is measured in seep water in this segment. The risk from several other contaminants falls in the range between the lower and upper reporting threshold. These contaminants include europium-154 in surface water; cobalt-60, nitrates, technetium-99, and uranium-234 in seep water; and uranium-238 in sediment.

In this segment the total risk to humans ranges from a stochastic median low for the Ranger Scenario of 1.1×10^{-4} lifetime risk and 2.9×10^{-3} hazard index to a median high for the Native American Subsistence Resident Scenario of 0.012 lifetime risk and 5.4 hazard index. These results are controlled by chromium and copper, respectively.

5.2.7.18 Segment 18: Washington Public Power Supply System

A commercial nuclear electric generating station operates in this segment, withdrawing makeup water from the Columbia River and returning blowdown water from the cooling tower. Relatively few measurements are available for this segment, and it is difficult to state which contaminants are not present in this segment. The limited information available does indicate that Hanford-related contaminants common in the other areas are also present in concentrations above reference. However, the water and shoreline of the

Columbia River are not noticeably different here from other Hanford-influenced areas. Contaminants identified as being above reference include those in the other areas upstream: benzene, cesium-137, chromium, diffuse cobalt-60, europium-152, europium-154, mercury, phosphates, strontium-90, tritium (hydrogen-3), and xylene. Through agreement with the CRCIA Team, only minimal analyses were performed for this river segment.

5.2.7.19 Segment 19: Between the Supply System and 300 Area

This segment is relatively far downstream of the Hanford Site operating reactors but is still within the zone of groundwater discharge from the 200 Areas. Contaminants identified as above reference levels include ammonia, benzene, cesium-137, chromium, diffuse cobalt-60, iodine-129, lead, mercury, nitrites, technetium-99, tritium (hydrogen-3), and uranium-238. Chromium is of greatest interest from a risk perspective. Chromium contributes to risk via sediment in this segment. The risk from several other contaminants falls in the range between the lower and upper reporting threshold. These contaminants include cesium-137 (extrapolated from upstream), cobalt-60 (extrapolated from upstream), technetium-99, and uranium-238 in surface water; and iodine-129, nitrites, and tritium (hydrogen-3) in seep water. This is one of the few areas with positive measurements of either iodine-129 or nitrites in groundwater, which was used as a surrogate for seep water.

In this segment the total risk to humans ranges from a stochastic median low for the Ranger Scenario of $2.6x10^{-4}$ lifetime risk and $2.5x10^{-3}$ hazard index to a median high for the Native American Subsistence Resident Scenario of 0.11 lifetime risk and 4.3 hazard index. These results are controlled by chromium and copper, respectively.

5.2.7.20 Segment 20: 300 Area

The 300 Area was used for research and development and also for manufacturing the uranium fuel elements used in the Hanford Site plutonium production reactors. Several well-documented environmental releases of uranium have occurred in this area. Contaminants identified as above reference levels include ammonia, cesium-137, chromium, diffuse cobalt-60, europium-154, iodine-129, lead, mercury, nitrates, phosphates, strontium-90, sulfates, technetium-99, tritium (hydrogen-3), uranium-234, and uranium-238. Those of particular interest are chromium, uranium-234, and uranium-238. Chromium is present in sediment. Uranium-234 is a decay product of uranium-238. They generally occur together in nature. Both are found in elevated quantities here in seep water and associated sediment. The risk from several other contaminants falls in the range between the lower and upper reporting threshold. These contaminants include lead and strontium-90 in surface water; and europium-154, nitrates, and tritium (hydrogen-3) in seep water.

In this segment the total risk to humans ranges from a stochastic median low for the Ranger Scenario of $1.7x10^{-4}$ lifetime risk and $2.2x10^{-3}$ hazard index to a median high for the Native American Subsistence Resident Scenario of 0.073 lifetime risk and 3.9 hazard index. These results are controlled by chromium and copper, respectively.

5.2.7.21 Segment 21: 1100 Area to the Richland Pumphouse

This segment downstream of the 300 Area includes portions of the inhabited part of the City of Richland. This segment marks the southern boundaries of known groundwater plumes from Hanford Site sources. Contaminants identified here as above reference include ammonia, cesium-137, cobalt-60, cyanide, europium-154, iodine-129, nitrates, nitrites, strontium-90, technetium-99, tritium (hydrogen-3), and uranium-238. None of the contaminants is present in sufficient concentration to result in estimated risk in excess of the upper threshold. The risk from several contaminants falls in the range between the lower and upper reporting threshold. These contaminants include cesium-137, cobalt-60, and europium-154 in seep water (surrogated with groundwater); and strontium-90 in surface water.

In this segment the total risk to humans ranges from a stochastic median low for the Ranger Scenario of $1.3x10^{-4}$ lifetime risk and $2.1x10^{-3}$ hazard index to a median high for the Native American Subsistence Resident Scenario of 0.042 lifetime risk and 4.1 hazard index. These results are controlled by chromium and copper, respectively.

5.2.7.22 Segment 22: Richland Pumphouse to Columbia Point

This segment comprises most of the City of Richland and is downstream of all Hanford Site production operations and groundwater plumes. Any contaminants found here related to Hanford Site operations would have to be transported via the Columbia River itself. Contaminants identified as being above reference include ammonia, benzene, cesium-137, cobalt-60, europium-154, iodine-129, lead, nitrates, nitrites, technetium-99, tritium (hydrogen-3), uranium-238, and xylene. Only lead is present in sediment in concentrations sufficient to exceed even the calculated lower risk threshold. It is within 50 percent of the reference concentration.

In this segment the total risk to humans ranges from a stochastic median low for the Ranger Scenario of $1.4x10^{-4}$ lifetime risk and $2.2x10^{-3}$ hazard index to a median high for the Native American Subsistence Resident Scenario of 0.04 lifetime risk and 3.7 hazard index. These results are controlled by chromium and copper, respectively.

5.2.7.23 Segment 23: Yakima River Influence

This segment was established between the Yakima River and Snake River entrances to the Columbia River and thus includes most of the cities of Pasco and Kennewick. Contaminants tentatively identified here above reference levels are ammonia, cesium-137, cobalt-60, europium-154, iodine-129, nitrates, sulfates, technetium-99, tritium (hydrogen-3), and uranium-238. None of the contaminants is present in sufficient quantity to score above the risk thresholds.

In this segment the total risk to humans ranges from a stochastic median low for the Ranger Scenario of $1.1x10^{-4}$ lifetime risk and $1.5x10^{-3}$ hazard index to a median high for the Native American Subsistence Resident Scenario of 0.012 lifetime risk and 7.1 hazard index. These results are controlled by chromium and copper, respectively.

5.2.7.24 Segment 24: Snake River Influence

In this segment, the Snake River joins the Columbia River. Contaminants tentatively identified here above reference levels are ammonia, benzene, cesium-137, cobalt-60, europium-152 and -154, iodine-129, mercury, nitrates, strontium-90, sulfates, technetium-99, tritium (hydrogen-3), and uranium-238. Strontium-90 is present in sufficient quantity to score above the lower risk threshold, but the calculated result is dominated by a surface water estimate calculated with concentrations extrapolated from Segment 21.

In this segment the total risk to humans ranges from a stochastic median low for the Ranger Scenario of 2.7×10^{-5} lifetime risk and 7.7×10^{-4} hazard index to a median high for the Native American Subsistence Resident Scenario of 3.3×10^{-3} lifetime risk and 4.6 hazard index. These results are controlled by chromium and copper, respectively.

5.2.7.25 Segment 25: Boise Cascade

This segment of the Columbia River includes the oxbow lakes of the Columbia River National Wildlife Refuge and is affected by a large paper pulp plant. This segment is not noticeably different from the one above it in terms of identified contaminants. Contaminants tentatively identified here above reference levels are ammonia, cesium-137, cobalt-60, europium-154, iodine-129, nitrates, sulfates, technetium-99, tritium (hydrogen-3), and uranium-238. None of the contaminants is present in sufficient quantity to score above the risk thresholds.

In this segment the total risk to humans ranges from a stochastic median low for the Ranger Scenario of 6×10^{-5} lifetime risk and 1.3×10^{-3} hazard index to a median high for the Native American Subsistence Resident Scenario of 7.1×10^{-3} lifetime risk and 6.5 hazard index. These results are controlled by chromium and copper, respectively.

5.2.7.26 Segment 26: Walla Walla River Influence

This segment corresponds with the influx of the Walla Walla River into the Columbia River. This segment is not noticeably different from the one above it in terms of identified contaminants. Contaminants tentatively identified here above reference levels are ammonia, cesium-137, cobalt-60, europium-154, iodine-129, nitrates, strontium-90, sulfates, technetium-99, tritium (hydrogen-3), and uranium-238. Strontium-90 is present in sufficient quantity to score above the lower risk threshold, but the calculated result is dominated by a surface water estimate calculated with concentrations extrapolated from Segment 21. As in Segment 24, this indication is likely a statistical variation near the reference level.

In this segment the total risk to humans ranges from a stochastic median low for the Ranger Scenario of 5.6×10^{-5} lifetime risk and 1.4×10^{-3} hazard index to a median high for the Native American Subsistence Resident Scenario of 6.7×10^{-3} lifetime risk and 5.7 hazard index. These results are controlled by chromium and copper, respectively.

5.2.7.27 Segment 27: McNary Dam and Reservoir

This segment includes the McNary Reservoir between the influx of the Walla Walla River and McNary Dam. This segment is not noticeably different from the one above it in terms of identified contaminants. Contaminants tentatively identified here above upstream reference are ammonia, cesium-137, chromium, cobalt-60, europium-152 and -154, nitrates, strontium-90, sulfates, technetium-99, and uranium-238. Chromium appears above the upper reporting threshold in this segment, but only for the Ranger Scenario. This seems to be a statistical artifact. Strontium-90 is present in sufficient quantity to score above the lower risk threshold, but the calculated result is dominated by a surface water estimate calculated with concentrations extrapolated from Segment 21. As in Segments 24 and 26, this indication is likely a statistical variation near the reference level.

In this segment the total risk to humans ranges from a stochastic median low for the Ranger Scenario of $1.5x10^{-4}$ lifetime risk and $2.3x10^{-3}$ hazard index to a median high for the Native American Subsistence Resident Scenario of 0.016 lifetime risk and 7.8 hazard index. These results are controlled by chromium and copper, respectively.