DOE/AL/62350-147
REV. 0

BASELINE RISK ASSESSMENT OF GROUND WATER CONTAMINATION AT THE URANIUM MILL TAILINGS SITES NEAR SLICK ROCK, COLORADO

November 1994

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November 1994

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CITIZENS' SUMMARY

This baseline risk assessment of ground water contamination at the uranium mill tailings sites near Slick Rock, Colorado, evaluates potential public health and environmental impacts resulting from ground water contamination at the former North Continent (NC) and Union Carbide (UC) uranium mill processing sites. The tailings at these sites will be placed in a disposal cell at the proposed Burro Canyon, Colorado, site. The U.S. Department of Energy (DOE) anticipates the start of the first phase remedial action by the spring of 1995 under the direction of the DOE's Uranium Mill Tailings Remedial Action (UMTRA) Project. The second phase of the UMTRA Project will evaluate ground water contamination. This baseline risk assessment is the first site-specific document for these sites under the Ground Water Project. It will help determine the compliance strategy for contaminated ground water at the site. In addition, surface water and sediment are qualitatively evaluated in this report.

Potential public health impacts

Currently, there are no private or domestic wells in the contaminated ground water associated with the NC and UC sites. Because contaminated ground water is not used for private or domestic use and there is no surface expression of the ground water, no current human health risks have been identified from ground water exposure. However, it is possible that ground water in the vicinity of the Slick Rock sites could be used as a potable water source in the future (a new well could be constructed in the alluvial aquifer). Therefore, this baseline risk assessment evaluates potential future domestic use of the contaminated ground water.

The DOE has determined that the alluvial and Entrada Formation aquifers have been impacted by site-related activities from the former Slick Rock processing sites, although only the most contaminated ground water from wells in the alluvial aquifer was evaluated for this risk assessment. This is a conservative approach because the alluvial aquifer is the most impacted aquifer, and in addition to the already occurring effects of dilution and dispersion in ground water, contaminant concentrations in this unit are expected to decrease over time due to the removal of the source of contamination (i.e., tailings).

This baseline risk assessment evaluates ground water data collected from alluvial monitor wells at the two sites over the last 9 years. The data evaluation indicates the contaminants of potential concern associated with the NC site are manganese, sodium, sulfate, and the radionuclides lead-210, polonium-210, radium-226, thorium-230, and uranium. The contaminants of potential concern associated with the UC site are cadmium, chloride, iron, manganese, molybdenum, nitrate, selenium, sodium, strontium, sulfate, vanadium, and the radionuclides lead-210, polonium-210, radium-226, thorium-230, and uranium. Uranium was evaluated for its noncarcinogenic and carcinogenic effects.

The next step in the baseline risk assessment estimates how much of these contaminants people would be exposed to if a drinking well were constructed in the contaminated ground water. Because contaminant concentrations vary each time a well is sampled and because people vary in how much they weigh and drink, this baseline risk assessment used probability distributions to determine the amount of contaminants that would likely be ingested by people using a well at one of the sites. The probability distributions describe how likely it is for something to happen. For example, based on population surveys, probability distributions determine the percentage of people who drink a half-gallon of water each day and who drink only one cup of water each day. Using these water intake probabilities, estimated amounts of contaminants that could be ingested through tap water then are compared to the toxic effects these contaminant levels might cause.

The most significant noncarcinogenic health hazards from the contaminants of potential concern in the ground water at the NC site are from sulfate, sodium, and manganese. The sulfate concentrations could cause severe diarrhea leading to dehydration, particularly in infants; in adults, these concentrations could cause laxative effects. The toxic effect of high sodium intake is an increased probability of developing hypertension. Exposure to manganese could cause adverse neurological symptoms such as tremors and mental disturbances. Noncarcinogenic effects from uranium would not be anticipated at this site. The radionuclide concentrations (primarily lead-210 and uranium) at the NC site may increase the risk of cancer. The additional lifetime cancer risk from ingesting contaminated ground water would be 5 in 1000 for lead-210 and 2 in 1000 for uranium. Lifetime cancer risks from polonium-210 and radium-226 fall within the EPA-acceptable risk range of 1 additional cancer in 10,000 to 1 additional cancer in 1,000,000; the additional lifetime cancer risk for thorium-230 was less than 1 in 1,000,000.

The most significant noncarcinogenic health hazards from contaminants of potential concern in the ground water at the UC site are from nitrate, sulfate, manganese, chloride, sodium, molybdenum, selenium, and iron. The sulfate concentrations could cause severe diarrhea leading to dehydration, particularly in infants; in adults, these concentrations could cause laxative effects. As it is for sulfate, nitrate is of primary concern for infants because at these levels, sulfate interferes with the blood's ability to carry oxygen, causing a condition called methemoglobinemia. Exposure to manganese in the ground water at the UC site could cause adverse neurological symptoms such as tremors and mental disturbances. In addition, toxic effects similar to Parkinson-like effects could develop in some cases. The toxic effects caused by high sodium and chloride intake would be the increased probability of developing hypertension. Molybdenum could cause increased body by-product buildup in joints, which could lead to gout. High selenium concentrations could cause hair loss and breakage and thickening and brittle nails. Liver dysfunction could occur from high iron intake. Noncarcinogenic adverse effects from vanadium, cadmium, strontium, and uranium would not be anticipated. The radionuclide concentrations (primarily lead-210) at the UC site may increase the risk of cancer. The additional lifetime cancer risk from ingesting contaminated ground water would be 2 in 10,000 for lead-210. Lifetime cancer risks from polonium-210, radium-226, and uranium fall within the EPA-acceptable risk range of 1 additional cancer in 10,000 to 1 additional cancer in 1,000,000; the additional lifetime cancer risk for thorium-230 was less than 1 in 1,000,000.

Data suggest that ground water and/or overland surface water flow discharges into the Dolores River; however, the geochemical data evaluation indicates that the quality of the surface water or sediment is not discernably affected. Therefore, surface water and sediment were not quantitatively evaluated for human health for these two media. Nonetheless, potential ecological impacts were qualitatively evaluated using surface water and sediment data. The most current data for these two media were used because current data more accurately represent the ecological environment at the sites.

Potential environmental impacts

Qualitative evaluation of the Dolores River surface water data indicates this water would be suitable as a long-term water source for livestock. However, ground water used as a sole drinking water source (e.g., a ground water-fed pond) would not be suitable as a long-term source of drinking water for livestock due to the adverse effects associated with elevated levels of sulfate at the NC site, and with the elevated levels of nitrate, sulfate, and total dissolved solids at the UC site. Nitrate and sulfate can cause diarrhea in cattle and, at very high concentrations, chronic diarrhea and dehydration. In addition, a ground water-fed pond from the most contaminated wells at both sites would not be suitable for fish to live in, primarily because of the elevated concentrations of aluminum, chloride, and iron at the NC site and the elevated concentrations of aluminum, cadmium, chloride, iron, manganese, molybdenum, and selenium at the UC site.

Additionally, at harvestable maturity, plants that have roots in contact with soil saturated with the most contaminated ground water in the alluvial aquifer at the NC site would not be adversely affected. However, at the UC site, the concentrations of cadmium, molybdenum, and zinc in the ground water fall within or exceed the range that is toxic to mature leaf tissue.

Sediment criteria are available to evaluate three contaminants of potential concern: cadmium, copper, and zinc. Evaluation of these three contaminants indicates adverse effects to aquatic organisms is unlikely. Additionally, sediment concentrations of contaminants of potential concern were compared to U.S. Geological Survey (USGS) values of naturally occurring concentrations of elements in surficial soil in the western United States. All concentrations of the contaminants of potential concern fell within reported USGS ranges.

A long-term ground water monitoring plan has been proposed and is being implemented for the former Slick Rock processing sites. As additional water quality data are collected and interpreted, the monitoring plan will be updated annually to provide ongoing protection for public health and the environment.

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LIST OF ACRONYMS

Acronym	Definition
ACL	alternate concentration limit
BCF	bioconcentration factor
BLM	Bureau of Land Management
CDPHE	Colorado Department of Public Health and Environment
DHHS	Department of Health and Human Services
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
FWQC	Federal Water Quality Criterion
HEAST	Health Effects Assessment Summary Tables
IRIS	Integrated Risk Information System
MCL	maximum concentration limits
MSL	mean sea level
NC	North Continent
NCP	National Contingency Plan
NOAA	National Oceanic and Atmospheric Administration
RAP	remedial action plan
RDA	recommended dietary allowance
RfD	reference dose
RRM	residual radioactive materials
SQC	sediment quality criteria
TDS	total dissolved solids
UC	Union Carbide
UCL	upper confidence limit
UMTRA	Uranium Mill Tailings Remedial Action
UMTRCA	Uranium Mill Tailings Radiation Control Act
USGS	U.S. Geological Survey

1.0 INTRODUCTION

The purpose of this baseline risk assessment is to determine whether the ground water at the Slick Rock, Colorado, uranium mill tailings sites could adversely affect human health or the environment. The Slick Rock sites (the North Continent [NC] and Union Carbide [UC] sites) are 2 of 24 designated uranium mill tailings sites that are undergoing remediation in accordance with the requirements of the *Uranium Mill Tailings Radiation Control Act* (UMTRCA) (42 USC §7901 *et seq.*) under the oversight of the U.S. Department of Energy (DOE) Uranium Mill Tailings Remedial Action (UMTRA) Project.

This risk assessment is a baseline assessment in that it describes preremediation ground water conditions at the sites; however, ground water contamination is only partially characterized. This document evaluates the potential for imminent public health or environmental risk that may need attention before the sites are fully characterized. The risk assessment is based on available ground water data from the most contaminated wells at the processing sites. Major exposure pathways are identified and examined.

This risk assessment follows the basic framework outlined by the U.S. Environmental Protection Agency (EPA) (EPA, 1989a) for evaluating hazardous waste sites to assess potential human health and environmental impacts. The risk assessment process for this report consists of the following steps:

- Data collection and evaluation.
    - Combining existing data from various site investigations and related reports.
    - Selecting chemical data for use in the risk assessment.
    - Selecting contaminants of potential concern.
- Exposure assessment.
    - Characterizing exposure settings.
    - Identifying exposure pathways.
    - Quantifying exposure.
- Toxicity assessment.
    - Identifying toxicity values.
    - Evaluating noncarcinogenic effects.
    - Evaluating the carcinogenic effects of radionuclides and chemical carcinogens.
- Public health risk characterization.
    - Characterizing the potential for adverse health effects to occur by estimating cancer risks and evaluating noncancer intake probability distributions.
    - Combining risks across exposure pathways and multiple contaminants for carcinogens.

  - Characterizing uncertainties.

- Ecological risk.

  - Characterizing potential biota exposure pathways.
  - Identifying potential ecological receptors.
  - Evaluating ecological risk qualitatively.

The framework is incorporated in the methodology developed to evaluate current human health risk at UMTRA Project sites and to estimate risks from potential future use of contaminated ground water near the former processing sites. A report describing this methodology is in preparation.

This risk assessment will support decisions made for the UMTRA Ground Water Project. The DOE was authorized to conduct ground water remediation under the 1988 UMTRA Amendments Act (42 USC §7922 *et seq.*), and will determine site-specific ground water compliance strategies for each site. This baseline risk assessment is one of the first Ground Water Project site-specific documents that provides information to assist in determining the site-specific ground water compliance strategy for the Slick Rock sites.

2.0 SITE DESCRIPTION

2.1 BACKGROUND

The Slick Rock UMTRA Project sites are near the small community of Slick Rock in San Miguel County, Colorado. UMETCO, a subsidiary of the Union Carbide Corporation, currently owns both the NC and UC sites (Figure 2.1).

Both sites are on the banks of the Dolores River (Figure 2.2). The sites are surrounded by steep, juniper-covered hillsides and cliffs of the Dolores River Canyon. The tailings sites are 5500 feet (ft) (1700 meters [m]) above mean sea level (MSL), while the surrounding hillsides reach 6500 ft (2000 m) above MSL. The UC tailings site is approximately 1 mile (mi) (2 kilometers [km]) downstream from the NC tailings site.

2.1.1 North Continent site

The NC mill site was built in 1931 by the Shattuck Chemical Company. The mill was designed to extract vanadium and radium salts from locally mined ores. In 1945, the federal government acquired control of the site through the Union Mines Development Corporation with the specific purpose of supplying uranium and radium for the Manhattan Project. Union Carbide became the owner of the site in 1957.

From 1931 until 1942, vanadium was extracted from ore by a sulfuric acid leaching process. In 1942, the extraction techniques included an initial salt-roast circuit with an acid-leach process to recover vanadium, uranium, and radium concentrates (Merritt, 1971). The tailings and milling wastes were then disposed of on the alluvial floodplain below the mill.

Currently, the NC site consists of the tailings pile and windblown contaminated areas. Approximately 12 acres (ac) (4.9 hectares [ha]) are contaminated, with approximately 85,000 cubic yards (yd^3) (65,000 cubic meters [m^3]) of contaminated materials. All structures (including foundations) have been removed from the NC sites. The tailings pile has been covered with approximately 6 inches (15 centimeters [cm]) of soil and is at least partially vegetated. The site is fenced and posted (DOE, 1994a).

2.1.2 Union Carbide site

The UC mill began operation in 1957 using a uranium-vanadium upgrading technique to process ore mined from the surrounding area. The milling process at the UC site included an initial step to dry-grind the coarse-grain sandstone, separating the fines from the coarser ore. The coarse ore fraction then was combined with a recirculated sulfuric acid solution. Following this step, a sand-slime separation process obtained a second uranium product. The sand product was further acid-leached, washed, and discharged to the tailings pile. A third

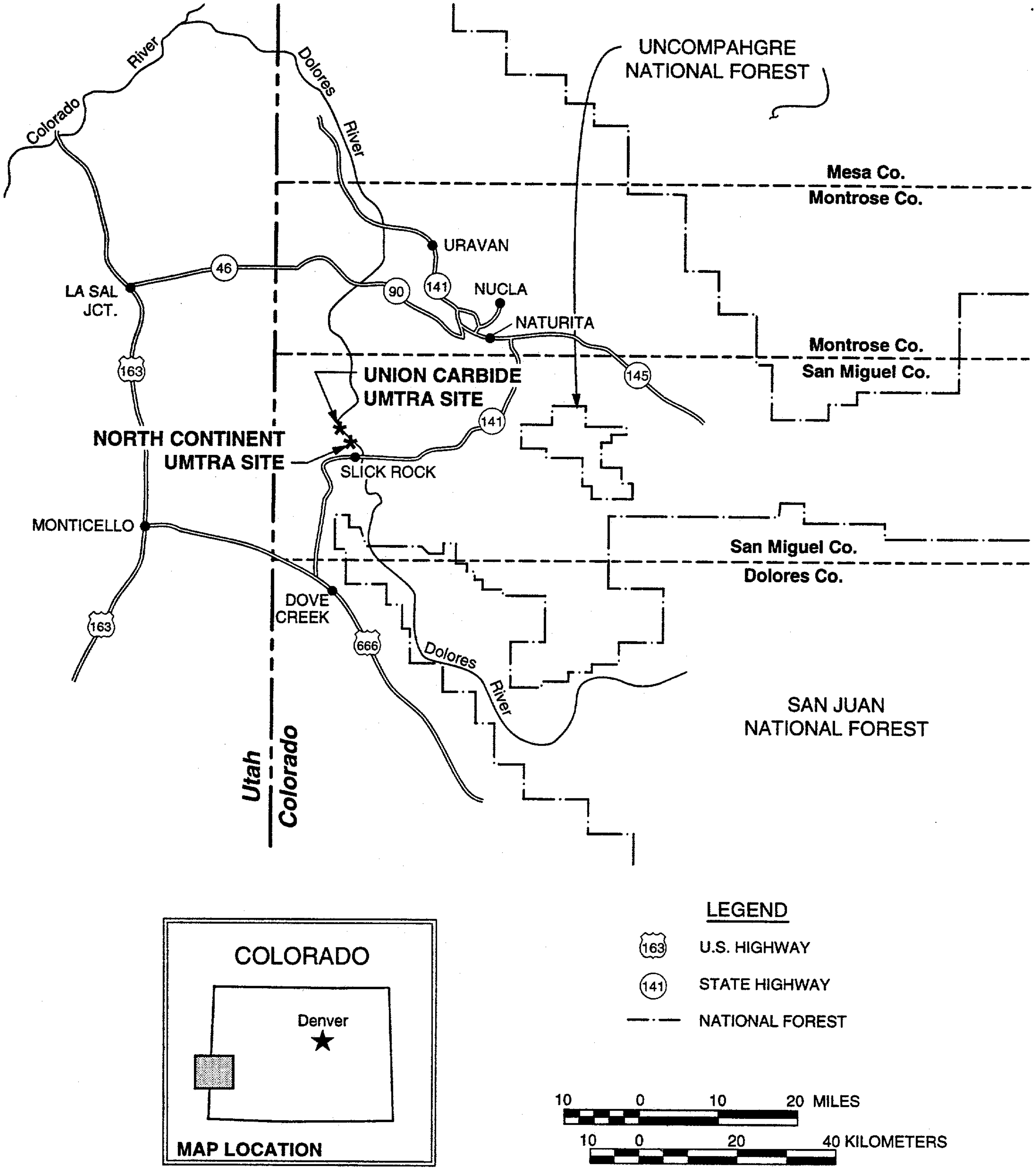


FIGURE 2.1
REGIONAL LOCATION OF THE NC AND UC UMTRA SITES NEAR SLICK ROCK, COLORADO

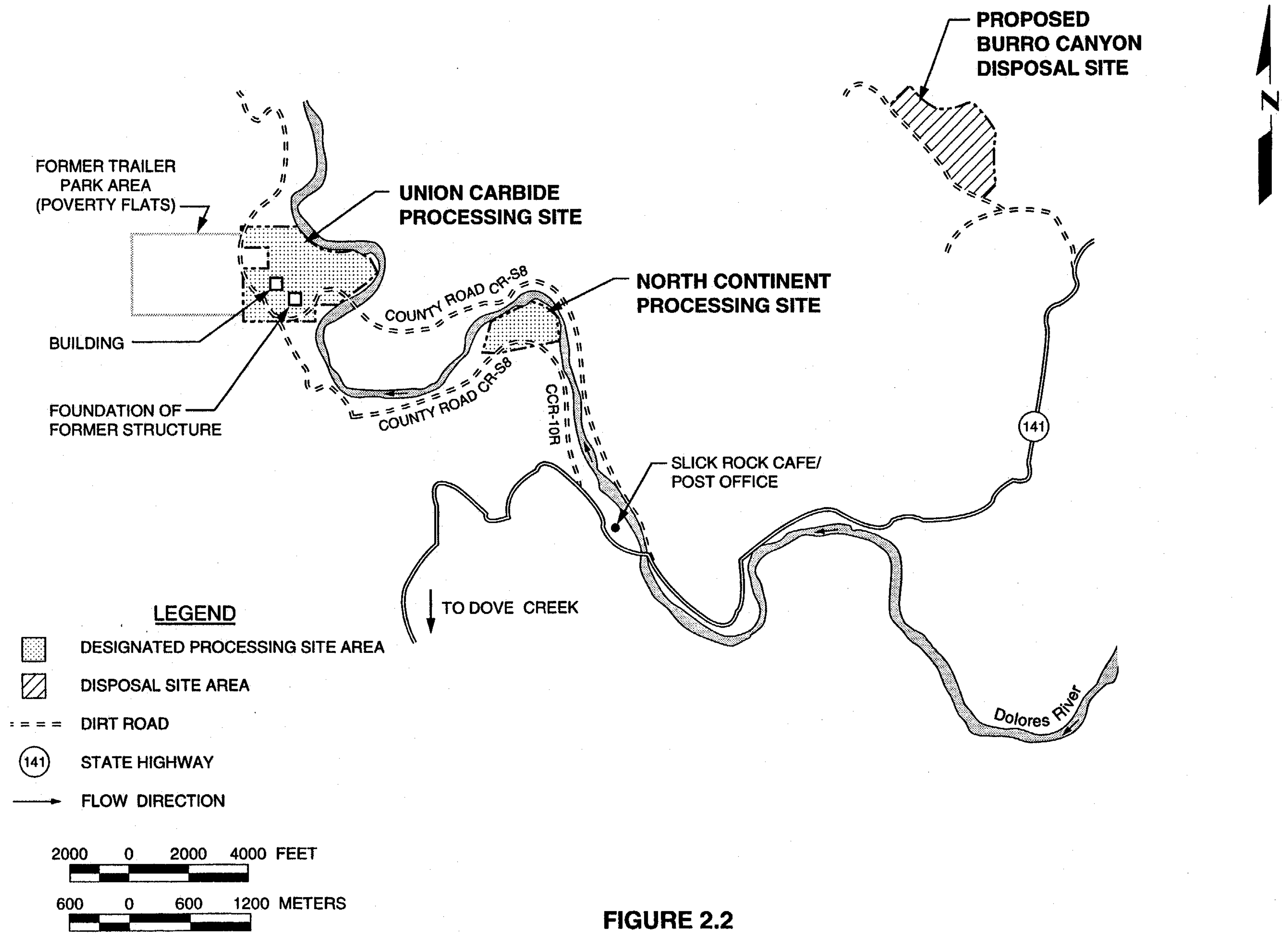


FIGURE 2.2
LOCATIONS OF PROCESSING AND DISPOSAL SITES
NEAR SLICK ROCK, COLORADO

MAC: SITE/SRK/BRA/PRO&DIS SITES

uranium product resulted from an ammonia neutralization step on part of the pregnant solution. All three products comprised the upgraded material, which was shipped to the UMETCO mill at Rifle, Colorado, for further processing. The process of separating the finer fraction for shipment off the site is the reason the tailings pile at the UC site is composed of fine-grained sand with virtually no slimes. The UC mill closed in December 1961 (Merritt, 1971).

The UC site consists of a tailings pile, mill site, mill site demolition debris, and windblown contaminated areas. The tailings pile and the surrounding contaminated land cover 55 ac (22 ha). The UC site contains approximately 536,000 yd^3 (410,000 m^3) of contaminated material. Except for some concrete foundations, the mill buildings have been removed from the site. The former recreational building and dormitory remain intact within the site boundary. Mobile homes have been removed from a trailer park area (Poverty Flats) that was upgradient of the site. The site is fenced and posted (DOE, 1994a).

2.2 CLIMATE

The Slick Rock area is arid, with a mean annual precipitation of 7 inches (18 cm). The average annual snowfall is approximately 30 inches (76 cm). High-intensity thunderstorms in the Slick Rock area have eroded the tailings piles at both the NC and UC sites. Thunderstorm activity and precipitation are greatest during August and September. The average wind speed in the Slick Rock area is estimated to be 3.4 mi (5.5 km) per hour (DOE, 1994a).

2.3 GEOLOGY

The Slick Rock sites' hydrogeologic model is based on available hydrogeologic information, site reconnaissance, and data from monitor wells installed in the alluvium, Entrada Formation, and the Navajo Sandstone (Figure 2.3). Three hydrostratigraphic units underlie the NC and UC processing sites; they are surficial deposits of Dolores River Quaternary alluvium, underlain by the Jurassic Entrada Formation (Slick Rock and Dewey Bridge Members) and the Jurassic Navajo Sandstone. Figure 2.4 provides a geologic cross sectional view of the subsurface materials.

The Jurassic Summerville Formation crops out as canyon walls of the alluvial terraces surrounding the Dolores River floodplain (Figure 2.4). The Summerville consists of eroded layers of interbedded, reddish-brown mudstones and siltstones and some fine-grained sandstone, limestone, and shale; it is not considered a hydrostratigraphic unit that directly affects, or is affected by, the NC or UC processing sites. The Dolores River meanders around these terraces. The Dolores River alluvium is composed of unconsolidated clayey sands, sandy gravels, and cobbles from the ground surface to an approximate depth of 20 ft (6 m) at both the NC and UC sites.

The Entrada Formation underlies the Dolores River alluvium and crops out in the area of both tailings piles. Two members of the Entrada Formation are present:

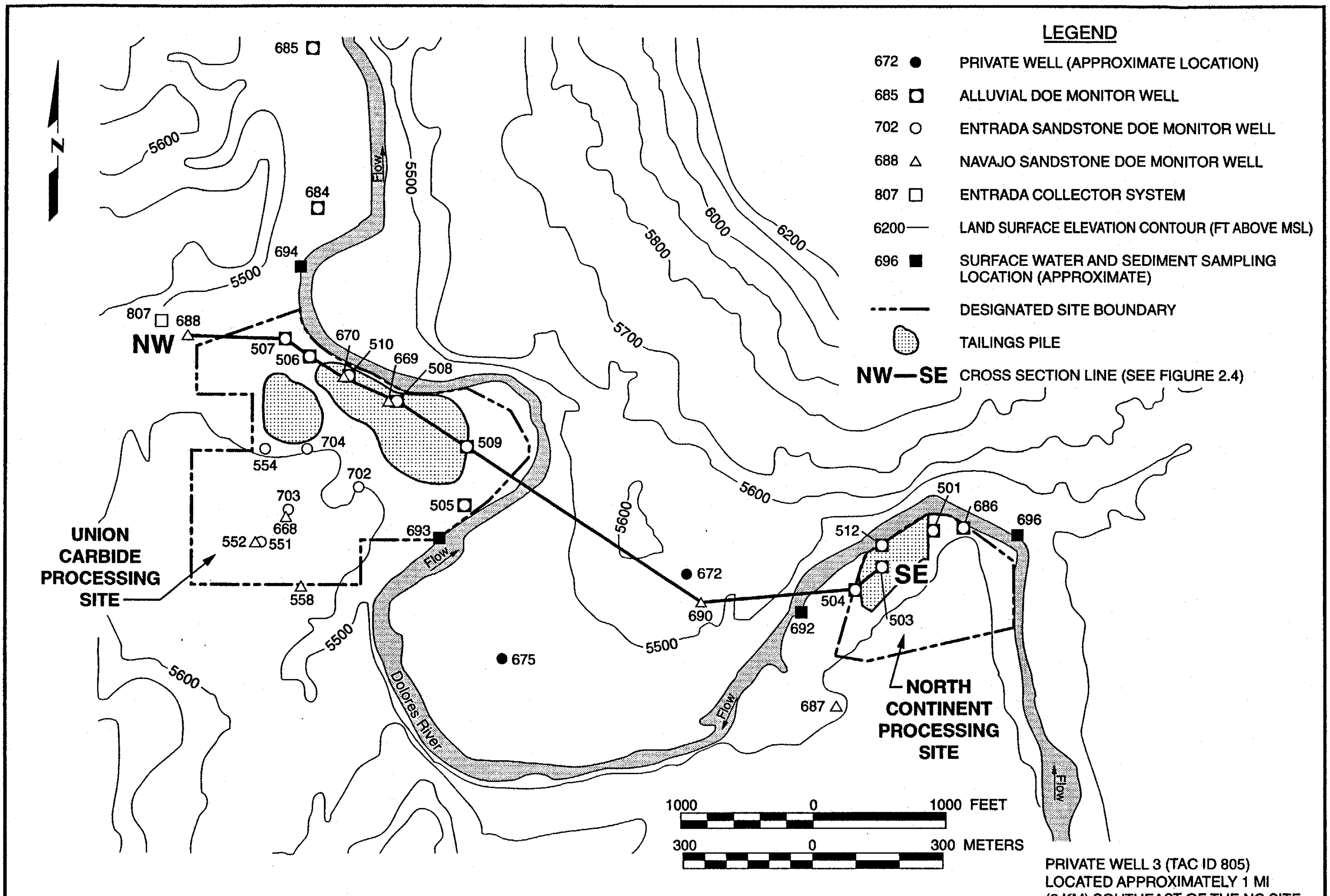
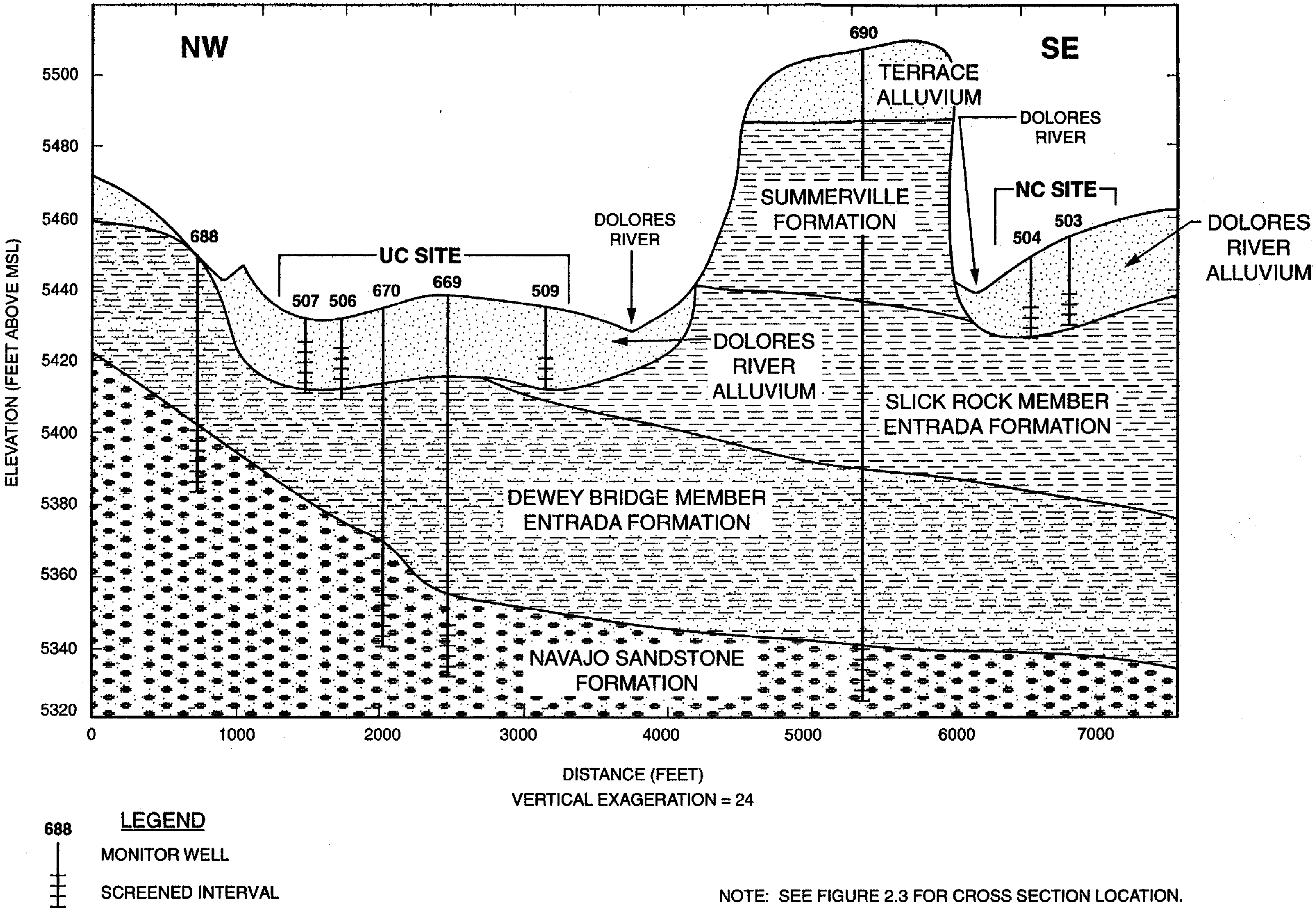


FIGURE 2.3
SAMPLING LOCATIONS FOR GROUND WATER, SURFACE WATER, AND SEDIMENT
NC AND UC SITES NEAR SLICK ROCK, COLORADO

MAC: SITE/SRK/BRA/BASE-WATQUAL



NOTE: SEE FIGURE 2.3 FOR CROSS SECTION LOCATION.

FIGURE 2.4
GEOLOGIC CROSS SECTION (NORTHWEST-SOUTHEAST)
OF THE NC AND UC SITES NEAR SLICK ROCK, COLORADO

MAC: SITE/SRK/BRA/GEOX-SEC(NW-SE)

1) the Slick Rock Member, and 2) the Dewey Bridge Member that dips toward the northeast. The Slick Rock Member underlies the Summerville Formation and alluvial deposits at the NC processing site and pinches out under the UC processing site. The Slick Rock Member is composed of eroded, light-brown, fine-grained sandstone and reddish-brown, sandy shale. The Dewey Bridge Member underlies the Slick Rock Member at the NC processing site. At the UC site, where the Slick Rock Member is absent, the Dewey Bridge Member directly underlies Dolores River alluvium; it consists of reddish-brown clayey siltstone, fine-grained sandstone, and shale. The tops of the Dewey Bridge or Slick Rock Members of the Entrada Formation were encountered beneath the alluvial deposits at depths ranging from 1 to 88 ft (0 to 27 m).

The Navajo Sandstone, composed of light-brown to reddish-brown, fine-grained sandstone, underlies the Entrada Formation at depths between 53 and 173 ft (16 and 53 m) and also crops out upslope of the UC site. Because the bottom of the Navajo Sandstone was not encountered in any DOE borings, the thickness of the Navajo Sandstone has not been determined directly in the area of the former Slick Rock processing sites. However, Shawe et al. (1968) report the Navajo Sandstone ranges from 0 to 420 ft (128 m) thick in the Slick Rock area.

2.4 HYDROLOGY

Ground water conditions at the former Slick Rock processing sites are highly dependent on local structural, stratigraphic, and topographic features. Lithologic log data and ground water levels indicate canyon cutting, tectonic fracturing, and discontinuities between the geologic formations caused by local hydraulic connection between the distinct stratigraphic units. Ground water is unconfined in the alluvium. In the Entrada Formation, ground water is expected to be semiconfined when medium- to coarse-grained sediments are interbedded with clayey siltstones and shales; confined conditions are expected when only low-permeability siltstones and shales occur. In the Navajo Sandstone, ground water is expected to be semiconfined to confined; the relative amount of hydraulic connection between the Navajo and Entrada Formations is dependent on the permeability of the Navajo Sandstone and the overlying materials of the Entrada Formation, as well as on variations in the contacts between the formations. Ground water elevations in the Dolores River alluvium, Entrada Formation, and the Navajo Sandstone have remained relatively constant and have not shown seasonal fluctuations (DOE, 1994a).

Dolores River alluvium

Depths to the water table at both former processing sites range from 5 to 20 ft (2 to 6 m) in wells screened in the alluvium. Ground water in the alluvium generally flows north (Figure 2.5). The average linear ground water velocity was estimated to be 100 ft per year (0.97×10^{-4} centimeters per second [cm/s]) at the NC site, based on an average hydraulic conductivity of 23 ft per day (8.1×10^{-3} cm/s), a hydraulic gradient of 0.003, and an effective porosity of 0.25 for sand and gravel (DOE, 1994a). At the UC site, the average linear

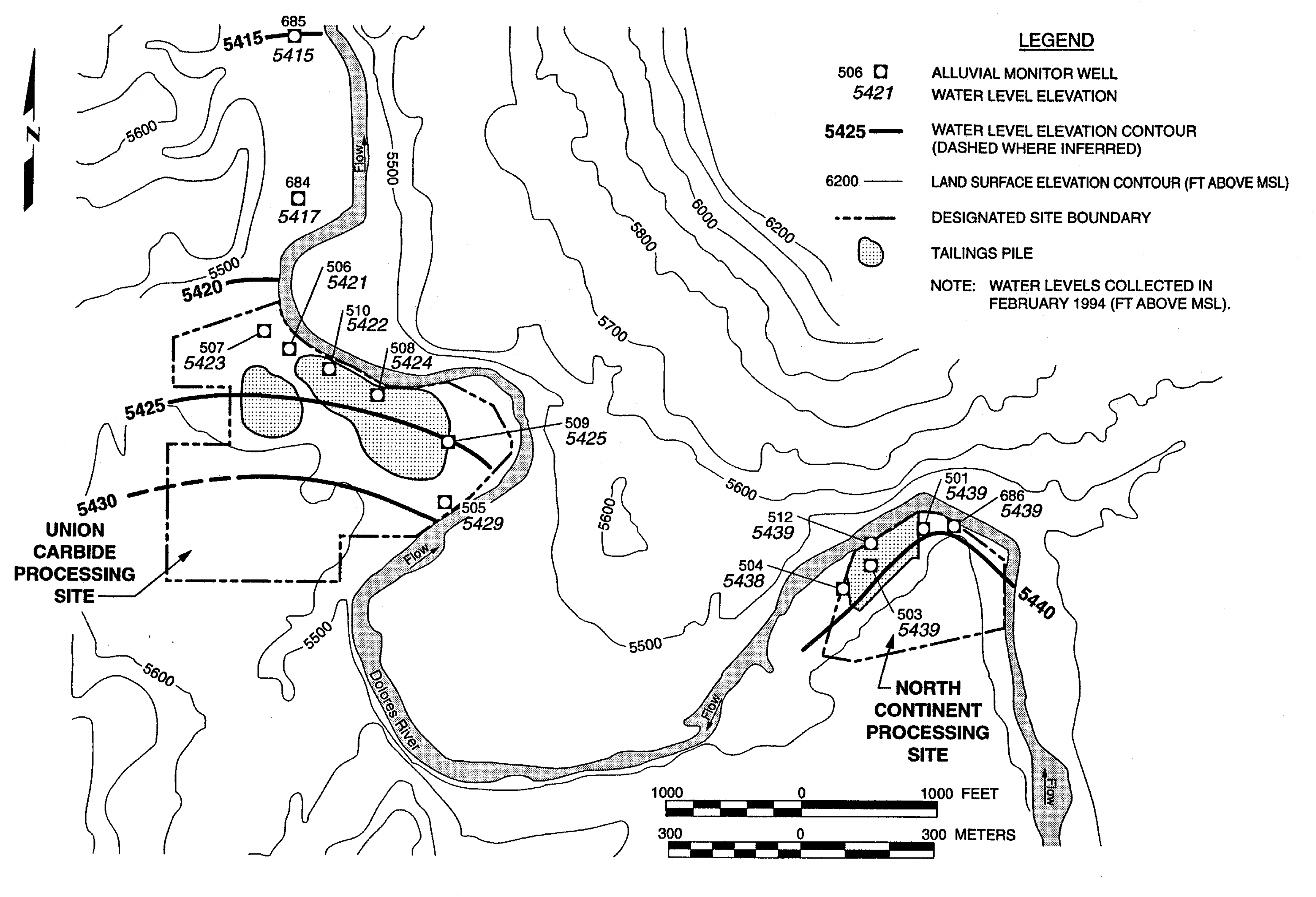


FIGURE 2.5
WATER TABLE CONTOUR MAP FOR THE DOLORES RIVER ALLUVIAL WELLS
NC AND UC SITES NEAR SLICK ROCK, COLORADO

MAC: SITE/SRK/WSAP/BASE-WATTAB(AL)

ground water velocity was estimated to be 160 ft per year (1.5 x 10^{-4} cm/s), based on an average hydraulic conductivity of 14 ft per day (4.9 x 10^{-3} cm/s), a hydraulic gradient of 0.008, and an effective porosity of 0.25. The Dolores River alluvium is recharged by the Dolores River upstream of the NC site and by precipitation. Ground water discharges from the alluvium into the Dolores River downgradient of both sites.

Entrada Formation

In monitor wells screened in the Entrada Formation at the UC processing site, the depth to ground water is approximately 27 to 47 ft (8.2 to 14 m). Because no monitor wells are screened in the Entrada Formation at the NC site, information on ground water movement in the Entrada Formation is limited. Ground water generally moves east in the Entrada Formation; however, this representation may be biased by the limited number of monitor wells placed across a relatively small areal extent of the UC site (DOE, 1994a). All the Entrada wells are screened in the Dewey Bridge Member. Based on lithologic log data from wells drilled in the southwest portion of the UC site, a layer of unconsolidated sandy gravel approximately 25 ft (8 m) thick appears to have filled a cut through the Slick Rock Member and eroded portions of the Dewey Bridge Member of the Entrada Formation. The Entrada Formation is capable of producing enough flow to provide water for livestock. This is evidenced by a gravity flow collector system tapping the Entrada on a canyon wall west (updip) of the UC site (DOE, 1994a). However, the hydraulic characteristics of the Entrada Formation have not been tested. Information on ground water movement in the Entrada Formation is limited to the UC site because no monitor wells are screened in the Entrada Formation at the NC site.

Navajo Sandstone

In NC and UC monitor wells screened in the Navajo Sandstone, depths to ground water vary from 0 to 57 ft (17 m). Ground water generally flows north at both sites; however, local variations of horizontal and vertical ground water movement are expected as a result of differences in subsurface material permeability. Adjacent to the Dolores River, static ground water elevations are approximately 10 to 15 ft (3 to 5 m) higher in the Navajo Sandstone wells (SRK-01-0669 and -0670) than in those screened in the alluvium (SRK-01-0505 to -0510). These static water levels indicate an upward vertical gradient (confined conditions) in the Navajo Sandstone near the Dolores River. The average linear horizontal ground water velocity of the Navajo Sandstone (0.58 ft per year [5.6 x 10^{-7} cm/s]) is considerably lower than that of the Dolores River alluvium. Linear ground water velocity was calculated using an average hydraulic conductivity value of 2.4 x 10^{-2} ft per day (8.5 x 10^{-6} cm/s), a hydraulic gradient of 0.02, and an estimated effective porosity of 0.30 (DOE, 1994a). The Navajo Sandstone is expected to be recharged by seepage from the overlying stratigraphic units where ground water movement is semiconfined. Ground water discharges into surrounding stratigraphic units.

2.5 LAND USE

The population of San Miguel County is approximately 3700 (DOE, 1994a). The Slick Rock area is sparsely populated; 10 people live within 1.6 mi (2.6 km) of the sites. The Slick Rock Cafe, approximately 1 mi (2 km) upgradient from the NC site on Route 141, consists of a combined cafe/post office. One ranch crossgradient of the two sites consists of a trailer, barns, and corrals. While children and horses were observed at the residence during a site visit in June 1994, observations on other site visits indicate the ranch is not continuously inhabited.

The dominant land use in the area is livestock grazing. In the past, mining was common and there are now numerous abandoned mines and mining roads in the area. Some of these roads are used for dirt biking (observed on a site visit). A gas sweetener plant is adjacent to the UC tailings pile. In addition, the Dolores River is popular for sport recreation (e.g., rafting) in this portion of the river.

2.6 GROUND WATER USE

A well survey conducted in February 1994 identified 18 current or historic private wells within a 2-mi (3-km) radius of the Slick Rock sites (Table 2.1). Fourteen of these wells are registered with the Colorado Division of Water Resources; the remaining four are nonregistered. Detailed information regarding private well locations, well permits, sampling dates, analytical results, well construction, ground water units of completion, well status, and water use is provided in the Slick Rock remedial action plan (RAP) (DOE, 1994a). Well permit information indicates the nearby private wells are screened in the alluvium, Entrada Formation, and Navajo Sandstone. The 1994 well survey and follow-up water sampling indicate that of the 18 private wells, 2 are actively used, 11 existing wells are presumed inactive, and 3 wells formerly identified as being adjacent to the site could not be located in the field. In addition, the status of two registered wells approximately 2 mi (3 km) east (upgradient) of the sites is unknown because of limited roadway access. Of the two active wells, one (SRK-01-0672) is crossgradient and on the side of the Dolores River opposite the NC and UC sites. The other well (SRK-01-0805) is upgradient of the NC site and supplies water to the Slick Rock Cafe (Figure 2.3).

Because of its location, contamination would not be expected in well SRK-01-0672. Ground water from the alluvial aquifer at the NC site would be expected to discharge into the surface water and be carried downstream (but not across) the river. Water quality monitoring conducted in February 1994 indicated the water quality in SRK-01-0672 is not impacted by the site. During the latest sampling effort in February 1994, monitor well SRK-01-0675, which could be screened in the alluvial aquifer, could not be sampled because it was covered and no longer in service (JEG, 1994). Therefore, the water quality in this well is not known. In addition, field observations indicate the trailer near well location SRK-01-0675 currently obtains ground water from monitor well SRK-01-0672. Staff from the Bureau of Land Management (BLM) and U.S. Geological Survey

Table 2.1 Domestic wells in the vicinity of the former processing sites, Slick Rock, Colorado

Private well ID No.	Permit No.	TAC ID[a]	Date sampled	Total/casing depth (ft)	Aquifer	Well status	Water use
1	25342F	672	7/86 4/91 2/94	Unknown	Unknown	Active	Domestic, stock
2	2135F	635	6/86	80/20-60	Morrison	Inactive	Industrial, domestic
3	15805F	805	4/91 2/94	200/unknown	Unknown	Active	Industrial, domestic
4	4483F	NA	NA	Unknown	Unknown	Unknown	Industrial
5	2164F	NA	NA	202/10-202	Alluvial, Entrada, Navajo	Inactive	Industrial, domestic
6	2165F	NA	NA	152/10-152	Alluvial, Entrada	Inactive	Industrial, domestic
7	2166F	NA	NA	150/10-150	Alluvial, Entrada	Inactive	Industrial, domestic
8	2163F	NA	NA	152/12-152	Alluvial, Entrada	Inactive	Industrial, domestic
9	2134F	634	6/86 10/87 2/88	125/20-125	Alluvial, Entrada, Navajo	Inactive?	Industrial, domestic
10	2133F	NA	NA	40/20-40	Entrada	Inactive	Industrial, domestic
11	2167F	NA	NA	200/5-200	Entrada, Navajo	Inactive	Industrial, domestic
12	2168F	NA	NA	106/43-106	Entrada, Navajo	Sealed?	Industrial, domestic
13	15806F	806	NA	125/unknown	Unknown	Inactive?	Industrial, domestic
14	142293	NA	NA	800/unknown	Unknown	Unknown	Unknown
15	NA	NA	NA	Unknown	Unknown	Inactive?	Unknown
16	NA	NA	NA	Unknown	Unknown	Sealed?	Unknown
17	NA	NA	NA	Unknown	Unknown	Sealed?	Unknown
18	NA	675	6/86 2/94	Unknown	Unknown	Inactive[b]	Domestic, stock
19	NA	807	NA	Unknown	Entrada	Active, collector system	Stock

[a] Location identification numbers shown in Figure 2.3.
[b] In 1986, this well was active.
NA - not available.
? - unknown.
TAC - Technical Assistance Contractor.
Source: DOE, 1994a; table has been updated for this report.

(USGS) reported in February 1994 they were unaware of any additional ground water users within 2 mi (3 km) of the former Slick Rock processing sites.

In addition, a collector system (Table 2.1) taps the Entrada Formation along a cliff face approximately 1500 ft (450 m) west (upgradient) of the UC site. This collector system appears to be in good condition and is believed to be used only for livestock.

2.7 SURFACE WATER

The Slick Rock processing sites are on the floodplain of the Dolores River. The tailings piles were deposited in mounds that sloped towards the river. Other than flooding, overland flow across the piles is limited to precipitation; surface water drainage from both sites tends to drain into the river.

3.0 EXTENT OF CONTAMINATION

The extent and magnitude of contamination at the NC and UC former processing sites are discussed below. Each site will be evaluated separately because of the different process chemistry used at each site, different contaminants detected in the soil and ground water at the two sites, and the distance between the two sites.

The hydrogeology at both sites is generally similar, consisting of a shallow alluvial system bound and hydraulically controlled by the Dolores River and the underlying bedrock. Underlying the alluvial system is the Entrada Formation and the semiconfined Navajo Sandstone.

Water quality data collected from 1986 through 1994 from 32 monitor wells has been used to define the magnitude and extent of contamination. Monitor well locations are shown in Figure 2.3. Screened intervals, location of wells with respect to the sites, years sampled and number of sampling rounds are presented in Table 3.1.

3.1 BACKGROUND WATER QUALITY

For this risk assessment, background ground water quality is defined as water quality that is not affected by uranium milling and processing activities. Therefore, ground water samples must be collected in areas that could not have been affected by site-related activities but that do have the same basic chemical characteristics. To date, site characterization studies at both the NC and UC sites have provided sufficient information to design and implement a surface remediation plan for relocating the residual radioactive materials (RRM) to the Burro Canyon disposal site (DOE, 1994b). However, for risk assessment purposes, the background water quality in the alluvial and Entrada Formation aquifers has not been characterized sufficiently to meet the requirements for defining background water quality.

At the NC site, monitor well SRK-01-0501 is screened in the alluvial aquifer. This well is upgradient from the central tailings pile within the boundaries of the site (Figure 2.3; Table 3.1). However, contaminated material has been identified in the soil above this well (DOE, 1994a) and uranium (up to 0.07 milligrams per liter [mg/L]) and sulfate (up to 500 mg/L) have been detected in ground water sampled from this well. Whether or not these levels of uranium and sulfate are present as a result of milling activities or represent background ground water chemistry has not been resolved. Therefore, SRK-01-0501 is not considered to represent background ground water quality sufficient for this baseline risk assessment.

No monitor wells are screened in the Entrada Formation at the NC site. Therefore, no background ground water quality information is available for this aquifer at the NC site.

Table 3.1 Monitor well information for the NC and UC sites near Slick Rock, Colorado

Location ID	Screen interval (ft)	Location	Years sampled	Number of rounds
NC site				
Alluvium				
501	12-21	On-site	1986-94	11
503	20-26	On-site	1986-94	12
504	14-18	On-site	1986-94	11
512	12-20	On-site	1986-94	10
Navajo Sandstone				
687	173-193	Off-site	1986-94	11
690	160-180	Off-site	1986-92	9
UC site				
Alluvium				
505	11-19	On-site	1986-94	10
506	12-19	On-site	1986-94	10
507	10-20	On-site	1986-94	10
508	12-19	On-site	1986-94	9
509	12-22	On-site	1986-94	10
510	15-24	On-site	1986-94	10
684	11-21	On-site	1986-94	10
685	15-25	On-site	1986-94	10
Entrada Formation				
551	46-56	On-site	1990-94	7
554	37.5-47.5	On-site	1990-94	7
702	55-65	On-site	1989-94	8
703	41.8-51.8	On-site	1989-94	8
704	46-56	On-site	1989-94	8
Navajo Sandstone				
552	68-78	On-site	1990-94	7
556	78-88	On-site	1990-92	6
558	68-78	On-site	1990-94	7
634	105	On-site	1986-88	4
668	111-151	Off-site	1986-94	9
669	100-105	On-site	1986-94	10
670	84-94	On-site	1986-94	11
688	53-68	Off-site	1986-94	11

Background ground water quality in the Navajo Sandstone is represented by monitor well SRK-01-0687, updip and upgradient from the NC site. Ground water quality in this well is a sodium-bicarbonate type, ranging from 520 to 890 mg/L total dissolved solids (TDS), 480 to 540 mg/L bicarbonate, 130 to 170 mg/L sodium, 24 to 28 mg/L calcium, and 43 to 64 mg/L sulfate. Trace elements are detected at or below analytical detection limits.

At the UC site, monitor well SRK-01-0505 is the farthest upgradient monitor well in the alluvial aquifer (Figure 2.3; Table 3.1). However, this well is within the identified site boundary and contaminated soil has been identified above the well (DOE, 1994a). Furthermore, concentrations of ammonium (up to 5.2 mg/L), molybdenum (up to 0.14 mg/L), sulfate (up to 600 mg/L), and uranium (up to 0.04 mg/L) have been detected in this well. Whether this represents contamination from site-related activities or background ground water chemistry has not been resolved. Therefore, this well does not meet the definition of background ground water quality in this baseline risk assessment.

All the monitor wells screened in the Entrada Formation at the UC site are on the site and are proximal to areas where milling activities occurred. Therefore, these wells do not represent background water quality in this baseline risk assessment. However, 1994 water quality data from a livestock water-collection system developed in the Entrada Formation (SRK-01-0807, off and west of the UC site [Figure 2.3]) are available. These data suggest Entrada Formation background ground water is a calcium-bicarbonate water with low TDS of approximately 110 mg/L, a pH of 8.0, and trace metal concentrations at or below analytical detection limits. However, data from this location cannot be used quantitatively as background because completion records are not available and the Entrada livestock water collection system was not installed according to DOE protocol.

Geochemically, monitor wells SRK-01-0668, SRK-01-0669, and SRK-01-0670 represent background ground water quality for the Navajo Sandstone aquifer at the UC site. Background ground water quality sampled from these wells is a calcium-bicarbonate type with pH ranging between 7.5 and 9 and trace element concentrations slightly above the analytical detection limit.

3.2 MAGNITUDE OF SITE-RELATED CONTAMINATION

Radiological surveys conducted at the NC and UC sites indicate surface soil contamination is present as a result of the milling operations. Furthermore, hydrogeochemical evidence suggests that water used during the milling process and infiltration of meteoric water through tailings and contaminated materials has impacted ground water beneath both sites. Monitor well locations are shown in Figure 2.3; well completion information is presented in Table 3.1. Ground water contamination in the multiple aquifers beneath each site is discussed below.

3.2.1 North Continent site

Milling operations at the NC site used a sodium perchlorate-sulfuric acid leach process to recover uranium, vanadium, and radium. Products of the leaching process (such as uranium, vanadium, chloride, sulfate, major cation and anions, and other trace elements related to uranium ore) have been detected in ground water beneath the site. High concentrations of uranium in tailings pore fluids sampled with a suction lysimeter indicate the milling process did not employ modern, more-efficient solvent extraction or resin-in-pulp techniques. Instead, inorganic acid-leach, neutralization and precipitation processes were used to extract uranium, vanadium, and radium at this site. This could explain the high uranium concentrations in ground water beneath the site and the lack of nitrogen compounds (nitrate or ammonium) and elevated organic carbon in ground water. Tailings pore fluid chemistry reflects this process, with up to 0.6 mg/L molybdenum, 13 mg/L selenium, 7000 mg/L sodium, 18,800 mg/L sulfate, and 10.7 mg/L uranium. Because sodium, sulfate, and uranium are directly related to the uranium milling process and typically are high in the contaminated ground water associated with this process, they were selected as indicator parameters to track and delineate the areal extent of the contamination.

Alluvial aquifer

Water quality data indicate ground water in the alluvial aquifer is affected by milling activities. Table 3.2 summarizes filtered alluvial ground water quality data for the NC site (represented by monitor well SRK-01-0503).

Monitor well SRK-01-0503 is screened directly below the tailings pile. Analytical data indicate this well represents the highest level of contamination measured in the vicinity of the NC site. Ground water from this well is moderately oxidizing (Eh is approximately +250 millivolts [mV]), suboxic with dissolved oxygen ranging from 0.1 to 0.6 mg/L, and a pH ranging from 6.9 to 7.1. Historical water quality data indicate TDS ranging from 1000 to 3400 mg/L, sodium from 480 to 650 mg/L, sulfate from 970 to 1650 mg/L, and uranium from 3 to 3.9 mg/L. Monitor well SRK-01-0504, directly downgradient from the tailings pile, generally has lower concentrations of sodium, sulfate, and uranium but elevated iron concentrations (up to 8.8 mg/L). Ground water sampled from the remaining monitor wells (SRK-01-0512 and SRK-01-0686) is typically lower in concentrations of milling-related constituents and probably is more influenced by the Dolores River. Generally, the hydrogeology and constituent distributions in ground water indicate the Dolores River recharges the upper floodplain above the NC site and flows beneath the tailings, receiving contaminants in the process. A hydrochemical transect showing select water quality data from monitor wells SRK-01-0686, SRK-01-0501, SRK-01-0503, and SRK-01-0504 (Figure 3.1) illustrates this observation.

The extent of contamination has not been defined at the NC site downgradient from the pile due to lack of monitor well coverage in this portion of the alluvial

Table 3.2 **Summary of filtered ground water quality data for the alluvium (monitor well SRK-01-0503) at the NC site, Slick Rock, Colorado**

Parameter[a]	Above detection[b]	Minimum	Median	Maximum
Inorganic[c]				
Aluminum	4/7	<0.05	0.05	0.4
Ammonium	5/9	<0.1	0.1	0.5
Antimony	1/5	<0.003	d	0.019
Arsenic	0/7	<0.005	d	<0.05
Barium	3/7	0.02	d	0.02
Beryllium	0/3	<0.05	d	<0.01
Boron	5/6	<0.10	0.345	0.4
Bromide	2/3	0.30	0.30	0.5
Cadmium	0/8	<0.001	d	<0.001
Calcium	9/9	147	213	264
Chloride	9/9	274	325	380
Chromium	1/7	<0.01	d	0.05
Cobalt	0/3	<0.03	d	<0.05
Copper	1/6	<0.01	d	0.05
Cyanide	0/2	<0.01	d	<0.01
Fluoride	7/7	0.10	0.24	0.4
Iron	9/9	1.50	2.4	3.2
Lead	0/6	<0.003	d	<0.01
Magnesium	9/9	71	100	127
Manganese	9/9	0.29	0.47	0.75
Mercury	0/5	<0.0002	d	<0.0002
Molybdenum	8/8	0.02	0.03	0.15
Nickel	1/7	<0.04	d	0.04
Nitrate	2/9	0.7	d	2.7
Phosphate	4/6	<0.1	0.1	0.2
Potassium	9/9	32	41	54
Selenium	1/8	<0.0050	d	0.015
Silica	8/8	7	14	15
Silver	0/5	<0.01	d	<0.01
Sodium	9/9	513	555	646

Table 3.2 Summary of filtered ground water quality data for the alluvium (monitor well SRK-01-0503) at the NC site, Slick Rock, Colorado (Concluded)

Parameter[a]	Above detection[b]	Minimum	Median	Maximum
Strontium	5/5	2	2.3	2.5
Sulfate	9/9	945	1380	1650
Sulfide	1/4	<0.10	d	0.3
Thallium	0/4	<0.005	d	<0.05
Tin	1/5	<0.005	d	0.018
Uranium	9/9	2.9	3.6	3.9
Vanadium	1/6	<0.01	d	0.03
Zinc	1/7	<0.005	d	0.03
Radionuclide[e]				
Lead-210	4/4	0.2	95	220
Polonium-210	4/4	0.0	0.05	0.80
Radium-226	7/7	0.3	0.6	2.4
Thorium-230	4/4	0.3	0.3	0.80

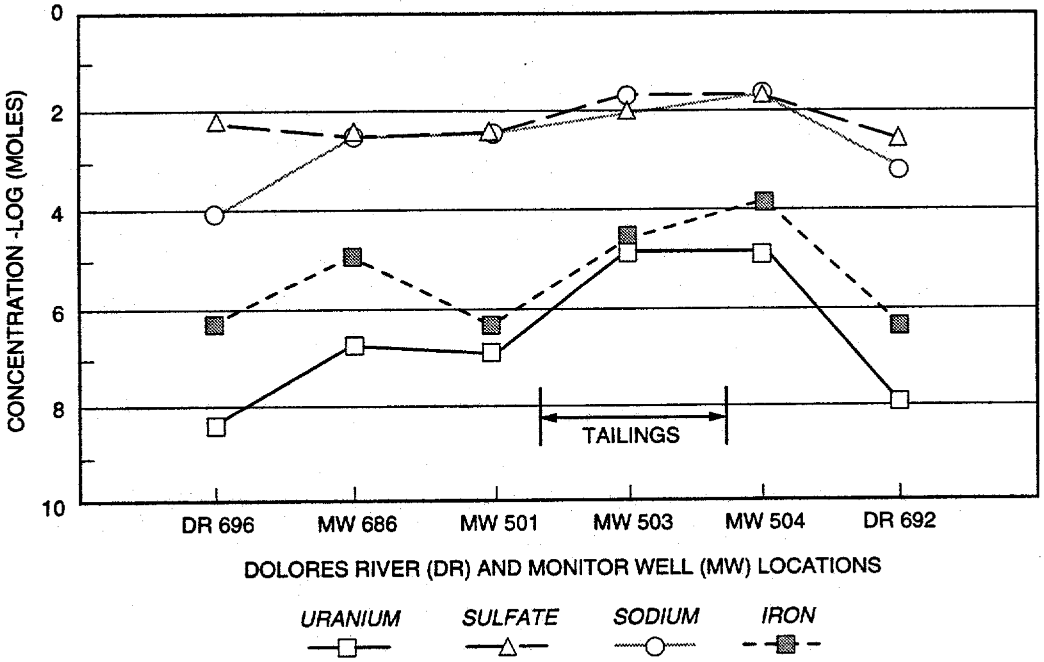
[a] Although data were available from sampling events as early as 1982, only data from 1986 through 1994 were included in this summary. Monitor well 503 was selected as the well most impacted at the NC site.

[b] Number of samples with detectable concentration/total number of samples.

[c] Concentrations are in milligrams per liter.

[d] Median is the 50th percentile of the data. The median cannot be calculated if 50 percent or more of the data are below detection.

[e] Radionuclides are in picocuries per liter. Maximum values were rounded off to two significant figures.



NOTES: 1. CONCENTRATIONS ARE IN -LOG (MOLES)
2. LARGER VALUES ON Y-AXIS INDICATE SMALLER CONCENTRATIONS.

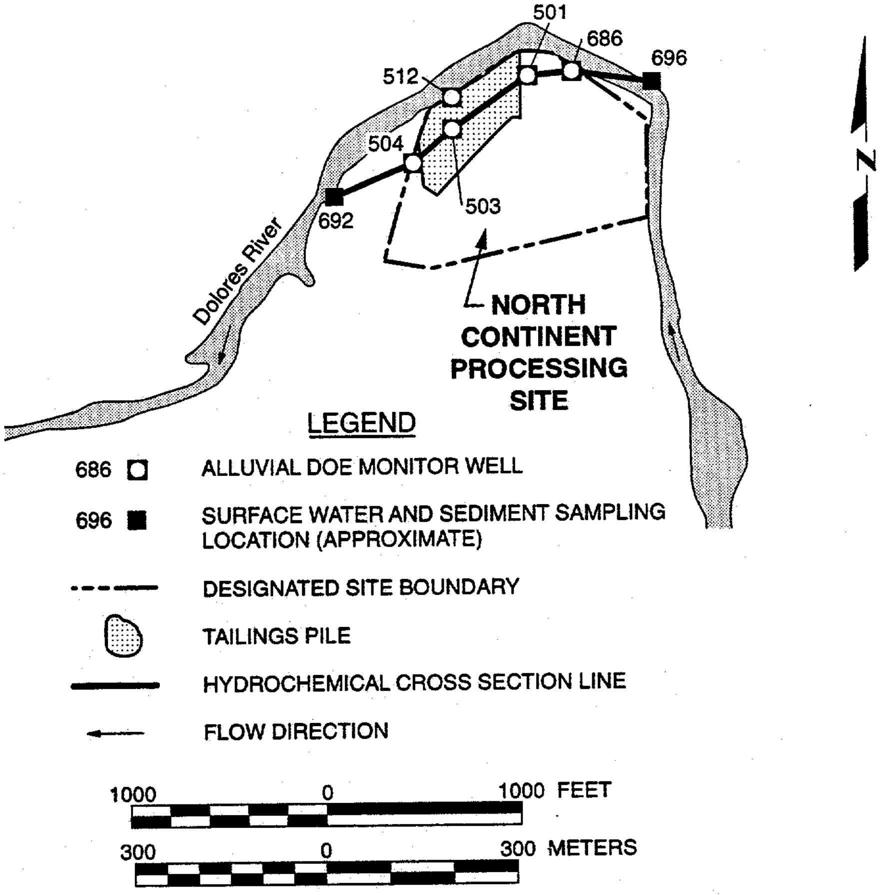


FIGURE 3.1
HYDROCHEMICAL TRANSECT ACROSS THE ALLUVIAL AQUIFER AT THE NC SITE NEAR SLICK ROCK, COLORADO

aquifer. Monitor well SRK-01-0504 is the farthest downgradient well and is clearly impacted, with up to 0.9 mg/L uranium in ground water. Water quality data from 1986 to 1994 indicate no clear decrease or increase of constituents in ground water.

Entrada and Navajo Sandstone aquifers

No monitor wells are developed in the Entrada Formation aquifer at the NC site; therefore, water quality and impact from the milling process cannot be determined.

One monitor well (SRK-01-0687) screened in the Navajo Sandstone upgradient from the processing area was sampled from 1986 to 1994 (Figure 2.3). Water chemistry data indicate milling activities have not impacted ground water at this location. No monitor wells exist in the Navajo sandstone downgradient from the tailings at the NC site. Water quality data for the Navajo Sandstone (monitor well SRK-01-0687) are presented in Table 3.3.

3.2.2 Union Carbide site

The UC site operated as an upgrading processing plant that crushed, separated, and leached ore with sulfuric acid and sodium perchlorate before shipment to a larger facility for final processing. The milling process is reflected in tailings pore fluid chemistries that show maximum concentrations of 13.5 mg/L molybdenum, 744 mg/L nitrate, 4580 mg/L sulfate, 8 mg/L selenium, and 0.8 mg/L uranium in samples collected by suction lysimeters in the tailings. These pore fluids and the milling process itself have affected both alluvial and Entrada Formation ground water.

Alluvial aquifer

The alluvial aquifer is recharged by the Dolores River upstream and discharges to the Dolores River in the downstream portion of the alluvial floodplain. Ground water chemistry is altered by tailings leachate as it flows from the Dolores River beneath the tailings and across the floodplain. Figure 3.2 presents a hydrochemical transect showing select constituents along the flow path from the Dolores River (surface location SRK-01-0693) to alluvial monitor wells (SRK-01-0505, SRK-01-0509 and SRK-01-0508) then discharging to the Dolores River (represented by water quality from surface location SRK-01-694).

Ground water in the alluvial aquifer is impacted by milling activities beneath and downgradient from the tailings. Monitor wells SRK-01-0506, SRK-01-0508, and SRK-01-0510 represent the greatest contamination in the alluvial aquifer with maximum concentrations of nitrate at 1600 mg/L (SRK-01-0508), sodium at 1580 mg/L (monitor well 506), sulfate at 3160 mg/L (SRK-01-0506), and uranium at 0.24 mg/L (monitor well 506). Monitor wells SRK-01-0508 and SRK-01-0510 are in the tailings pile approximately 200 ft (60 m) south of the Dolores River. Monitor well SRK-01-506 is downgradient from the tailings pile

Table 3.3 Summary of filtered background ground water quality data from monitor well SRK-01-0687 in the Navajo Sandstone at the NC site near Slick Rock, Colorado

Parameter[a]	Above detection[b]	Minimum	Median	Maximum
Inorganic[c]				
Aluminum	3/8	<0.05	d	0.3
Ammonium	5/9	<0.1	0.2	0.6
Antimony	0/6	<0.003	d	0.003
Arsenic	6/7	0.01	0.018	0.022
Barium	5/8	0.04	0.04	0.02
Beryllium	0/3	<0.005	d	<0.01
Boron	5/6	<0.10	1.6	1.6
Bromide	1/4	<0.10	d	0.2
Cadmium	0/8	<0.001	d	<0.001
Calcium	9/9	24	25	28
Chloride	9/9	7.4	9.4	45
Chromium	1/8	<0.01	d	0.05
Cobalt	0/3	<0.03	d	<0.05
Copper	1/7	<0.01	d	0.03
Cyanide	0/3	<0.01	d	<0.01
Fluoride	8/8	0.50	0.80	0.90
Iron	6/9	<0.03	0.03	0.07
Lead	0/7	<0.001	d	<0.02
Magnesium	9/9	18	20	21
Manganese	9/9	0.02	0.02	0.08
Mercury	0/6	<0.0002	d	<0.0002
Molybdenum[e]	2/8	0.01	d	0.02
Nickel	2/8	<0.01	d	0.06
Nitrate	4/9	<0.10	d	80
Phosphate	4/8	<0.1	d	0.2
Potassium	9/9	23	24	30
Selenium	0/8	<0.002	d	0.005
Silica	9/9	4	8.6	11
Silver	0/6	<0.01	d	<0.01
Sodium	9/9	130	140	180

Table 3.3 **Summary of filtered background ground water quality data from monitor well SRK-01-0687 in the Navajo Sandstone at the NC site near Slick Rock, Colorado (Concluded)**

Parameter[a]	Above detection[b]	Minimum	Median	Maximum
Strontium	5/5	1.05	1.1	1.2
Sulfate	9/9	33	58	64
Sulfur	3/5	<0.10	0.3	0.6
Thallium	0/4	<0.005	d	<0.01
Tin	0/5	<0.005	d	0.005
Uranium	9/9	0.001	0.002	1.3
Vanadium[e]	0/7	<0.01	d	0.2
Zinc	3/8	<0.005	d	0.24
Radionuclide[f]				
Lead-210	4/4	0.0	0.15	0.4
Polonium-210	4/4	0.0	0.05	0.1
Radium-226	8/8	0.0	0.35	0.9
Thorium-230	4/4	0.0	0.05	0.4

[a] Data from 1986 through 1994 were used in this summary.

[b] Above detection - number of samples with detectable concentration/total number of samples.

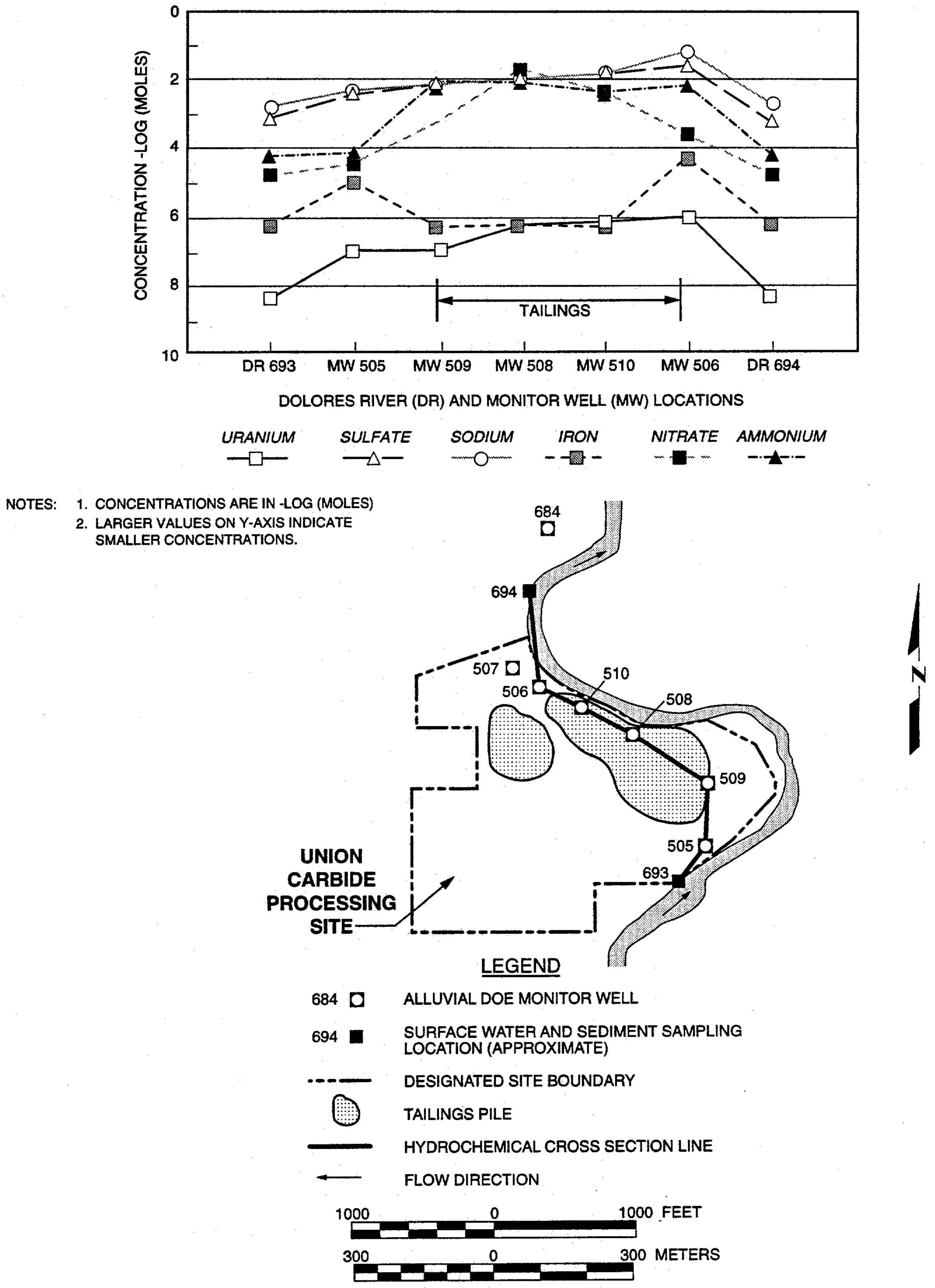
[c] Only the last three digits of monitor well identifications are presented in this table (e.g., SRK-01-0687 is presented as 687. Monitor well 687 is located downgradient of the NC site and is not considered to be impacted by site-related contamination. Concentrations are reported in milligrams per liter.

[d] Median is the 50th percentile of the data. The median cannot be calculated if 50 percent or more of the data are below detection.

[e] Data collected in June 1986 and July 1986 were not used for this parameter because of errors in analysis or reporting.

[f] Radionuclides are in picocuries per liter.

Note: If detection limits reported for nondetect samples exceeded the maximum detected concentration, the detected concentration is reported as the maximum.



NOTES:
1. CONCENTRATIONS ARE IN -LOG (MOLES)
2. LARGER VALUES ON Y-AXIS INDICATE SMALLER CONCENTRATIONS.

FIGURE 3.2
HYDROCHEMICAL TRANSECT ACROSS THE ALLUVIAL AQUIFER
AT THE UC SITE NEAR SLICK ROCK,COLORADO

approximately 300 ft (90 m) from the river (Figure 2.3). Table 3.4 summarizes the alluvial water quality at the UC site (represented by monitor wells SRK-01-0506, SRK-01-0508, and SRK-01-0510). Ground water in this region of the aquifer is suboxic (dissolved oxygen between 0 and 0.6 mg/L), with moderately oxidizing redox conditions (calculated Eh ranges from approximately +250 to +400 mV) and pH values range from 6.1 to 6.8. The oxidation-reduction potential of ground water most likely is controlled by the ammonium/nitrate (NH_4^+/NO_3^-) couple when concentrations of these constituents are high and the iron ferrous/ferric (Fe^{2+}/Fe^{3+}) couple when iron concentrations are high. When iron and nitrogen species are present in ground water simultaneously, as in monitor well SRK-01-0506, calculated Eh varies between +300 mV (Fe-couple) to +400 mV (nitrogen species couple). The behavior of nitrogen and iron is discussed below.

Entrada Formation

Water quality data indicate ground water in the Entrada Formation is impacted on the site beneath the mill location. Table 3.5 summarizes water quality from the Entrada Formation (represented by SRK-01-0702 and -0703). Monitor wells screened in the Entrada Formation are shown in Figure 2.3. Ground water in the vicinity of monitor well SRK-01-0702, in the former mill area, has relatively high levels of nitrate (up to 126 mg/L), sulfate (up to 436 mg/L), and uranium (up to 0.047 mg/L). Although concentrations of uranium, nitrate, and trace elements are not high in monitor well SRK-01-0554 (below or slightly above the analytical detection limits) the high concentrations of chloride (up to 1330 mg/L), bicarbonate (up to 760 mg/L), and sodium (up to 300 mg/L) suggest this region of the aquifer may be contaminated. The remaining Entrada Formation monitor wells (SRK-01-0551, SRK-01-0703, and SRK-01-0704) have relatively low-range contaminant concentrations: 0.001 to 0.02 mg/L uranium, 8 to 540 mg/L sulfate, and 1 to 12 mg/L nitrate. These concentration levels indicate limited impact from the milling process that cannot be ascertained with the available water quality data. However, all monitor wells screened in the Entrada Formation are in an on-site area that is contaminated on the surface. Therefore, ground water from these wells could be impacted by milling or milling-related activities at the UC site.

Navajo Sandstone

A review of the ground water quality data from on-site monitor wells SRK-01-0668, SRK-01-0669, and SRK-01-0670 indicate that ground water in the Navajo Sandstone is not impacted by the milling process. Background ground water quality conditions in these wells are similar to those in off-site Navajo Sandstone well SRK-01-0687. However, monitor well SRK-01-0552 has nitrate concentrations of 30 mg/L, selenium of 0.07 mg/L, and uranium of 0.031 mg/L. Ground water from this well does not adequately represent Navajo Sandstone ground water because it is screened at the top of the Navajo Sandstone and the filter pack extends 15 ft (5 m) in the overlying Entrada Formation. Therefore, ground water sampled from this well may be influenced by Entrada Formation

Table 3.4 **Summary of filtered ground water quality data (monitor wells SRK-01-0506, SRK-01-0508, and SRK-01-0510) for the alluvium at the UC site, Slick Rock, Colorado**

Parameter[a]	Above detection[b]	Minimum	Median	Maximum
Inorganic				
Aluminum[c]	6/18	<0.05	d	0.4
Ammonium[c]	23/23	14	139	190
Antimony[c]	1/10	<0.003	d	0.013
Arsenic[c]	0/18	0.005	d	<0.10
Barium[c]	9/16	0.02	0.02	0.10
Beryllium[c]	0/6	<0.005	d	<0.01
Boron[c]	12/13	<0.10	0.46	0.5
Bromide[c]	2/9	<0.10	d	5.7
Cadmium[e]	4/6	<0.002	0.018	0.027
Calcium[c]	24/24	383	520	758
Chloride[f]	8/8	430	1125	3980
Chromium[c]	3/16	<0.01	d	0.05
Cobalt[c]	0/6	<0.03	d	<0.05
Copper[c]	2/13	<0.01	d	0.06
Cyanide[c]	0/6	<0.01	d	<0.01
Fluoride[c]	17/17	0.19	0.34	0.50
Iron[f]	8/8	2.4	9.3	14
Lead[c]	0/13	<0.005	d	<0.05
Magnesium[c]	24/24	172	250	580
Manganese[g]	8/8	4.7	6.6	7.5
Mercury[c]	0/10	<0.0002	d	<0.0002
Molybdenum[e]	7/7	1.1	1.4	2.2
Nickel[c]	4/16	<0.04	d	0.11
Nitrate[e]	7/7	290	1200	1600
Phosphate[c]	7/14	<0.01	0.05	0.10
Potassium[c]	24/24	11	18	40
Selenium[e]	8/8	0.012	0.99	1.2
Silica[c]	20/20	7	16	22
Silver[c]	0/10	<0.01	d	<0.01
Sodium[f]	8/8	479	899	1580

Table 3.4 Summary of filtered ground water quality data (monitor wells SRK-01-0506, SRK-01-0508, and SRK-01-0510) for the alluvium at the UC site, Slick Rock, Colorado (Concluded)

Parameter[a]	Above detection[b]	Minimum	Median	Maximum
Strontium[f]	5/5	5.3	7.6	8.6
Sulfate[f]	8/8	2080	2625	3160
Sulfide[c]	3/12	<0.10	d	0.5
Thallium[c]	0/9	<0.005	d	<0.01
Tin[c]	0/10	<0.005	d	0.05
Uranium[f]	8/8	0.013	0.038	0.24
Vanadium[e]	5/5	0.44	0.59	0.66
Zinc[c]	7/16	<0.005	d	0.06
Radionuclide				
Lead-210[c]	10/10	0.0	2.8	6.5
Polonium-210[c]	10/10	0.0	0.10	0.40
Radium-226[c]	20/20	0.0	0.6	3.3
Thorium-230[c]	10/10	0.10	0.35	0.80

[a] Data were available from sampling events as early as 1982. Only data from 1986 through 1994 were used in this summary. Water quality data from monitor wells 506, 508, and 510 are summarized here.

[b] Number of samples with detectable concentration/total number of samples.

[c] Data from monitor wells 506, 508, and 510 were combined for the statistical summary for this parameter.

[d] Median is the 50th percentile of the data. The median cannot be calculated if 50 percent or more of the data are below detection.

[e] Data from monitor well 508 were used for the statistical summary for this parameter.

[f] Data from monitor well 506 were used for the statistical summary for this parameter.

[g] Data from monitor well 510 were used for the statistical summary for this parameter.

Notes: 1. Inorganic parameter concentrations are reported in milligrams per liter.
2. Radionuclides are reported in picocuries per liter.

Table 3.5 **Summary of filtered ground water quality data (monitor wells SRK-01-0702 and SRK-01-0703) for the Entrada Formation at the UC site near Slick Rock, Colorado**

Parameter[a]	Above detection[b]	Minimum	Median	Maximum
Inorganic				
Aluminum				
703[c]	0/5	<0.05	d	<0.10
702[e]	0/5	<0.05	d	<0.10
Ammonium				
703	2/6	0.05	d	0.10
702	3/6	0.04	d	0.20
Antimony				
703	0/5	<0.001	d	<0.003
702	1/5	<0.002	d	0.004
Arsenic				
703	0/5	<0.001	d	<0.01
702	1/5	0.001	d	0.001
Barium				
703	6/6	0.12	0.18	0.31
702	4/6	0.05	0.05	0.38
Beryllium				
703	0/4	<0.005	d	<0.01
702	0/4	<0.005	d	<0.01
Boron				
703	4/4	0.07	0.14	0.30
702	0/4	<0.05	d	<0.10
Bromide				
703	0/4	<0.10	d	<0.10
702	2/4	0.10	d	0.90
Cadmium				
703	0/6	<0.0001	d	<0.005
702	1/6	0.0002	d	0.0002
Calcium				
703	6/6	19	22	26
702	6/6	41	63	72
Chloride				
703	6/6	4	4.3	4.8
702	6/6	44	71	340
Chromium				
703	0/6	<0.01	d	<0.01
702	0/6	<0.01	d	<0.01

Table 3.5 **Summary of filtered ground water quality data (monitor wells SRK-01-0702 and SRK-01-0703) for the Entrada Formation at the UC site near Slick Rock, Colorado (Continued)**

Parameter[a]	Above detection[b]	Minimum	Median	Maximum
Cobalt				
703	0/4	<0.02	d	<0.05
702	0/4	<0.02	d	<0.05
Copper				
703	0/5	<0.01	d	<0.02
702	0/5	<0.01	d	<0.02
Cyanide				
703	0/4	<0.002	d	<0.01
702	1/4	0.007	d	0.007
Fluoride				
703	5/5	0.30	0.40	0.60
702	5/5	0.20	0.20	0.30
Iron				
703	0/6	<0.02	d	<0.03
702	2/6	<0.02	d	0.11
Lead				
703	1/5	0.003	d	0.003
702	0/5	<0.001	d	<0.02
Magnesium				
703	6/6	18	22	26
702	6/6	65	96	108
Manganese				
703	2/6	<0.01	d	0.03
702	3/6	<0.01	d	0.05
Mercury				
703	0/4	<0.0002	d	<0.0002
702	0/4	<0.0002	d	<0.0002
Molybdenum				
703	2/6	0.002	d	0.03
702	2/6	<0.01	d	0.04
Nickel				
703	0/5	<0.02	d	<0.04
702	0/5	<0.02	d	<0.04
Nitrate				
703	5/6	<1.0	6	9
702	6/6	46	91	130
Phosphate				
703	4/6	<0.10	0.10	0.50
702	4/6	<0.10	0.05	1.2

Table 3.5 **Summary of filtered ground water quality data (monitor wells SRK-01-0702 and SRK-01-0703) for the Entrada Formation at the UC site near Slick Rock, Colorado (Continued)**

Parameter[a]	Above detection[b]	Minimum	Median	Maximum
Potassium				
703	6/6	3.8	5.9	7.8
702	6/6	2.3	3.6	11
Selenium				
703	0/6	<0.001	d	<0.005
702	5/6	0.007	0.025	0.042
Silica				
703	6/6	9.6	11	13
702	6/6	8.1	10	11
Silver				
703	0/4	<0.01	d	<0.01
702	0/4	<0.01	d	<0.01
Sodium				
703	6/6	2	3.3	5.5
702	6/6	10	36	280
Strontium				
703	5/5	0.33	0.47	0.6
702	5/5	0.45	0.69	0.9
Sulfate				
703	5/6	4	5.6	8
702	6/6	141	314	436
Sulfur				
703	3/4	<0.10	0.15	0.3
702	3/4	<0.10	0.15	0.3
Thallium				
703	0/5	<0.001	d	<0.01
702	0/5	<0.001	d	<0.01
Tin				
703	1/5	0.001	d	0.001
702	0/5	<0.001	d	<0.05
Uranium				
703	6/6	0.002	0.004	0.007
702	6/6	0.004	0.024	0.047
Vanadium				
703	1/6	<0.01	d	0.02
702	2/6	<0.01	d	0.03
Zinc				
703	0/6	<0.005	d	<0.05
702	2/6	<0.005	d	0.01

Table 3.5 Summary of filtered ground water quality data (monitor wells SRK-01-0702 and SRK-01-0703) for the Entrada Formation at the UC site near Slick Rock, Colorado (Concluded)

Parameter[a]	Above detection[b]	Minimum	Median	Maximum
Radionuclide				
Lead-210				
703	3/3	0.0	0.4	1.7
702	3/3	0.0	1.2	1.4
Polonium-210				
703	3/3	0.0	0.0	0.1
702	3/3	0.0	0.3	0.3
Radium-226				
703	5/5	0.0	0.3	0.6
702	5/5	0.1	0.3	0.8
Thorium-230				
703	3/3	0.2	0.7	1.1
702	3/3	0.1	0.2	0.5

[a] Data from 1986 through 1994 were used in this summary. Data collected in March 1991 were not used because of errors in analysis or reporting.

[b] Above detection. Number of samples with detectable concentration/total number of samples.

[c] Only the last three digits of monitor well identifications are presented on this table (e.g., SRK-01-073 is presented as 703). Monitor well 703 is located upgradient of the UC site and is not considered impacted by site-related contamination.

[d] Median is the 50th percentile of the data. The median cannot be calculated if 50 percent or more of the data are below detection.

[e] Monitor well 702 is located downgradient of the UC site and has been impacted by site-related contamination.

Notes:
1. Inorganic parameter concentrations are in milligrams per liter.
2. Radionuclides are in picocuries per liter.
3. If detection limits reported for nondetect samples exceeded the maximum detected concentration, the detected concentration is reported as the maximum.

ground water chemistry and should not be used to evaluate potential contamination from milling. Monitor well SRK-01-0558 is also screened in the upper Navajo Sandstone with the filter pack extending into the overlying Entrada Formation. The position of the well screen and filter pack as well as slightly high uranium (up to 0.03 mg/L), nitrate (up to 30 mg/L), and sulfate (up to 950 mg/L) values measured in ground water suggest this well may also be influenced by Entrada Formation ground water. Finally, although water quality from monitor well SRK-01-0688 indicates no impact from milling, the filter pack extends 19 ft (6 m) into the Entrada Formation. Therefore, this well is not representative of Navajo Sandstone ground water (Table 3.6).

Organic contamination at both sites

In July 1986, two ground water wells were screened for organic constituents including priority pollutants, pesticides, and additional regulated compounds. Toluene and di-n-butylphthalate were detected in monitor well SRK-01-0503. However, these chemicals are common laboratory contaminants that also were detected in the associated field blanks. Therefore, these chemicals were determined to be most likely the result of laboratory contamination and not site-related.

3.3 CONTAMINANTS OF POTENTIAL CONCERN

The data summarized in Tables 3.2 and 3.4 were used to compile the lists of contaminants of potential concern in ground water for the assessment of risk to human health at the Slick Rock sites. Contaminants of potential concern for human health have not been selected for surface water and sediment because it was determined that contamination at the Slick Rock sites has not adversely affected the surface water quality and because the sediment could not be meaningfully characterized from the available analytical data. The ecological contaminants of potential concern are discussed in the ecological assessment presented in Section 7.0.

The DOE has determined that the alluvial and Entrada Formation aquifers are impacted by mill site-related activities. However, only the most contaminated wells in the alluvial aquifer were quantitatively evaluated for this baseline risk assessment. This is a conservative approach because 1) the alluvial unit is the more contaminated of the aquifers, 2) contaminant concentrations in the alluvial unit are expected to decrease over time due to removal of the source of contamination (i.e., tailings), and 3) because contaminant concentrations will decrease over time due to the effects of dilution and dispersion.

Background ground water quality data are not available to determine if constituents detected at the sites are significantly above background.

Table 3.6 **Summary of filtered background ground water quality data (monitor wells SRK-01-0668, SRK-01-0669, and SRK-01-0670) from the Navajo Sandstone at the UC site near Slick Rock, Colorado**

Parameter[a]	Above detection[b]	Minimum	Median	Maximum
Inorganic				
Aluminum	6/19	<0.05	c	0.4
Ammonium	9/22	<0.10	c	1.7
Antimony	1/10	<0.003	c	0.009
Arsenic	11/19	0.005	0.007	0.025
Barium	15/15	0.06	0.12	0.20
Beryllium	0/7	<0.005	c	<0.01
Boron	12/12	0.10	0.31	0.55
Bromide	0.11	<0.10	c	<0.10
Cadmium	0/18	<0.001	c	<0.005
Calcium	24/24	6.6	31	46
Chloride	25/25	4.0	8.0	39
Chromium	0/15	<0.01	c	<0.01
Cobalt	0/7	<0.03	c	<0.05
Copper	0/13	<0.01	c	<0.02
Cyanide	0/8	<0.01	c	<0.01
Fluoride	17/17	0.70	1.0	1.4
Iron	10/24	<0.03	c	0.74
Lead	0/13	<0.003	c	<0.02
Magnesium	24/24	17	33	51
Manganese	20/24	<0.01	0.035	0.18
Mercury	0/10	<0.0002	c	<0.0002
Molybdenum[d]	11/20	<0.01	0.01	0.13
Nickel	2/16	<0.01	c	0.01
Nitrate	9/24	0.30	c	7.9
Phosphate	7/16	<0.01	c	0.20
Potassium	24/24	1.8	13	47
Selenium	1/21	<0.005	c	0.006
Silica	18/18	5.9	9.8	15
Silver	1/11	<0.01	c	0.30
Sodium	24/24	9	15	34

Table 3.6 **Summary of filtered background ground water quality data (monitor wells SRK-01-0668, SRK-01-0669, and SRK-01-0670) from the Navajo Sandstone at the UC site, Slick Rock, Colorado (Concluded)**

Parameter[a]	Above detection[b]	Minimum	Median	Maximum
Strontium	12/12	0.66	1.0	1.8
Sulfate	25/25	11	20	55
Sulfur	6/14	<0.10	c	0.6
Thallium	0/10	<0.005	c	<0.01
Tin	0/10	<0.005	c	<0.005
Uranium	17/25	<0.0003	0.001	0.007
Vanadium[d]	1/15	<0.01	c	0.01
Zinc	3/15	<0.005	c	0.036
Radionuclide				
Lead-210	7/7	0.0	0.0	0.90
Polonium-210	7/7	0.0	0.10	0.20
Radium-226	19/19	0.30	0.70	1.0
Thorium-230	7/7	0.0	0.30	1.2

[a] Data from 1986 through 1994 were used in this summary. Data collected in March 1991 were not used because of errors in analysis or reporting.

[b] Above detection. Number of samples with detectable concentration/total number of samples.

[c] Median is the 50th percentile of the data. The median cannot be calculated if 50 percent or more of the data are below detection.

[c] Data collected in June 1986 and July 1986 were not used for this parameter because of errors in analysis or reporting.

Notes:
1. Inorganic parameter concentrations are in milligrams per liter.
2. Radionuclides are in picocuries per liter.
3. If detection limits reported for nondetect samples exceeded the maximum detected concentration, the detected concentration is reported as the maximum.

Therefore, all constituents detected in the alluvial ground water at each site were evaluated. Constituents were evaluated based on the following criteria:

- History of the processing sites. Could the contaminant be expected at the NC and UC sites based on former processing site activities. For example, sodium and sulfate have been identified as chemicals used during processing at the two Slick Rock sites. In addition, sodium, nitrate, sulfate, and uranium have been detected consistently at other UMTRA sites (DOE, 1994b; 1994c; 1994d).
- Essential human nutrients or dietary requirements for adults. When a sensitive population was identified, it was evaluated specifically. For example, nitrate and sulfate tend to adversely affect the infant population more readily than adults.
- Toxicity. Adverse toxicity levels were evaluated for constituents that did not fall into essential nutrient or normal dietary intake levels.
- Frequency of detection. Constituents that were not eliminated because of low toxicity potential did not fall within high nutritional ranges, and were detected only infrequently (i.e., less than 25 percent of the time) were not retained as contaminants of potential concern.

3.3.1 North Continent site

Several constituents excluded as contaminants of potential concern for the NC site are essential nutrients and fall within nutritional ranges at the detected levels: calcium, chromium, copper, fluoride, iron, magnesium, nickel, potassium, vanadium, and zinc.

Additional screening of the remaining constituents was based on the low toxicity and/or relatively high normal dietary intake compared to the values detected. These criteria were used to screen out ammonium, barium, boron, bromide, chloride, molybdenum, nitrate, phosphate, selenium, silica, and strontium. The frequency of detection was considered in the final screening selection process. Constituents were excluded as a contaminant of potential concern when they showed high toxicity potential, did not fall within high nutritional ranges, or were detected infrequently. These criteria screened out antimony, sulfide, and tin (antimony, sulfide, and tin were all detected one time).

The contaminants of potential concern retained and evaluated for noncarcinogenic effects are manganese, sodium, sulfate, and uranium. In addition, lead-210, polonium-210, thorium-230, radium-226, and uranium were evaluated for carcinogenic effects. These constituents form the basis of the human health evaluation of this baseline risk assessment for the NC site. Table 3.7 summarizes the constituents evaluated for inclusion in this baseline risk assessment and contaminants of potential concern selected for the NC site.

Table 3.7 Contaminants of potential concern for the NC site near Slick Rock, Colorado

Constituents evaluated	Constituent levels in nutritional range	Constituents of low toxicity and/or high dietary range	Contaminants of potential concern
Aluminum	Aluminum	Ammonium	Manganese
Ammonium	Calcium	Antimony[a]	Sodium
Antimony	Chromium	Barium	Sulfate
Barium	Copper	Boron	Uranium
Boron	Fluoride	Bromide	Lead-210
Bromide	Iron	Chloride	Polonium-210
Calcium	Magnesium	Molybdenum	Radium-226
Chloride	Manganese	Nickel	Thorium-230
Chromium	Nickel	Nitrate	
Copper	Potassium	Phosphate	
Fluoride	Zinc	Selenium	
Iron		Silica	
Magnesium		Strontium	
Manganese		Sulfide[a]	
Molybdenum		Tin[a]	
Nickel		Vanadium	
Nitrate			
Phosphate			
Potassium			
Selenium			
Silica			
Sodium			
Strontium			
Sulfate			
Sulfide			
Tin			
Uranium			
Vanadium			
Zinc			
Lead-210			
Polonium-210			
Radium-226			
Thorium-230			

[a] Detected 25 percent of the time or less.

3.3.2 Union Carbide site

Chromium, copper, fluoride, potassium, and zinc were excluded as contaminants of potential concern for the UC site because they are essential nutrients and fall within nutritional ranges.

The remaining constituents were screened based on the low toxicity and/or relatively high normal dietary intake compared to the values detected. These criteria were used to screen out aluminum, ammonium, barium, boron, calcium, magnesium, phosphate, and silica. Finally, the frequency of detection was considered in the selection process for the UC site. Constituents were excluded as contaminants of potential concern when they showed high toxicity potential, did not fall into nutritional ranges, or were detected infrequently. These criteria screened out antimony, bromide, nickel, and sulfide.

The contaminants of potential concern retained and evaluated for noncarcinogenic effects are cadmium, chloride, iron, manganese, molybdenum, nitrate, selenium, sodium, strontium, sulfate, uranium, and vanadium. In addition, lead-210, polonium-210, thorium-230, radium-226, and uranium were evaluated for carcinogenic effects. These contaminants form the basis of the human health evaluation of the baseline risk assessment for the UC site. Table 3.8 summarizes the constituents evaluated for inclusion in the baseline risk assessment and contaminants of potential concern selected for the UC site.

3.4 CONTAMINANT FATE AND TRANSPORT

The fate and mobility of contaminants in ground water beneath and downgradient from the processing site are discussed below. Excluding hydrodynamic dispersion (which acts to dilute all constituents in ground water), geochemical sinks, sorption, and precipitation in the aquifer are responsible for the decreased contamination in ground water down the flow path.

Hydrochemical analysis of ground water in the vicinity of the Slick Rock sites was performed to determine contaminant sinks, mobility, and toxicity. This analysis relies on geochemical modeling, the geochemical character of the aquifer matrix, and observation of the spatial and temporal distribution of elements in ground water. Geochemical modeling using the computer codes MINTEQA2/PRODEFA2 (Allison et al., 1991) and PHREEQE (Parkhurst et al., 1980) were used to determine the species and saturation indexes of contaminants of potential concern in ground water beneath the site. If the reactions are kinetically favorable, mineral phases that are over-saturated with respect to ground water (saturation indexes greater than 1) will remove constituents from the plume through precipitation. Water quality data from the centroid of the plume at the NC site (monitor well SRK-01-0503) and UC site (monitor wells SRK-01-0506, SRK-01-0508, and SRK-01-0510) were included in the models. Redox conditions were determined with the Fe^{2+}/Fe^{3+} iron couple (monitor well SRK-01-0503), NH_4^+/NO_3^- (monitor wells SRK-01-0508 and SRK-01-0510) and both the Fe^{2+}/Fe^{3+} iron and NH_4^+/NO_3^- couples at monitor well

Table 3.8 Contaminants of potential concern for the UC site near Slick Rock, Colorado

Constituents evaluated	Constituent levels in nutritional range	Constituents of low toxicity and/or high dietary range	Contaminants of potential concern
Aluminum	Chromium	Aluminum	Cadmium
Ammonium	Copper	Ammonium	Chloride
Antimony	Fluoride	Antimony[a]	Iron
Barium	Potassium	Barium	Manganese
Boron	Zinc	Boron	Molybdenum
Bromide		Bromide[a]	Nitrate
Cadmium		Calcium	Selenium
Calcium		Magnesium	Sodium
Chloride		Nickel[a]	Strontium
Chromium		Phosphate	Sulfate
Copper		Silica	Uranium
Fluoride		Sulfide[a]	Vanadium
Iron			Lead-210
Magnesium			Polonium-210
Manganese			Radium-226
Molybdenum			Thorium-230
Nickel			
Nitrate			
Phosphate			
Potassium			
Selenium			
Silica			
Sodium			
Strontium			
Sulfate			
Sulfide			
Uranium			
Vanadium			
Zinc			
Lead-210			
Polonium-210			
Radium-226			
Thorium-230			

[a] Detected 25 percent of the time or less.

SRK-01-0506. Table 3.9 presents the aqueous species of the contaminants of potential concern.

3.4.1 Cadmium

Cadmium in ground water at the UC site is probably caused by the acidic dissolution of minerals commonly associated with oxidized uranium mineralization. Cadmium levels in ground water at the NC site are below the analytical detection limit in all wells. The divalent cadmium ion and the neutral cadmium sulfate complexes are the predominant species formed in ground water. Geochemical modeling indicates the mineral phase otavite is thermodynamically saturated with respect to ground water and may control concentrations in the center of the contaminated area. Cadmium exchanges with other cations in clays (John, 1971) and ferric oxyhydroxides (Kinniburgh et al., 1977). These processes and octavite precipitation may control cadmium concentrations in the alluvial aquifer.

3.4.2 Chloride

Although chloride is found in alluvial ground water at the NC site, it is only a potential contaminant of concern at the UC site. Chloride concentrations are high as a result of the reduction of sodium perchlorate oxidant added to ore in the milling process. Because of its conservative behavior and the high solubility of chloride mineral phases, chloride is not expected to remove from ground water through sorption or precipitation reactions. Therefore, hydrodynamic dispersion effects (mixing and dilution) will be primarily responsible for reducing chloride concentrations down the ground water flow path.

3.4.3 Iron

Iron is present in ground water predominantly as the ferrous (Fe_{2+}) ion and ferrous sulfate complexes. Ground water is saturated with respect to the ferric oxyhydroxide phases of iron at all locations modeled when ferric iron is present. Precipitation of these minerals will remove and control dissolved ferric iron downgradient from the tailings. Given the geochemical conditions of ground water beneath both sites (i.e., pH between 6.5 and 7.2 and a suboxic environment), the redox state of the aquifer controls ferrous iron mobility, generally requiring an Eh from +250 to -100 mV for stable ferrous species. However, ferrous iron readily oxidizes to the ferric state in the presence of molecular oxygen and then quickly precipitates as ferric oxyhydroxides. Therefore, if ground water flows from the suboxic environment beneath the site into regions of the aquifer where oxygen concentrations are higher, ferrous iron will oxidize and precipitate as ferric oxyhydroxides. This process is important because other constituents such as selenium, molybdenum, arsenic, and uranium coprecipitate or readily sorb onto ferric phases (Groffman, 1994). Therefore, as iron precipitates, it effectively scrubs contaminants from the ground water in the alluvial aquifer downgradient from the tailings.

Table 3.9 Aqueous species of contaminants of potential concern in the alluvial aquifer at the NC and UC sites near Slick Rock, Colorado

Contaminant of potential concern	Valence state	Aqueous species	Valence state	Molar percent
Inorganic constituents				
NC site				
Manganese[a]	Manganese	Mn^{2+}	Mn(II)	71
		$MnSO_4^0$	Mn(II)	23
		$MnHCO_3^+$	Mn(II)	4
		$MnCl^+$	Mn(II)	1
Sodium[a]	Sodium	Na^+	Na(I)	98
	Sodium sulfate	$Na(SO_4)^-$	Na(I)	2
Sulfate[a]	Sulfate	SO_4^{2-}	S(VI)	79
	Calcium sulfate	$CaSO_4^0$	S(VI)	10
	Magnesium sulfate	$MgSO_4^0$	S(VI)	7
	Sodium sulfate	$NaSO_4^-$	S(VI)	3
Uranium[a]	Uranyl tricarbonate	$UO_2(CO_3)_3^{4-}$	U(VI)	57
	Uranyl dicarbonate	$UO_2(CO_3)_2^{2-}$	U(VI)	38
	Uranyl diphosphate	$UO_2(HPO_4)_2^{4-}$	U(VI)	5
UC site				
Cadmium[b]	Cadmium ion	Cd^{2+}	Cc(II)	49
	Cadmium sulfate	$CdSO_4^0$	Cc(II)	22
	Cadmium bicarbonate	$CdHCO_3^+$	Cc(II)	13
	Cadmium carbonate	$CdCO_3^0$	Cc(II)	6
	Cadmium chloride	$CdCl^+$	Cc(II)	6
	Cadmium sulfate	$CdSO_4^0$	Cc(II)	3
	Cadmium nitrate	$CdNO_3^+$	Cc(II)	1
Chloride[c]	Chloride	Cl^-	Cl(I)	100[d]
Iron[c]	Ferrous ion[e]	Fe^{2+}	Fe(II)	79
	Ferrous sulfate	$FeSO_4^0$	Fe(II)	21
	Ferric dihydroxyl[f]	$Fe(OH)_2^+$	Fe(III)	96
	Ferric trihydroxyl	$Fe(OH)_3^0$	Fe(III)	4
Manganese[g]	Manganese	Mn^{2+}	Mn(II)	73
	Manganese sulfate	$MnSO_4^0$	Mn(II)	23
	Manganese bicarbonate	$MnHCO_3^+$	Mn(II)	4
Molybdenum[b,h]	Molybdate	MoO_4^{2-}	Mo(VI)	100[d]

Table 3.9 Aqueous species of contaminants of potential concern in the alluvial aquifer at the NC and UC sites Near Slick Rock, Colorado (Concluded)

Contaminant of potential concern	Valence state	Aqueous species	Valence state	Molar percent
Nitrate[b]	Nitrate	NO_3^-	N(V)	100[d]
Selenium[b]	Selenite	$HSeO_3^-$	Se(IV)	96
	Selenite	SeO_3^{2-}	Se(IV)	4
Sodium[c]	Sodium	Na^+	Na(I)	98
	Sodium sulfate	$NaSO_4^-$	Na(I)	2
Strontium[c]	Strontium	Sr^+	Sr(I)	100[d]
Sulfate[c]	Sulfate	SO_4^{2-}	S(VI)	66
	Calcium sulfate	$CaSO_4^o$	S(VI)	14
	Magnesium sulfate	$MgSO_4^o$	S(VI)	14
	Sodium sulfate	$NaSO_4^-$	S(VI)	4
	Ammonium sulfate	$NH_4SO_4^-$	S(VI)	2
Uranium[c]	Uranyl tri-carbonate	$UO_2(CO_3)_3^{4-}$	U(VI)	68
	Uranyl di-carbonate	$UO_2(CO_3)_2^{2-}$	U(VI)	22
Vanadium[c]	Vanadate	$HV_2O_7^{3-}$	V(V)	82
	Vanadate	$H_2VO_4^-$	V(V)	15
	Vanadate	$H_3V_2O_7^-$	V(V)	2
	Vanadate	HVO_4^{2-}	V(V)	1
Radionuclides, NC and UC sites				
Lead-210[i]	Lead carbonate	$PbCO_3^o$	Pb(II)	68
	Lead bicarbonate	$PbHCO_3^+$	Pb(II)	15
	Lead ion	Pb^{2+}	Pb(II)	9
	Lead sulfate	$PbSO_4^o$	Pb(II)	8
Polonium-210	Polonium ion	Po^{2+}	Po(II)	100[d]
Radium-226	Radium ion	Ra^{2+}	Ra(II)	100[d]
Thorium-230	Thorium hydroxide	$Th(OH)_3^+$	Th(IV)	100[d]

[a] Monitor well SRK-01-0503, NC site.
[b] Monitor well SRK-01-0508, UC site.
[c] Monitor well SRK-01-0506, UC site.
[d] Approximately 100 percent of this constituent is present as this species.
[e] Primary form of iron.
[f] Secondary form of iron.
[g] Monitor well SRK-01-0510, UC site.
[h] Redox information from Brookins (1988).
[i] Approximate predominance of species at both sites.

3.4.4 Manganese

Manganese is a contaminant of potential concern in the alluvial ground water at both the NC and UC sites. The mobility of manganese is primarily controlled by the redox state of the aquifers. Manganese is present in ground water in the Mn(II) valence state (predominantly as Mn^{2+}) and complexes with sulfate and bicarbonate. Geochemical modeling indicates mineral phases are not saturated with respect to ground water, discounting precipitation as a mechanism for manganese removal. However, removal through sorption and coprecipitation with ferric oxyhydroxide phases (Rai et al., 1984) probably controls manganese concentrations in ground water. Dilution as a result of hydrodynamic dispersion probably affects the manganese concentration in ground water downgradient from the site.

3.4.5 Molybdenum

Molybdenum is present predominantly as the Mo(VI) molybdate species in alluvial ground water in the UC site vicinity. Molybdate is relatively mobile under the geochemical conditions found in ground water beneath the UC site (i.e., moderately oxidizing conditions with a pH between 6 and 7). No mineral phases are saturated with respect to ground water beneath the site, precluding the possibility of molybdenum removal by precipitation. Sorption onto aquifer materials such as ferric oxyhydroxides (Rai et al., 1984) and organic material (Bloomfield et al., 1973) will attenuate molybdenum concentrations in the contaminated area. Hydrodynamic dispersion also will contribute to reduced concentrations downgradient from the sites.

3.4.6 Nitrate

Nitrogen contamination is present as ammonium and nitrate in both the alluvial and Entrada Formation aquifers beneath the UC site. The only nitrogen complex used in the milling process was ammonia; it was used to adjust the pH of the pulp. During the process, ammonia reacted with hydrogen ions to form ammonium, which was discarded to the tailings pile. In the presence of oxygen, some of the ammonium was biologically oxidized to nitrate in the tailings pile and alluvial ground water system, resulting in the current nitrate plume. Nitrate is present in ground water as the N(V) nitrate ion. The predominant mechanism responsible for nitrate attenuation in ground water is most likely denitrifying reactions which occur under suboxic conditions (less than 1 mg/L dissolved oxygen). These conditions exist in ground water downgradient from the processing site. For example, nitrate concentrations in ground water decrease from approximately 1600 mg/L in monitor well SRK-01-0508 (at the toe of the tailings) to approximately 1 to 10 mg/L in monitor well SRK-01-0507 (downgradient from the tailings). The decrease in concentration suggests nitrate is biologically transformed into molecular nitrogen in the aquifer along the ground water flow path. This is probably the case because there is very little sorption of nitrate onto the aquifer matrix due to its conservative nature (low reactivity) with respect to the aquifer matrix. Also, no nitrate solid mineral phases are saturated with respect to ground water in the vicinity of the processing site.

3.4.7 Selenium

Selenium is associated with uranium ore and was mobilized with uranium during the acid leach portion of the milling process. Selenium as selenite, Se(IV), is the predominant species in the vicinity of monitor well SRK-01-0508 (UC site). No mineral phases are saturated with respect to ground water in the vicinity of the contamination zone due to the relatively high redox potential as a result of high nitrate concentrations. Therefore, hydrodynamic dispersion and sorption of selenium species on aquifer materials such as ferric oxyhydroxides (Rai et al., 1984) downgradient from the pile would probably be responsible for decreased concentrations in ground water.

3.4.8 Sodium

The addition of sodium chlorate as an oxidizing agent, dissolution of sodium-bearing minerals during the acid leach circuit, and cation exchange with calcium and magnesium in clay minerals are responsible for the elevated sodium concentrations in ground water at the NC and UC processing sites. Sodium is present in ground water predominately as a cation, Na(I). The primary mechanism of sodium attenuation is most likely cation exchange with clay minerals. However, sodium acts as a somewhat conservative cation if calcium or other divalent alkali earth elements are elevated within the system. Therefore, if divalent cations saturate clay exchange sites, sodium is expected to persist in ground water downgradient from the tailings.

3.4.9 Strontium

Strontium is present in ground water primarily as the divalent strontium ion. Although no strontium mineral phases are saturated with respect to ground water, coprecipitation with gypsum and carbonate phases may remove some strontium from ground water. With hydrodynamic dispersion processes, cation exchange with clay minerals in the aquifer matrix also will reduce strontium concentrations.

3.4.10 Sulfate

Elevated sulfate concentrations in ground water in the vicinity of the NC and UC processing sites are due to the addition of sulfuric acid (H_2SO_4) during the milling process. Sulfate is present in ground water predominantly as the SO_4^{2-} ion or it is complexed with calcium, magnesium, or sodium. As the contaminant zone migrates, hydrodynamic dispersion will be the primary mechanism responsible for the decrease of sulfate concentrations along the ground water flow path. However, sulfate is expected to persist in ground water downgradient from the former mill site due to its conservative nature (stable oxyanion) and the relatively high solubility of gypsum compared to other components of the aquifer matrix.

3.4.11 Uranium

Uranium is present in ground water in the vicinity of the NC and UC processing sites as a residual product of the milling process. Uranium is present in the contamination zones predominantly as U(VI) and uranyl tri-carbonate and di-carbonate complexes. These species are mobile under the geochemical conditions in the aquifer. Ground water is not oversaturated with respect to uranium mineral phases; therefore, sorption onto the aquifer matrix is most likely responsible for the removal of uranium downgradient from the sites. The removal of uranium through coprecipitation with ferric oxyhydroxide has been documented in ground water collected from monitor wells SRK-01-0503 and SRK-01-0504 at the NC site (Groffman, 1994). This removal mechanism is expected to occur at both the NC and UC sites where ferrous iron is oxidized and precipitated as ferric oxyhydroxide phases in the aquifer. This anoxic/oxic interface probably exists on the lateral and downgradient periphery of the alluvial aquifer/Dolores River boundary. Furthermore, dilution by hydrodynamic dispersion and mixing occurs down the ground water flow path.

3.4.12 Vanadium

Vanadium is associated with the uranium ores processed at the site and is mobilized with uranium in the leaching process. Therefore, high vanadium concentrations in ground water beneath the UC site indicate impact by milling activities. Vanadium is present in the plume predominantly as vanadate V(V) complexes. Vanadium in the V(V) oxidation state sorbs and coprecipitates strongly with iron oxyhydroxides (Groffman, 1994) within which ground water is oversaturated beneath the processing site. Furthermore, ground water is oversaturated with respect to vanadate oxide phases. If these solids are thermodynamically favorable, precipitation and sorption onto the aquifer matrix will attenuate vanadium from the contaminant zone down the ground water flow path. This explains the low vanadium concentration (at or slightly above the detection limit) in distal ground water sampled from SRK-01-0506 and SRK-01-0507 downgradient from the UC processing site.

3.4.13 Radionuclides

Lead-210, polonium-210, radium-226, and thorium-230 are residual decay products of uranium and were mobilized with uranium in the acid circuit of the milling process. Excluding monitor well SRK-01-0503 (with lead-210 detected up to 216 picocuries per liter [pCi/L]), all four radionuclides are present in concentrations at or slightly above the analytical detection limit (taking into account analytical uncertainties). In alluvial ground water at both sites, lead-210 is complexed with carbonate and sulfate, polonium-210 and radium-226 exist predominantly as uncomplexed cations, and thorium-230 is present as a hydroxyl species (Table 3.9). All four radionuclides form low-solubility mineral phases and strongly sorb onto aquifer materials (Fairbridge, 1972). Both these mechanisms control the concentration of these radionuclides in ground water; therefore, these radionuclides will probably not be found in ground water downgradient from the tailings.

3.5 SURFACE WATER

Water quality data were collected from 1987 to 1994 from upstream SRK-01-696 and downstream SRK-01-0692, SRK-01-SRK-01-693, SRK-01-694 surface water locations on the Dolores River (Figure 2.3). Tables 3.10 through 3.13 summarize filtered and unfiltered surface water quality from the Dolores River. In the vicinity of the Slick Rock sites, Dolores River water and ground water are hydraulically connected in the alluvial aquifer. The Dolores River meanders back and forth across the valley floor, forming discreet packages of alluvium cut by the river channel. Generally, Dolores River water recharges the alluvial system in the upstream portion of the floodplain and ground water discharges into the Dolores River in the downstream segment of the floodplain.

Water quality in the Dolores River is dominated by sulfate and calcium with lesser bicarbonate and sodium concentrations. Measured pH of the river water ranges between 8 and 8.8, and TDS range from approximately 200 to 1000 mg/L.

Generally, unfiltered water analyses are higher than filtered samples in the transition elements iron, manganese, and cadmium, and in the clay-forming constituents aluminum and silica. This disparity in filtered and unfiltered water quality data results from the abundant colloidal material in the river water and is not site-related. Therefore, due to the variability of flow and the turbid nature of the water in the Dolores River, constituent concentrations measured from filtered and especially nonfiltered samples are expected to vary.

Filtered and unfiltered water quality data from upstream background location SRK-01-0696 and downstream locations SRK-01-0692 through SRK-01-0694 (Figure 2.3) indicate no discernible impact from milling activities on Dolores River water quality. Excluding measurement and sampling variability, there are no apparent differences in trace element concentrations (including uranium, vanadium, selenium, and cadmium) from filtered water samples taken upstream and downstream of the NC and UC sites. Furthermore, no significant changes in concentrations of major cations and anions downstream from the NC and UC sites indicate no impact from uranium mill tailings activities. However, more unfiltered and filtered water quality data must be collected synoptically to strengthen the statistical database.

3.6 SEDIMENT

One round of sediment samples was collected from surface sediment background location SRK-01-0696 upstream and locations SRK-01-0692, SRK-01-0693, and SRK-01-0694 downstream from the background location during

Table 3.10 Summary of filtered and unfiltered surface water data, sampling location SRK-01-0696, from the Dolores River near Slick Rock, Colorado

Parameter[a]	Above detection[b]	Minimum	Median	Maximum
Inorganic				
Cadmium				
Filtered	0/1	<0.001	c	<0.001
Unfiltered	0/2	<0.001	c	<0.001
Calcium				
Filtered	1/1	45	c	45
Unfiltered	2/2	33	38	43
Copper				
Filtered	d	d	c	d
Unfiltered	1/1	<0.01	0.01	<0.01
Magnesium				
Filtered	1/1	11	11	11
Unfiltered	2/2	6	8.1	10
Molybdenum				
Filtered	0/1	<0.01	c	<0.01
Unfiltered	0/2	<0.01	c	<0.01
Nitrate				
Filtered	d	d	c	d
Unfiltered	1/2	<1.0	c	13
Selenium				
Filtered	0/1	<0.005	c	<0.005
Unfiltered	0/2	<0.005	c	<0.005
Uranium				
Filtered	0/1	<0.001	c	<0.001
Unfiltered	1/2	<0.001	c	<0.001
Vanadium				
Filtered	0/1	<0.01	c	<0.01
Unfiltered	0/2	<0.01	c	<0.01
Zinc				
Filtered	0/1	<0.05	c	<0.05
Unfiltered	1/2	<0.05	c	0.044

[a] Location 696 was sampled only in 1993 and 1994. Sampling locations were not analyzed for the same parameters during all surface water sampling periods.

[b] Number of samples with detectable concentration/total number of samples.

[c] The 50th percentile of the data. The median cannot be calculated if 50 percent or more of the data are below detection.

[d] Samples not analyzed for this constituent.

Note: 1. If detection limits reported for nondetect samples exceeded the maximum detectable concentration, the detectable concentration is reported as the maximum.
2. Concentrations are in milligrams per liter.

Table 3.11 Summary of filtered and unfiltered surface water data, sampling location SRK-01-0692, from the Dolores River near Slick Rock, Colorado

Parameter[a]	Above detection[b]	Minimum	Median	Maximum
Inorganic				
Aluminum				
Filtered	1/4	<0.1	c	0.14
Unfiltered	3/3	0.33	29	36
Ammonium				
Filtered	0/3	<0.1	c	<0.1
Unfiltered	2/3	<0.1	0.2	0.6
Antimony				
Filtered	0/2	<0.003	c	<0.003
Unfiltered	1/3	<0.003	c	0.003
Arsenic				
Filtered	0/3	<0.001	c	<0.01
Unfiltered	1/3	<0.001	c	0.02
Barium				
Filtered	2/3	<0.1	0.1	0.2
Unfiltered	3/3	0.18	0.38	0.55
Beryllium				
Filtered	0/1	<0.01	c	<0.01
Unfiltered	1/3	<0.005	c	0.005
Boron				
Filtered	0/2	<0.1	c	<0.1
Unfiltered	2/3	<0.05	0.09	0.12
Bromide				
Filtered	1/2	<0.1	c	0.1
Unfiltered	1/2	<2.0	c	0.1
Cadmium				
Filtered	0/4	<0.001	c	<0.001
Unfiltered	1/4	<0.001	c	0.006
Calcium				
Filtered	5/5	42	58	79
Unfiltered	4/4	54	220	460
Chloride				
Filtered	4/4	8.0	23	49
Unfiltered	3/3	21	33	37
Chromium				
Filtered	0/3	<0.01	c	<0.01
Unfiltered	2/3	<0.01	0.03	0.06

Table 3.11 Summary of filtered and unfiltered surface water data, sampling location SRK-01-0692, from the Dolores River near Slick Rock, Colorado (Continued)

Parameter[a]	Above detection[b]	Minimum	Median	Maximum
Cobalt				
Filtered	0/1	<0.05	c	<0.05
Unfiltered	1/3	<0.03	c	0.04
Copper				
Filtered	0/3	<0.01	c	<0.02
Unfiltered	2/3	<0.01	0.07	0.09
Cyanide				
Filtered	0/1	<0.01	c	<0.01
Unfiltered	0/3	<0.01	c	<0.01
Fluoride				
Filtered	3/4	<0.1	0.12	0.2
Unfiltered	3/3	0.2	0.3	0.4
Iron				
Filtered	2/4	<0.03	c	0.04
Unfiltered	3/3	2.0	60	74
Lead				
Filtered	0/3	<0.001	c	<0.01
Unfiltered	2/3	<0.005	0.038	0.08
Magnesium				
Filtered	5/5	9.4	16	29
Unfiltered	4/4	13	60	95
Manganese				
Filtered	3/4	<0.01	0.015	0.02
Unfiltered	3/3	0.02	0.82	1.2
Mercury				
Filtered	0/3	<0.0002	c	<0.0002
Unfiltered	0/3	<0.0002	c	<0.0002
Molybdenum				
Filtered	2/5	<0.01	c	0.02
Unfiltered	0/4	<0.01	c	<0.01
Nickel				
Filtered	2/4	0.01	c	0.02
Unfiltered	2/3	<0.04	0.09	0.13
Nitrate				
Filtered	2/4	0.1	c	1.0
Unfiltered	2/4	<1.0	c	4.0
Phosphate				
Filtered	0/3	<0.1	c	<0.1
Unfiltered	3/3	0.1	7.5	21

Table 3.11 Summary of filtered and unfiltered surface water data, sampling location SRK-01-0692, from the Dolores River near Slick Rock, Colorado (Continued)

Parameter[a]	Above detection[b]	Minimum	Median	Maximum
Potassium				
Filtered	4/4	1.6	1.9	2.7
Unfiltered	3/3	2.0	9.2	11
Selenium				
Filtered	0/4	<0.002	c	<0.005
Unfiltered	0/4	<0.005	c	<0.05
Silica				
Filtered	4/4	2.8	4.6	7.9
Unfiltered	3/3	4.8	87	100
Silver				
Filtered	0/3	<0.01	c	<0.01
Unfiltered	0/3	<0.01	c	<0.01
Sodium				
Filtered	4/4	16	38	62
Unfiltered	3/3	29	42	110
Strontium				
Filtered	1/1	0.8	0.8	0.8
Unfiltered	3/3	0.66	1.6	2.0
Sulfate				
Filtered	4/4	44	93	260
Unfiltered	3/3	72	420	600
Sulfur				
Filtered	0/1	<0.1	c	<0.1
Unfiltered	2/3	0.1	<0.2	0.9
Thallium				
Filtered	0/1	<0.01	c	<0.01
Unfiltered	0/3	<0.01	c	<0.01
Tin				
Filtered	0/1	<0.005	c	<0.005
Unfiltered	0/3	<0.005	c	<0.05
Uranium				
Filtered	4/5	0.0005	0.002	0.003
Unfiltered	4/4	0.001	0.004	0.009
Vanadium				
Filtered	1/4	<0.01	c	0.03
Unfiltered	3/4	<0,01	0.05	0.13
Zinc				
Filtered	0/4	<0.005	c	<0.05
Unfiltered	3/4	0.017	0.17	0.37

Table 3.11 Summary of filtered and unfiltered surface water data, sampling location SRK-01-0692, from the Dolores River near Slick Rock, Colorado (Concluded)

Parameter[a]	Above detection[b]	Minimum	Median	Maximum
Radionuclide				
Lead-210				
Filtered	2/2	0.6	1.1	1.5
Unfiltered	2/2	0.3	5.7	11
Polonium-210				
Filtered	2/2	0.00	0.2	0.4
Unfiltered	2/2	0.00	0.3	0.6
Radium-226				
Filtered	4/4	0.00	0.1	0.4
Unfiltered	3/3	0.2	2.7	11
Thorium-230				
Filtered	2/2	0.1	0.1	0.1
Unfiltered	2/2	0.7	0.75	0.8

[a] Data from 1987 through 1994 were used in this summary. Location SRK-01-0692 was sampled only in 1993 and 1994. All sampling locations were not analyzed for the same parameters during all surface water sampling periods.

[b] Number of samples with detectable concentration/total number of samples.

[c] The 50th percentile of the data. The median cannot be calculated if 50 percent or more of the data are below detection.

Notes:
1. If detection limits reported for nondetect samples exceeded the maximum detected concentration, the detected concentration is reported as the maximum.
2. Inorganic concentrations are reported in milligrams per liter.
3. Radionuclides are reported in picocuries per liter.

Table 3.12 Summary of filtered and unfiltered surface water data, sampling location SRK-01-0693, from the Dolores River near Slick Rock, Colorado

Parameter[a]	Above detection[b]	Minimum	Median	Maximum
Inorganic				
Aluminum				
Filtered	1/4	<0.1	c	0.14
Unfiltered	3/3	0.58	35	95
Ammonium				
Filtered	0/3	<0.1	c	<0.1
Unfiltered	3/3	0.1	0.2	1.2
Antimony				
Filtered	0/2	<0.003	c	<0.003
Unfiltered	1/3	<0.003	c	0.003
Arsenic				
Filtered	0/3	<0.001	c	<0.01
Unfiltered	1/3	<0.01	c	0.03
Barium				
Filtered	2/3	<0.1	0.1	0.2
Unfiltered	3/3	0.13	0.45	0.8
Beryllium				
Filtered	0/1	<0.01	c	<0.01
Unfiltered	1/3	<0.005	c	0.024
Boron				
Filtered	0/2	<0.1	c	<0.1
Unfiltered	2/3	<0.05	0.11	0.22
Bromide				
Filtered	1/2	<0.1	c	0.1
Unfiltered	0/2	<0.1	c	<0.2
Cadmium				
Filtered	0/4	<0.001	c	<0.001
Unfiltered	2/4	0.002	c	0.006
Calcium				
Filtered	5/5	42	50	74
Unfiltered	4/4	45	210	4200
Chloride				
Filtered	4/4	7.6	24	43
Unfiltered	3/3	22	26	36
Chromium				
Filtered	0/3	<0.01	c	<0.01
Unfiltered	2/3	<0.01	0.04	0.12

Table 3.12 Summary of filtered and unfiltered surface water data, sampling location SRK-01-0693, from the Dolores River near Slick Rock, Colorado (Continued)

Parameter[a]	Above detection[b]	Minimum	Median	Maximum
Cobalt				
Filtered	0/1	<0.05	c	<0.05
Unfiltered	2/3	<0.03	0.03	0.19
Copper				
Filtered	0/3	<0.01	c	<0.02
Unfiltered	2/3	<0.01	0.08	0.16
Cyanide				
Filtered	0/1	<0.01	c	<0.01
Unfiltered	0/3	<0.01	c	<0.01
Fluoride				
Filtered	3/4	<0.1	0.13	0.2
Unfiltered	2/3	<0.1	0.3	0.3
Iron				
Filtered	2/4	<0.03	c	0.06
Unfiltered	3/3	1.0	72	85
Lead				
Filtered	0/3	<0.001	c	<0.01
Unfiltered	2/3	0.007	c	0.044
Magnesium				
Filtered	5/5	9.5	14	29
Unfiltered	4/4	11	53	580
Manganese				
Filtered	3/4	<0.01	0.01	0.01
Unfiltered	3/3	0.02	0.82	7.4
Mercury				
Filtered	0/3	<0.0002	c	<0.0002
Unfiltered	0/3	<0.0002	c	<0.0002
Molybdenum				
Filtered	2/5	<0.01	c	0.02
Unfiltered	1/4	<0.01	c	0.01
Nickel				
Filtered	1/4	<0.01	c	0.03
Unfiltered	2/3	<0.04	0.10	0.47
Nitrate				
Filtered	2/4	0.1	c	0.7
Unfiltered	1/4	<1.0	c	3.1
Phosphate				
Filtered	0/3	<0.1	c	<0.1
Unfiltered	3/3	0.2	10	25

Table 3.12 Summary of filtered and unfiltered surface water data, sampling location SRK-01-0693, from the Dolores River near Slick Rock, Colorado (Continued)

Parameter[a]	Above detection[b]	Minimum	Median	Maximum
Potassium				
Filtered	4/4	1.5	2.0	3.0
Unfiltered	3/3	1.7	10	25
Selenium				
Filtered	0/4	<0.002	c	<0.005
Unfiltered	0/4	<0.005	c	<0.05
Silica				
Filtered	4/4	3.2	4.5	7.7
Unfiltered	3/3	5.5	120	200
Silver				
Filtered	0/3	<0.01	c	<0.01
Unfiltered	0/3	<0.01	c	<0.01
Sodium				
Filtered	4/4	18	39	64
Unfiltered	3/3	21	75	110
Strontium				
Filtered	1/1	0.8	0.8	0.8
Unfiltered	3/3	0.57	2.0	10
Sulfate				
Filtered	4/4	49	93	270
Unfiltered	3/3	54	340	630
Sulfur				
Filtered	0/1	<0.1	c	<0.1
Unfiltered	2/3	<0.2	0.5	1.0
Thallium				
Filtered	0/1	<0.01	c	<0.01
Unfiltered	0/3	<0.01	c	<0.01
Tin				
Filtered	0/1	<0.005	c	<0.005
Unfiltered	0/3	<0.005	c	<0.05
Uranium				
Filtered	3/5	<0.0003	0.0025	0.0025
Unfiltered	4/4	0.001	0.0025	0.009
Vanadium				
Filtered	1/4	<0.01	c	0.03
Unfiltered	3/4	<0.01	0.10	0.13
Zinc				
Filtered	1/4	<0.005	c	0.034
Unfiltered	3/4	0.015	0.18	0.95

Table 3.12 Summary of filtered and unfiltered surface water data, sampling location SRK-01-0693, from the Dolores River near Slick Rock, Colorado (Concluded)

Parameter[a]	Above detection[b]	Minimum	Median	Maximum
Radionuclide				
Lead-210				
Filtered	2/2	0.0	0.05	0.1
Unfiltered	2/2	0.1	1.6	3.1
Polonium-210				
Filtered	2/2	0.0	0.1	0.2
Unfiltered	2/2	0.1	0.35	0.6
Radium-226				
Filtered	3/3	0.0	0.0	0.1
Unfiltered	3/3	0.8	2.3	3.8
Thorium-230				
Filtered	2/2	0.1	0.55	1.0
Unfiltered	2/2	0.2	1.9	3.5

[a] Data from 1987 through 1994 were used in this summary. Location SRK-01-0693 was sampled only in 1993 and 1994. All sampling locations were not analyzed for the same parameters during all surface water sampling periods.

[b] Number of samples with detectable concentration/total number of samples.

[c] The 50th percentile of the data. The median cannot be calculated if 50 percent or more of the data are below detection.

Notes:
1. If detection limits reported for nondetect samples exceeded the maximum detected concentration, the detected concentration is reported as the maximum.
2. Inorganic concentrations are reported in milligrams per liter.
3. Radionuclides are reported in picocuries per liter.

Table 3.13 Summary of filtered and unfiltered surface water data, sampling location SRK-01-0694, from the Dolores River near Slick Rock, Colorado

Parameter[a]	Above detection[b]	Minimum	Median	Maximum
Inorganic				
Aluminum				
Filtered	1/4	<0.1	c	0.13
Unfiltered	3/3	0.32	17	42
Ammonium				
Filtered	0/3	<0.1	c	<0.1
Unfiltered	2/3	<0.1	0.3	0.7
Antimony				
Filtered	0/2	<0.003	c	<0.003
Unfiltered	0/3	<0.003	c	<0.003
Arsenic				
Filtered	0/3	<0.001	c	<0.01
Unfiltered	1/3	<0.01	c	0.01
Barium				
Filtered	2/3	<0.1	0.1	0.2
Unfiltered	3/3	0.16	0.62	0.83
Beryllium				
Filtered	0/1	<0.01	c	<0.01
Unfiltered	1/3	<0.005	c	0.006
Boron				
Filtered	0/2	<0.1	c	<0.1
Unfiltered	2/3	<0.05	0.09	0.1
Bromide				
Filtered	1/2	<0.1	c	0.1
Unfiltered	1/2	0.1	c	0.1
Cadmium				
Filtered	0/4	<0.001	c	<0.001
Unfiltered	1/5	<0.001	c	0.0039
Calcium				
Filtered	5/5	42	52	82
Unfiltered	5/5	34	56	470
Chloride				
Filtered	4/4	8.5	22	40
Unfiltered	3/3	21	39	45
Chromium				
Filtered	0/3	<0.01	c	<0.01
Unfiltered	2/3	<0.01	0.02	0.07

Table 3.13 Summary of filtered and unfiltered surface water data, sampling location SRK-01-0694, from the Dolores River near Slick Rock, Colorado (Continued)

Parameter[a]	Above detection[b]	Minimum	Median	Maximum
Cobalt				
Filtered	0/1	<0.05	c	<0.05
Unfiltered	1/3	<0.03	c	0.04
Copper				
Filtered	0/3	<0.01	c	<0.02
Unfiltered	2/3	<0.01	0.01	0.09
Cyanide				
Filtered	0/1	<0.01	c	<0.01
Unfiltered	0/3	<0.01	c	<0.01
Fluoride				
Filtered	3/4	<0.1	0.13	0.2
Unfiltered	3/4	<0.1	0.3	0.3
Iron				
Filtered	2/4	<0.03	c	0.04
Unfiltered	3/3	0.72	39	81
Lead				
Filtered	0/3	<0.001	c	<0.01
Unfiltered	2/3	<0.005	0.02	0.07
Magnesium				
Filtered	5/5	9.8	13	33
Unfiltered	5/5	6.3	13	90
Manganese				
Filtered	3/4	<0.01	0.02	0.02
Unfiltered	3/3	0.02	0.61	1.3
Mercury				
Filtered	0/3	<0.0002	c	<0.0002
Unfiltered	0/3	<0.0002	c	<0.0002
Molybdenum				
Filtered	2/5	<0.01	c	0.02
Unfiltered	0/5	<0.01	c	<0.01
Nickel				
Filtered	2/4	0.01	c	0.03
Unfiltered	2/3	<0.04	0.05	0.15
Nitrate				
Filtered	2/4	0.4	c	3.7
Unfiltered	3/5	<1.0	2.0	7.8
Phosphate				
Filtered	0/3	<0.1	c	<0.1
Unfiltered	3/3	0.1	7.4	15

Table 3.13 Summary of filtered and unfiltered surface water data, sampling location SRK-01-0694, from the Dolores River near Slick Rock, Colorado (Continued)

Parameter[a]	Above detection[b]	Minimum	Median	Maximum
Potassium				
Filtered	4/4	1.6	2.1	2.8
Unfiltered	3/3	1.7	8.0	12
Selenium				
Filtered	0/4	<0.005	c	<0.005
Unfiltered	0/5	<0.005	c	<0.05
Silica				
Filtered	4/4	3.0	4.6	8.0
Unfiltered	3/3	4.2	59	110
Silver				
Filtered	0/3	<0.01	c	<0.01
Unfiltered	0/3	<0.01	c	<0.01
Sodium				
Filtered	4/4	18	39	74
Unfiltered	3/3	32	43	130
Strontium				
Filtered	1/1	0.8	0.8	0.8
Unfiltered	3/3	0.7	1.7	1.9
Sulfate				
Filtered	4/4	52	95	330
Unfiltered	3/3	76	430	710
Sulfur				
Filtered	0/1	<0.1	c	<0.1
Unfiltered	3/3	0.1	1.3	3.0
Thallium				
Filtered	0/1	<0.01	c	<0.01
Unfiltered	0/3	<0.01	c	<0.01
Tin				
Filtered	0/1	<0.005	c	<0.005
Unfiltered	0/3	<0.005	c	<0.05
Uranium				
Filtered	4/5	0.0004	0.0013	0.0023
Unfiltered	5/5	0.001	0.001	0.014
Vanadium				
Filtered	1/4	<0.01	c	0.03
Unfiltered	2/5	<0.01	c	0.14
Zinc				
Filtered	0/4	<0.005	c	<0.05
Unfiltered	4/5	0.012	0.077	0.41

Table 3.13 Summary of filtered and unfiltered surface water data, sampling location SRK-01-0694, from the Dolores River near Slick Rock, Colorado (Concluded)

Parameter[a]	Above detection[b]	Minimum	Median	Maximum
Radionuclide				
Lead-210				
Filtered	2/2	0.0	0.2	0.4
Unfiltered	2/2	0.0	4.0	7.9
Polonium-210				
Filtered	2/2	0.0	0.0	0.0
Unfiltered	2/2	0.0	0.6	1.2
Radium-226				
Filtered	4/4	0.0	0.2	0.3
Unfiltered	3/3	0.4	1.8	6.8
Thorium-230				
Filtered	2/2	0.1	0.1	0.1
Unfiltered	2/2	0.0	0.45	0.9

[a] Data from 1987 through 1994 were used in this summary. Location SRK-01-0694 was sampled only in 1993 and 1994. All sampling locations were not analyzed for the same parameters during all surface water sampling periods.

[b] Number of samples with detectable concentration/total number of samples.

[c] The 50th percentile of the data. The median cannot be calculated if 50 percent or more of the data are below detection.

Notes:
1. If detection limits reported for nondetect samples exceeded the maximum detected concentration, the detected concentration is reported as the maximum.
2. Inorganic concentrations are reported in milligrams per liter.
3. Radionuclides are reported in picocuries per liter.

1994. Sediment sampling locations are shown in Figure 2.3 and Table 3.14 summarizes the analytical results. The data from the sediment leaching analysis are difficult to interpret due to the natural geochemical heterogeneity of sediments. Furthermore, the trace element concentrations in fine-grained materials are probably naturally high due to the complex clay mineralogy and trace element mineralization of the overlying Morrison Formation. Therefore, one round of data is insufficient to determine if these locations are contaminated.

The variability of data between sampling locations in Table 3.14 is likely a result of the natural chemical variability of the sediments. All these elements are associated with uranium ore, which is ubiquitous to the area, and are present in sediments in measurable concentrations. Concentrations of vanadium, zinc, and uranium typically are high in continental shales (Krauskopf, 1967), which the Dolores River flows through at and upstream from the site. The apparent difference in concentrations between upstream and downstream locations may be attributed to one sampling round not adequately representing the sediment composition and sampling only a few upstream sampling locations does not show the true variability of sediment composition or the tailings contribution to sediments.

Table 3.14 Constituents analyzed in Dolores River sediment near Slick Rock, Colorado

	NC site			UC site		
	Upstream SRK-01-0696		Downstream SRK-01-0692	Downstream SRK-01-0693		Downstream SRK-01-0692
Constituent	(9/93)	(2/94)	(2/94)	(9/93)	(2/94)	(2/94)
Cadmium	0.5	1.3	1.2	1.1	1.7	0.77
Copper	3.0	NA	NA	NA	15	NA
Molybdenum	2.0	4.8	6.3	5.2	3.0	<2.6
Selenium	<0.5	1.2	3.1	3.2	3.0	<1.5
Uranium	1.4	2.0	2.2	1.9	1.9	1.4
Vanadium	18	33	46	43	32	24
Zinc	38	53	75	86	73	40

NA - not analyzed.

Note: Data are reported in milligrams per kilogram.

4.0 EXPOSURE ASSESSMENT

The potential ground water exposures to human receptors at the NC and UC sites are discussed and quantified below. The methodology is consistent with the latest EPA guidance on exposure assessments (EPA, 1989a), which recommends an analysis based on the reasonable maximum exposure under both current and future land-use conditions. Reasonable maximum exposure is defined as the highest exposure that can be reasonably expected at the site; it accounts for both uncertainty in the contaminant concentration and variability in exposure parameters. The DOE has determined that the alluvial and Entrada Formation aquifers are impacted by mill site-related activities. However, only the most contaminated wells in the alluvial aquifer are quantitatively evaluated for this baseline risk assessment.

4.1 POTENTIALLY EXPOSED POPULATION

Exposure can occur only if there are a source of contamination, a mechanism of transport, and a receptor. Ground water could be used for drinking water and bathing, watering livestock, and/or irrigating gardens. Eating livestock that ingested impacted water or impacted vegetation could create an exposure pathway to humans. In addition, plants with roots in the alluvial aquifer or garden produce irrigated with water from this zone could bioaccumulate contaminants, creating yet another potential exposure pathway to humans through plant consumption.

The Dolores River is used for sportfishing and recreational water sports (e.g., rafting) in the vicinity of the Slick Rock sites. A recreational water user could incidentally ingest or come into dermal contact with surface water and sediment. Surface water and sediment quality data indicate contamination at the Slick Rock sites has not discernably impacted these media (Section 3.6). However, surface water and sediment have not been adequately characterized, due to limited analytical data. Therefore, these exposure pathways were not quantitatively evaluated for human receptors.

Ingesting fish that could bioaccumulate contaminants from surface water and sediment could complete another exposure pathway. However, the fish-ingestion scenario was not evaluated for human receptors because fish tissue was not analyzed for bioaccumulation. The ecological assessment in Section 7.0, however, evaluates the surface water and sediment and possible adverse effects to fish.

4.2 EXPOSURE PATHWAYS

Although no current potential exposure to ground water has been identified in the vicinity of the Slick Rock sites, potential future use of contaminated ground water is possible.

Ground water in the Slick Rock area is used primarily for household purposes such as drinking, cooking, and bathing. Other uses typical of the region that could indirectly lead to human exposure include irrigation and livestock watering. A conceptual site model, representing both the NC and UC sites, presents potential exposure pathways from various ground water uses (Figure 4.1).

For this baseline risk assessment, the direct ingestion of contaminants of potential concern in ground water is assumed to cause the greatest adverse health effects because direct ingestion should result in the greatest contaminant intake. To support this assumption, a relative ratio of the exposure pathways most likely encountered at the sites was compared to the direct ingestion of ground water (as drinking water). Comparing the relative significance of each nondrinking water exposure pathway to the drinking water pathway identifies and focuses on the pathway of greatest potential risk based on exposure dose. The screening calculations are based on the 95-percent upper confidence limit (UCL) of the mean from the most contaminated wells at the two Slick Rock sites. However, when the UCL exceeded the maximum concentration detected, the maximum value was used. In addition, the maximum detected concentrations from the most contaminated plume well were used to evaluate for radionuclide carcinogens. A limited database for radionuclides necessitated use of this conservative approach.

The exposure doses were based on an adult exposure for a chronic residence time (greater than 7 years). Only the pathways contributing the majority of the exposure were further evaluated quantitatively using probability intake distributions. Furthermore, exposure pathways that could have a major contribution to the total exposure dose, relative to the drinking water pathway, were identified in the screening assessment. The results of the screening assessment are presented below.

4.2.1 Drinking water ingestion

Drinking water ingestion is generally the most significant exposure pathway for ground water contaminated with metals and other nonvolatile compounds. In this evaluation, drinking water consumption includes water consumed by drinking as well as water used in food preparation (e.g., reconstituted juices, soup, rice, and beans). Table 4.1 shows the screening level calculation for drinking water intake.

4.2.2 Dermal absorption

Dermal absorption is the process by which chemicals coming into contact with the skin are absorbed into the blood vessels near the surface of the skin. Some compounds are absorbed easily in this manner, though metals do not possess the chemical properties that are conducive to skin absorption.

To evaluate this exposure route, a screening calculation was performed to determine if a dermal absorption pathway would be significant compared to the

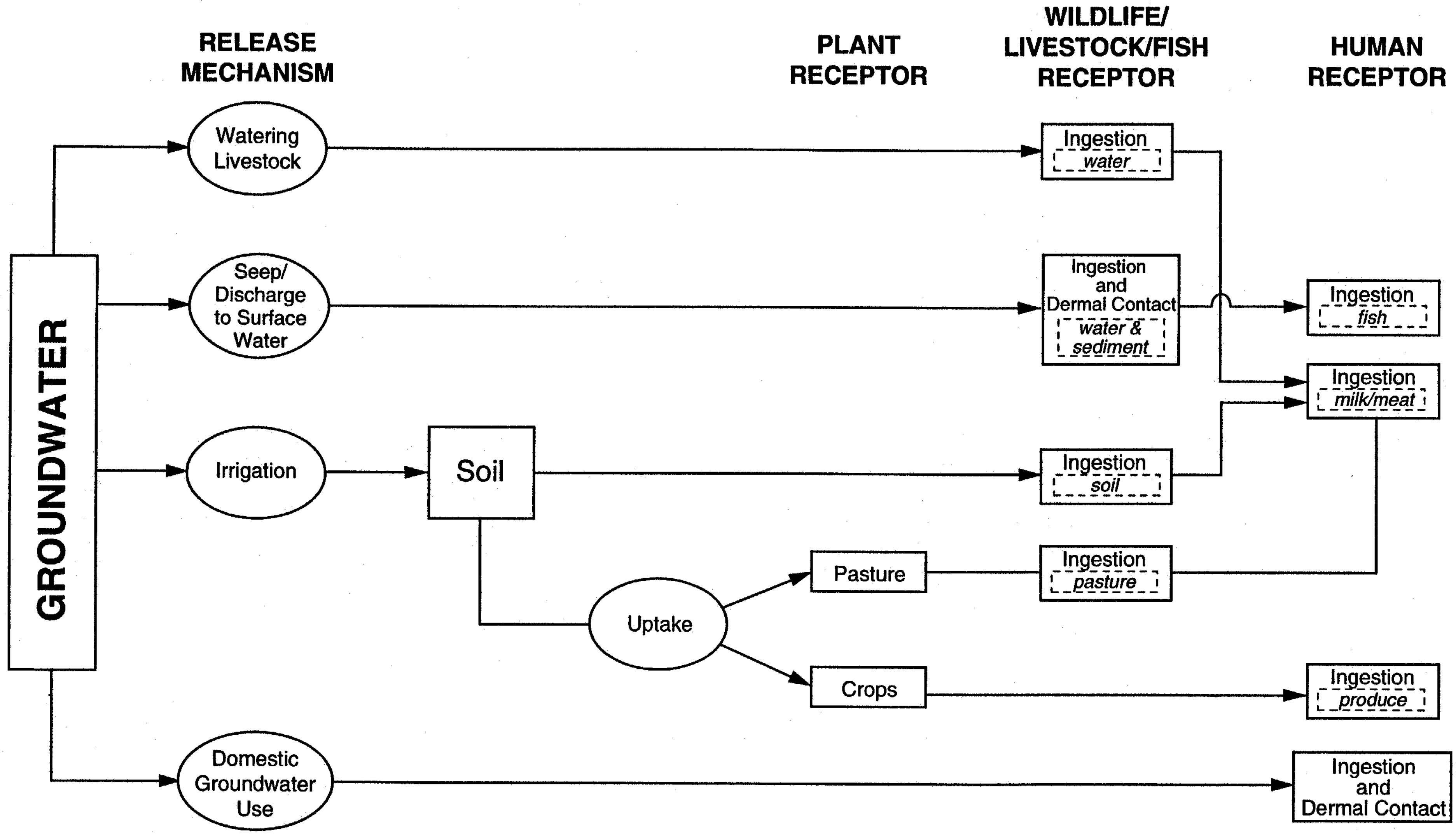


FIGURE 4.1
CONCEPTUAL SITE MODEL
NC AND UC SITES NEAR SLICK ROCK, COLORADO

MAC: SITE/SRK/BRA/CONCEPTMOD

Table 4.1 Exposure dose calculations for ground water ingestion and dermal contact, NC and UC sites, near Slick Rock, Colorado

Contaminant of potential concern	Cw[b]	Ground water exposure doses[a]		Ratio of dermal contact to ingestion[c]
		Ingestion	Dermal contact	
NC site				
Noncarcinogenic effects				
Manganese	0.61	0.02	0.00003	0.002
Sodium	600	17	0.03	0.002
Sulfate	1500	41	0.08	0.002
Uranium	3.7	0.1	0.0002	0.002
Carcinogenic effects				
Lead-210	220	10,000,000	20,000	0.002
Polonium-210	0.8	40,000	80	0.002
Radium-226	2.4	100,000	200	0.002
Thorium-210	0.8	40,000	76	0.002
Uranium[d]	2700	100,000,000	300,000	0.002
UC site				
Noncarcinogenic effects				
Cadmium	0.025	0.0007	0.000001	0.002
Chloride	2500	70	0.1	0.002
Iron	12	0.3	0.0006	0.002
Manganese	6.9	0.2	0.0004	0.002
Molybdenum	1.81	0.05	0.0001	0.002
Nitrate	1400	37	0.07	0.002
Selenium	1.1	0.03	0.00006	0.002

Table 4.1 Exposure dose calculations for ground water ingestion and dermal contact, NC and UC sites, near Slick Rock, Colorado (Continued)

Contaminant of potential concern	Cw^b	Ground water exposure doses[a]		Ratio of dermal contact to ingestion[c]
		Ingestion	Dermal contact	
UC site				
Sodium	1200	33	0.06	0.002
Strontium	8.7	0.24	0.0005	0.002
Sulfate	2900	79	0.015	0.002
Uranium	0.11	0.003	0.000006	0.002
Vanadium	0.65	0.02	0.00003	0.002
Carcinogenic effects				
Lead-210	6.5	300,000	620	0.002
Polonium-210	0.40	20,000	38	0.002
Radium-226	3.3	200,000	310	0.002
Thorium-210	0.80	40,000	76	0.002
Uranium[d]	160	8,000,000	20,000	0.002

Equation definitions for exposure dose calculations

Ingestion of ground water

Noncarcinogens

$$\text{Chronic daily intake (mg/kg-day)} = \frac{Cw \times IRw \times EF \times ED}{BW \times AT}$$

Radionuclides

$$\text{Lifetime intake (pCi/lifetime)} = Cw \times IRw \times EF \times ED$$

Table 4.1 Exposure dose calculations for ground water ingestion and dermal contact, NC and UC sites, near Slick Rock, Colorado (Concluded)

Dermal contact with ground water

Noncarcinogens

$$\text{Chronic daily intake (mg/kg-day)} = \frac{(Cw \times SA \times Pc \times Cf) \times ET \times EF \times ED}{BW \times AT}$$

Radionuclides

$$\text{Lifetime intake (pCi/lifetime)} = Cw \times SA \times Pc \times Cf \times ET \times EF \times ED$$

Where:

Cw = Contaminant concentration in ground water (milligrams per liter or picocuries per liter).
IRw = Ingestion rate for water (2 L per day for an adult).
EF = Exposure frequency (350 days per year).
ED = Exposure duration (70 years for an adult).
BW = Body weight (70 kg for an adult).
AT = Averaging time (365 days x ED for noncarcinogens).
SA = Skin surface area (19,400 square centimeters).
Pc = Dermal permeability constant (0.001 cm per hour).
Cf = Conversion factor (0.001 L per cubic centimeter).
ET = Exposure time (0.2 hour per day).

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[a] Noncarcinogen concentrations are reported in milligrams per kilogram per day. Carcinogens are reported in picocuries per lifetime.
[b] Noncarcinogen concentrations are reported in milligrams per liter. Carcinogens are reported in picocuries per liter.
[c] Calculated by dividing the dermal contact exposure dose by the ingestion exposure dose.
[d] Concentration reported is for uranium-234 and uranium-238 combined.

mg/kg-day - milligrams per kilogram per day.

drinking water pathway for the contaminants of potential concern. Because chemical-specific absorption factors are not available for these contaminants, they are assumed to absorb across the skin at the same rate as water. This assumption will probably overestimate any potential contribution from dermal absorption.

For all contaminants of potential concern for both sites, additional exposure doses were calculated of considerably less than 1 percent, relative to drinking water ingestion. Based on these results, dermal absorption was eliminated from more detailed evaluation because at these exposure doses, adverse toxic effects would not be expected if dermal contact were the only exposure pathway considered.

4.2.3 Ingestion of ground water-irrigated produce

The ingestion of ground water-irrigated produce was also evaluated for its potential adverse effect contribution relative to the drinking water ingestion exposure pathway. The assumptions for this evaluation will probably overestimate the potential for exposure from this route, because the garden produce watered with contaminated ground water is assumed to be the source of all garden produce in the diet. The results of this screening show that, for most contaminants of potential concern at both sites, ingesting garden vegetables and fruit irrigated with contaminated ground water would lead to potential dose exposures of considerably less than 1 percent than those associated with the drinking water ingestion pathway for the same contaminant. At these levels, garden produce ingestion exposures would not be expected to cause toxic effects. However, at the NC site, lead-210 would contribute an additional 5 percent exposure dose from the produce ingestion pathway relative to the ground water ingestion pathway. At the UC site, the additional risk from the produce ingestion pathway to the ground water ingestion pathway included cadmium (43 percent), chloride (4 percent), manganese (1 percent), molybdenum (6 percent), strontium (50 percent), and lead-210 (7 percent). The impact of this additional source will be discussed in Sections 6.1 and 6.2. Table 4.2 gives the results of the screening calculations for the ground water irrigated garden produce pathway for both the NC and UC sites.

4.2.4 Ingestion of milk or meat from ground water-fed livestock

These pathways were eliminated from evaluation for the UC site because the concentrations of nitrate and sulfate (in conjunction with TDS) are so high that livestock could not survive long-term ingestion of the ground water. If the livestock cannot consume the water, constituents cannot bioaccumulate or transfer to livestock muscle tissue or milk. This topic is further discussed in the ecological assessment in Section 7.0.

At the NC site, however, nitrate and sulfate concentrations are detected at levels that would permit long-term ground water ingestion by livestock. Therefore, the meat and milk ingestion pathways were evaluated for the NC site.

Table 4.2 Exposure dose calculations for the ingestion of ground water-irrigated garden produce, NC and UC sites, near Slick Rock, Colorado

Contaminant of potential concern	Cw^b	Kd (L/kg)	Bv	Br	Ground water ingestion exposure dose^c	Garden produce ingestion exposure doses^a (mg/kg-day)	Ratio of produce ingestion to water ingestion^d
NC site							
Noncarcinogenic effects							
Manganese	0.61	25.3	0.25	0.05	0.017	2E-04	0.01
Sodium	600	0.2	0.075	0.055	17	0.0006	0.00004
Sulfate	1500	0	0.5	0.5	41	e	e
Uranium	3.7	50	0.0085	0.004	0.1	0.00009	0.0009
Carcinogenic effects							
Lead-210	220	597	0.045	0.009	10,000,000	500,000	0.05
Polonium-210	0.8	14.9	0.0025	0.0004	40,000	2.6	0.00007
Radium-226	2.4	100	0.015	0.0015	100,000	310	0.003
Thorium-230	0.8	500	0.00085	0.000085	40,000	30	0.0008
Uranium^f	2700	50	0.0085	0.004	100,000,000	100,000	0.001
UC site							
Noncarcinogenic effects							
Cadmium	0.025	423	0.55	0.15	0.0007	0.0003	0.43
Chloride	2400	0.25	70	70	68	3	0.04
Iron	12	15	0.004	0.001	0.3	0.00004	0.0001
Manganese	6.9	25.3	0.25	0.05	0.2	0.002	0.01
Molybdenum	1.8	120	0.25	0.06	0.05	0.003	0.06
Nitrate	1400	0	30	30	37	e	e
Selenium	1.1	14.9	0.025	0.025	0.03	0.00003	0.001
Sodium	1200	0.2	0.075	0.055	33	0.001	0.00003
Strontium	8.7	100	2.5	0.25	0.2	0.1	0.5
Sulfate	2900	0	0.5	0.5	79	e	e
Uranium	0.11	50	0.0085	0.004	3E-03	0.000003	0.001
Vanadium	0.65	100	0.0055	0.003	2E-02	0.00002	0.001
Carcinogenic effects							
Lead-210	6.5	597	0.045	0.009	300,000	20,000	0.07

Table 4.2 Exposure dose calculations for the ingestion of ground water-irrigated garden produce, NC and UC sites, near Slick Rock, Colorado (Concluded)

Contaminant of potential concern	Cw[b]	Kd (L/kg)	Bv	BR	Ground water ingestion exposure dose[c]	Garden produce ingestion exposure dose[a] (mg/kg-day)	Ratio of produce ingestion to water ingestion[d]
Polonium-210	0.4	14.9	0.0025	0.0004	20,000	1.3	0.00007
Radium-226	3.3	100	0.015	0.0015	200,000	400	0.002
Thorium-230	0.8	500	0.00085	0.000085	20,000	30	0.0008
Uranium[f]	160	50	0.0085	0.004	8,000,000	7,000	0.0009

Equation definitions for exposure dose calculations

Ingestion of garden produce irrigated with ground water

Chemicals

$$\text{Chronic daily intake (mg/kg-day)} = \frac{\text{Cw x Kd x (Bv or Br) DF x IRp x FI x EF x ED}}{\text{BW x AT}}$$

Radionuclides

$$\text{Lifetime intake (pCi/lifetime)} = \text{Cw x Kd x (Bv or Br) x DF x IRp x FI x EF x ED}$$

Where:

CW = Contaminant concentration in ground water (milligrams per liter or picocuries per liter).
Kd = Soil-water partition coefficient (liters per kilogram) (PNL, 1989).
Bv = Soil-to-plant concentration ratio for vegetative portions of plants (unitless) (Baes et al., 1984).
Br = Soil-to-plant concentration ratio for reproductive portions (fruits, tubers) of plants (unitless) (Baes et al., 1984).
DF = Dry weight fraction of plant (0.066 unitless).
IRp = Ingestion rate for garden produce (0.05 kilograms per day for vegetative parts; 0.03 kilograms per day for reproductive parts).
FI = Fraction of garden produce ingested from contaminated source (1.0 unitless).
EF = Exposure frequency (350 days per year).
ED = Exposure duration (70 years for an adult).
BW = Body weight (70 kilograms for an adult).
AT = Averaging time (365 days x ED for noncarcinogens).

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[a] The exposure doses presented are the sum of the vegetative parts of the plant and the reproductive parts.

[b] The units for noncarcinogens are in milligrams per liter. For carcinogens, the units are in picocuries per liter.

[c] The units for noncarcinogens are in milligrams per kilogram per day. For carcinogens, the units are in picocuries per lifetime.

[d] The ratio is calculated by dividing the dermal contact exposure dose by the ingestion exposure dose.

[e] Ratio cannot be calculated because the Kd value is equal to zero.

[f] Concentration reported is for uranium-234 and uranium-238 combined.

The exposure dose contribution from ingesting milk from ground water-fed livestock is less than 2 percent total of the ground water ingestion pathway (these contaminants include manganese, uranium [as a noncarcinogen], polonium-210, radium-226, and thorium-230). Sodium, sulfate, lead-210, and uranium contributed 1 percent or greater additional dose. At these levels, milk ingestion was determined to not cause toxic effects. However, sodium could contribute an additional exposure dose of 25 percent and sulfate could contribute an additional 5 percent to the drinking water ingestion pathway. Additionally, lead-210 contributed 3 percent; radium-226 contributed 1 percent; and as a carcinogen, uranium contributed 1 percent. Table 4.3 presents the results of the screening assessment for the milk ingestion exposure pathway.

Ingesting meat from ground water-fed livestock at the NC site would also contribute to the exposure dose of sodium (10 percent) and sulfate (8 percent), relative to ground water ingestion. Lead-210 contributed approximately 1 percent additional exposure dose, and polonium-210 contributed approximately 2 percent additional exposure dose. The remaining contaminants of potential concern evaluated for meat ingestion are not expected to cause toxic effects at the exposure doses calculated. The impact of the additional milk and meat sources is discussed in Sections 6.1 and 6.2. Table 4.4 presents the results of the screening assessment for the meat ingestion exposure pathway.

4.2.5 Summary

The results from all of the screening pathways (ground water ingestion, dermal contact with ground water, and garden produce, milk, and meat ingestion) indicate drinking water ingestion is the primary exposure pathway for potential adverse health effects. Therefore, the only exposure pathway probabilistically evaluated was the ingestion of drinking water. However, ingestion of garden-irrigated produce for both the NC and UC sites and ingestion of contaminated milk and meat from the NC site are other exposure pathways that may contribute adverse impacts to human health. The impact of the additional exposure dose due to these exposure pathways are qualitatively addressed in Sections 6.1 and 6.2.

For the probabilistic intake distribution evaluation, the drinking water ingestion scenario evaluates domestic ground water use by the rural population in the region. The potentially exposed populations for the distributions included the following age groups: infants (birth to 1 year old), children (1 to 10 years old), and adults (11 to 64 years old). These age groups were selected for the following reasons:

- Survey data for population variables such as age, weight, and daily water intake are available for these age groups.
- Toxicological variables are similar within these age groups, including responsiveness of sensitive subgroups (infants and children) to the contaminants of potential concern, toxicant intake to body weight ratios, and toxicokinetics.

Table 4.3 Exposure dose calculations for ingestion of milk from ground water-fed livestock, NC site, near Slick Rock, Colorado

Contaminant of potential concern	Cw[a]	Kd (L/kg)	Bv	Fm	Ground water ingestion exposure dose[b]	Milk ingestion exposure dose[b]	Ratio of milk ingestion to water ingestion[c]
Noncarcinogenic effects							
Manganese	0.61	25.3	0.25	0.00035	0.017	0.0002	0.01
Sodium	600	0.2	0.075	0.035	20	5	0.25
Sulfate	1500	0	0.5	0.005	40	2	0.05
Uranium	3.7	50	0.0085	0.0006	0.1	0.0008	0.008
Carcinogenic effects							
Lead-210	220	597	0.045	0.00025	10,000,000	300,000	0.03
Polonium-210	0.8	14.9	0.0025	0.00035	40,000	100	0.003
Radium-226	2.4	100	0.015	0.00045	100,000	1,000	0.01
Thorium-230	0.8	500	0.00085	0.000005	40,000	7	0.0002
Uranium[d]	2700	50	0.0085	0.0006	100,000,000	1,000,000	0.01

Equation definitions for exposure dose calculations

Ingestion of garden produce irrigated with ground water

Chemicals

$$\text{Chronic daily intake (mg/kg-day)} = \frac{\text{Cm x IRm x FI x EF x ED}}{\text{BW x AT}}$$

Radionuclides

$$\text{Lifetime intake (pCi/lifetime)} = \text{Cm x IRm x FI x EF x ED}$$

Table 4.3 Exposure dose calculations for ingestion of milk from ground water-fed livestock, NC site, near Slick Rock, Colorado (Concluded)

Where:

CM = Contaminant concentration in milk (milligrams per liter or picocuries per liter, estimated using the following equations:
Cm = Fm x ([Qp x Cp] + [Qs x Cs] + [Qw x Cw]).
where
Fm = Feed-to-milk transfer coefficient (days per kilogram).
Qp = The quantity of pasture eaten by cattle per day (19 kg per day).
Qs = The quantity of soil eaten by cattle per day (0.38 kg per day).
Qw = The quantity of water consumed by cattle per day (56 L per day).
Cp = Contaminant concentration in pasture (milligrams per kilogram). Cp = Kd x Cw x Bv.
Cs = Contaminant concentration in soil (milligrams per kilogram). Cs = Kd x Cw.
Cw = Contaminant concentration in ground water (milligrams per liter or picocuries per liter.
Kd = Soil-water partition coefficient (liters per kilogram); from PNL (1989), except for nitrate and chloride from ORNL (1984).
Bv = Soil-to-plant concentration ratio for vegetative portions of plants (unitless); from ORNL (1984).
EF = Exposure frequency (350 days per year).
ED = Exposure duration (70 years for an adult).
BW = Body weight (70 kg for an adult).
AT = Averaging time (350 days x ED for noncarcinogens).
IRm = Ingestion rate of milk (0.3 kg per day).
FI = Fraction of milk ingested from contaminated source (1.0 unitless).

---

[a] Noncarcinogens are reported in milligrams per liter. Carcinogens are reported in picocuries per liter.

[b] Noncarcinogens are reported in milligrams per kilogram per day. Carcinogens are reported in picocuries per lifetime.

[c] Calculated by dividing the dermal contact exposure dose.

[d] Concentration reported is for uranium-234 and uranium-238 combined.

Table 4.4 Exposure dose calculations for ingestion of meat from ground water-fed livestock, NC site, near Slick Rock, Colorado

Contaminant of potential concern	Cw[a]	Bv	Ff	Ground water ingestion exposure dose[b]	Meat ingestion exposure dose[b]	Ratio meat ingestion to ground water ingestion[c]
Noncarcinogenic effects						
Manganese	0.61	0.25	0.0004	0.017	0.00005	0.003
Sodium	600	0.075	0.055	20	2	0.1
Sulfate	1500	0.5	0.033	40	3	0.08
Uranium	3.7	0.0085	0.0002	0.1	0.00006	0.0006
Carcinogenic effects						
Lead-210	220	0.045	0.0003	10,000,000	90,000	0.009
Polonium-210	0.8	0.0025	0.0095	40,000	900	0.02
Radium-226	2.4	0.015	0.00025	100,000	100	0.001
Thorium-230	0.8	0.00085	0.000006	40,000	2	0.00005
Uranium[d]	2700	0.0085	0.0002	100,000,000	80,000	0.0008

Equation definitions for exposure dose calculations
Ingestion of meat from ground water-fed livestock

Chemicals

$$\text{Chronic daily intake (mg/kg-day)} = \frac{\text{Cb} \times \text{IRb} \times \text{FI} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}}$$

Radionuclides

$$\text{Lifetime intake (pCi/lifetime)} = \text{Cb} \times \text{IRb} \times \text{FI} \times \text{EF} \times \text{ED}$$

Table 4.4 Exposure dose calculations for ingestion of meat from ground water-fed livestock, NC site near Slick Rock, Colorado (Concluded)

Where:

Cb = Contaminant concentration in beef (milligrams per kilogram or picocuries per kilogram), estimated using the following equation:
Cb = Ff x ([Qp x Cp] + [Qs x Cs] + [Qw x Cw]).
where
Ff = Feed-to-flesh transfer coefficient (days per kilogram).
Qp The quantity of pasture eaten by cattle per day (19 kg per day).
Qs = The quantity of soil eaten by cattle per day (0.38 kg per day).
Qw = The quantity of water consumed by cattle per day (56 L per day).
Cp = Contaminant concentration in pasture (milligrams per kilogram). Cp = Kd x Cw x Bv.
Cs = Contaminant concentration in soil (milligrams per kilogram). Cs = Kd x Cw.
Cw = Contaminant concentration in ground water (maximum concentration detected) (milligrams per liter or picocuries per liter).
Kd = Soil-water partition coefficient (liters per kilogram) (PNL, 1989).
Bv = Soil-to-plant concentration ratio for vegetative portions of plants (unitless).
EF = Exposure frequency (350 days per year).
ED = Exposure duration (70 years for an adult).
BW = Body weight (70 kg for an adult).
AT = Averaging time (365 days x ED for noncarcinogens).
IRb = Ingestion of meat (0.075 kg per day).
FI = Fraction of meat ingested from contaminated source (1.0 unitless).

---

[a] Noncarcinogens are reported in milligrams per liter. Carcinogens are reported in picocuries per liter.

[b] Noncarcinogens are reported in milligrams per kilogram per day. Carcinogens are reported in picocuries per lifetime.

[c] Calculated by dividing the dermal contact exposure dose by the ingestion exposure dose.

[d] Concentration reported is for uranium-234 and uranium-238 combined.

4.3 EXPOSURE CONCENTRATIONS

The exposure concentration of a contaminant in ground water is defined as the concentration an individual is assumed to take in over a specific period. For this baseline risk assessment, the contaminant concentrations are assumed to be in a steady state, although actual constituent concentrations (and therefore exposures) are expected to decrease with time after the tailings are removed. Chronic exposure for noncarcinogens is considered exposure for any period longer than 7 years.

For noncarcinogens, exposure concentrations were evaluated as a probability of occurrence based on ground water data collected from monitor wells on the former Slick Rock processing sites. The wells that have consistently shown the highest concentrations of most contaminants since 1986 were included in the distributions. Monitor well SRK-01-0503 was evaluated at the NC site. Monitor wells SRK-01-0506, -0508, and -0510 were evaluated at the UC site. These wells are all within the site boundaries.

The probability distribution selected for each contaminant of potential concern reflected the same mean, median, standard deviation, and shape observed in historical water quality data. The upper tail of each distribution was truncated at the 99th percentile. For every contaminant of potential concern, this highest allowable concentration was higher than the maximum observed concentration in the historical water quality data. The software package @RISK (Palisade Corporation, 1992) was used to generate the probability curves of exposure concentrations for the contaminants of potential concern. Figures 4.2 through 4.5 show the results for the NC site and Figures 4.6 through 4.17 show results for the UC site. The exposure concentrations for radionuclides were represented by the maximum detected concentrations at each site.

4.4 ESTIMATION OF INTAKE

Within the population of future residents, individuals are expected to vary with respect to water consumption, stable body weight, and length of time they reside in the potential contamination zone. Consequently, health risks associated with ground water consumption vary among this population. To adequately describe the range of potential risks to the exposed population, naturally occurring variability in daily water intake, body weight, and residence time were incorporated in this assessment through probability distributions; these distributions were generated with information from United States public health and census documents. All distributions were truncated at the upper and lower 0.01 percentile. Within the hypothetical population, values disallowed through this truncation may occur with a probability of less than 1 in 10,000.

The potential toxicity of noncarcinogenic constituents in drinking water depends primarily on long-term average daily consumption of the constituent per kilogram

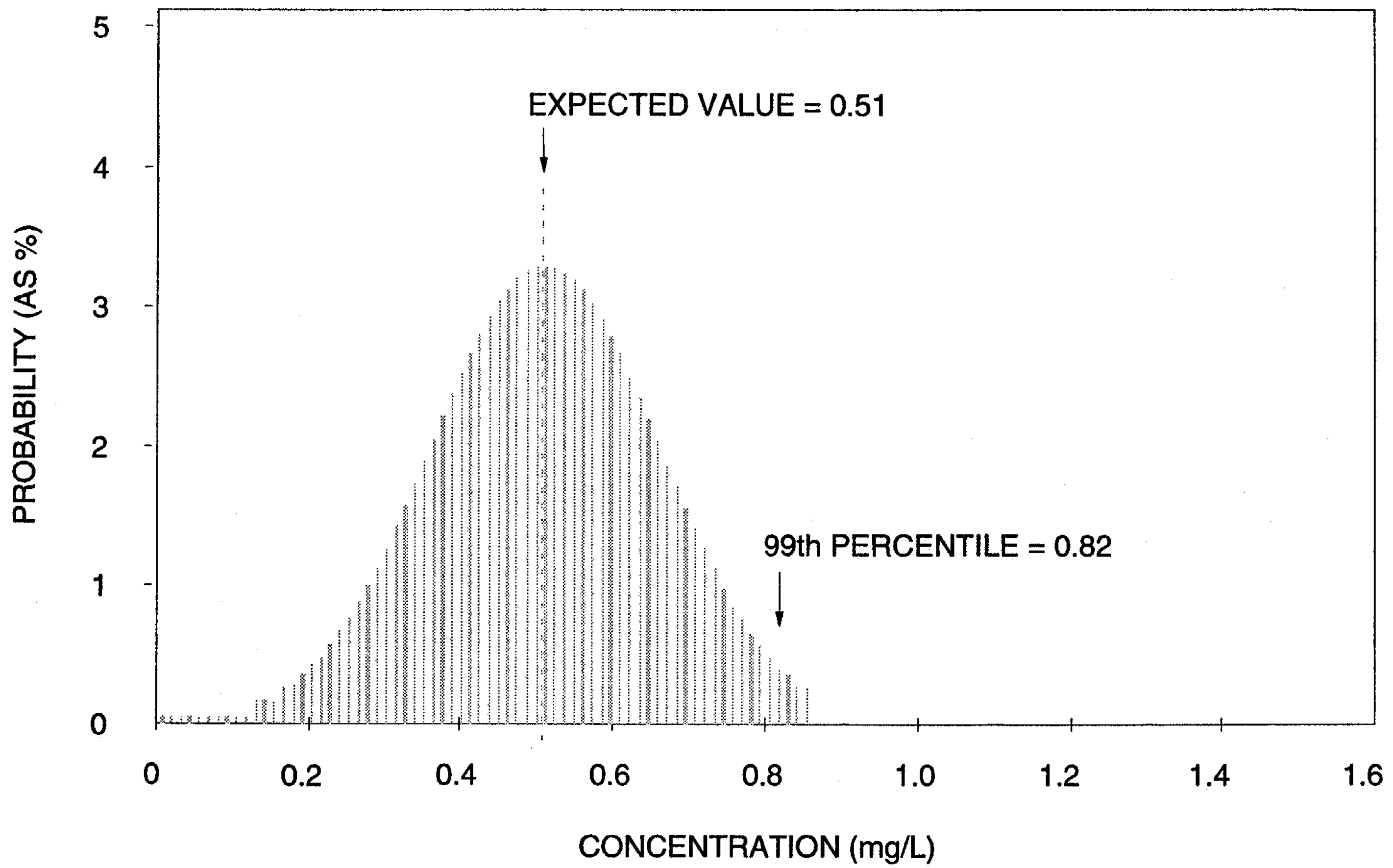

FIGURE 4.2
PROBABILITY DISTRIBUTION OF MANGANESE CONCENTRATIONS
SLICK ROCK, COLORADO, NC SITE

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MANGCONC.DRW

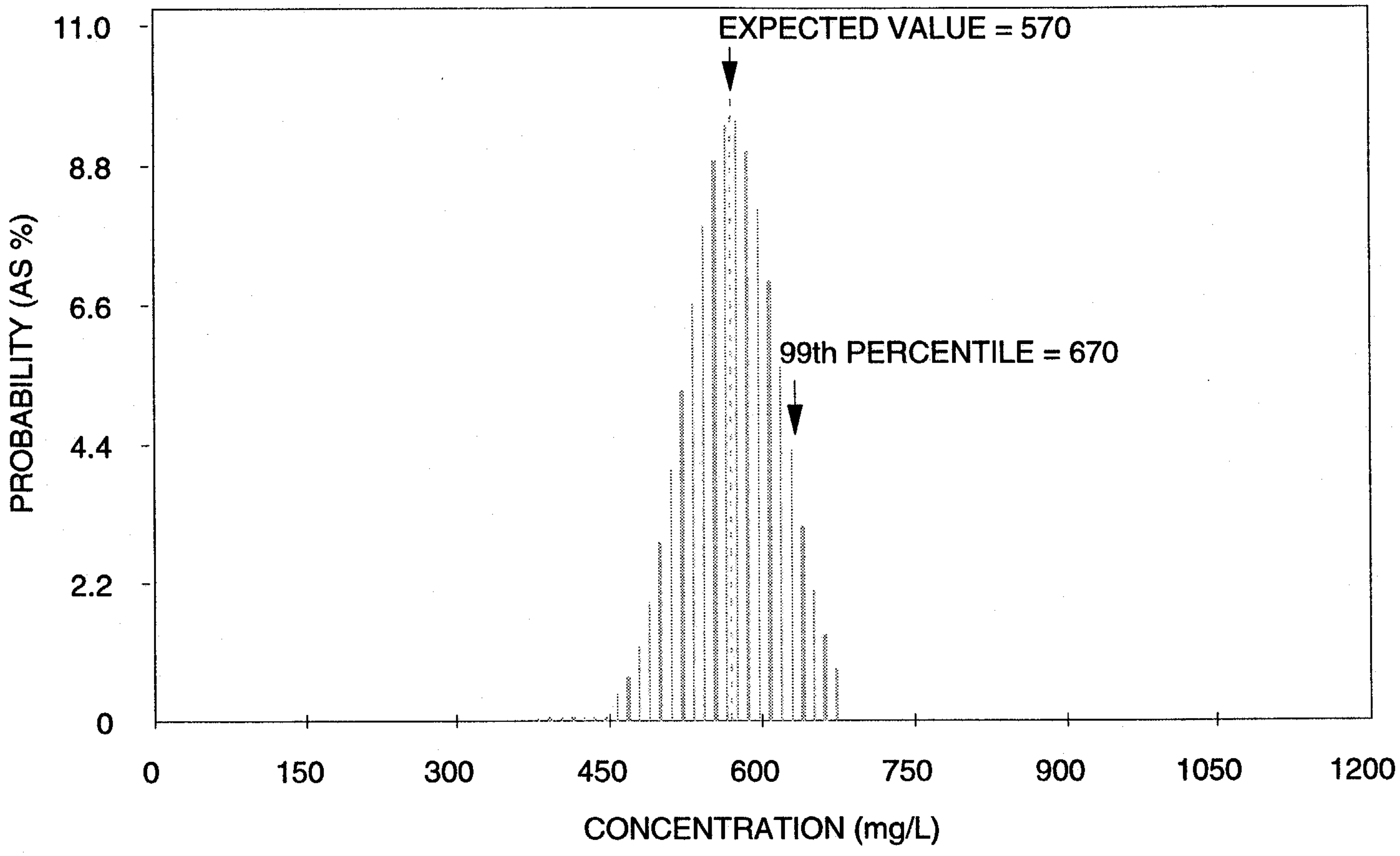

FIGURE 4.3
PROBABILITY DISTRIBUTION OF SODIUM CONCENTRATIONS
SLICK ROCK, COLORADO, NC SITE

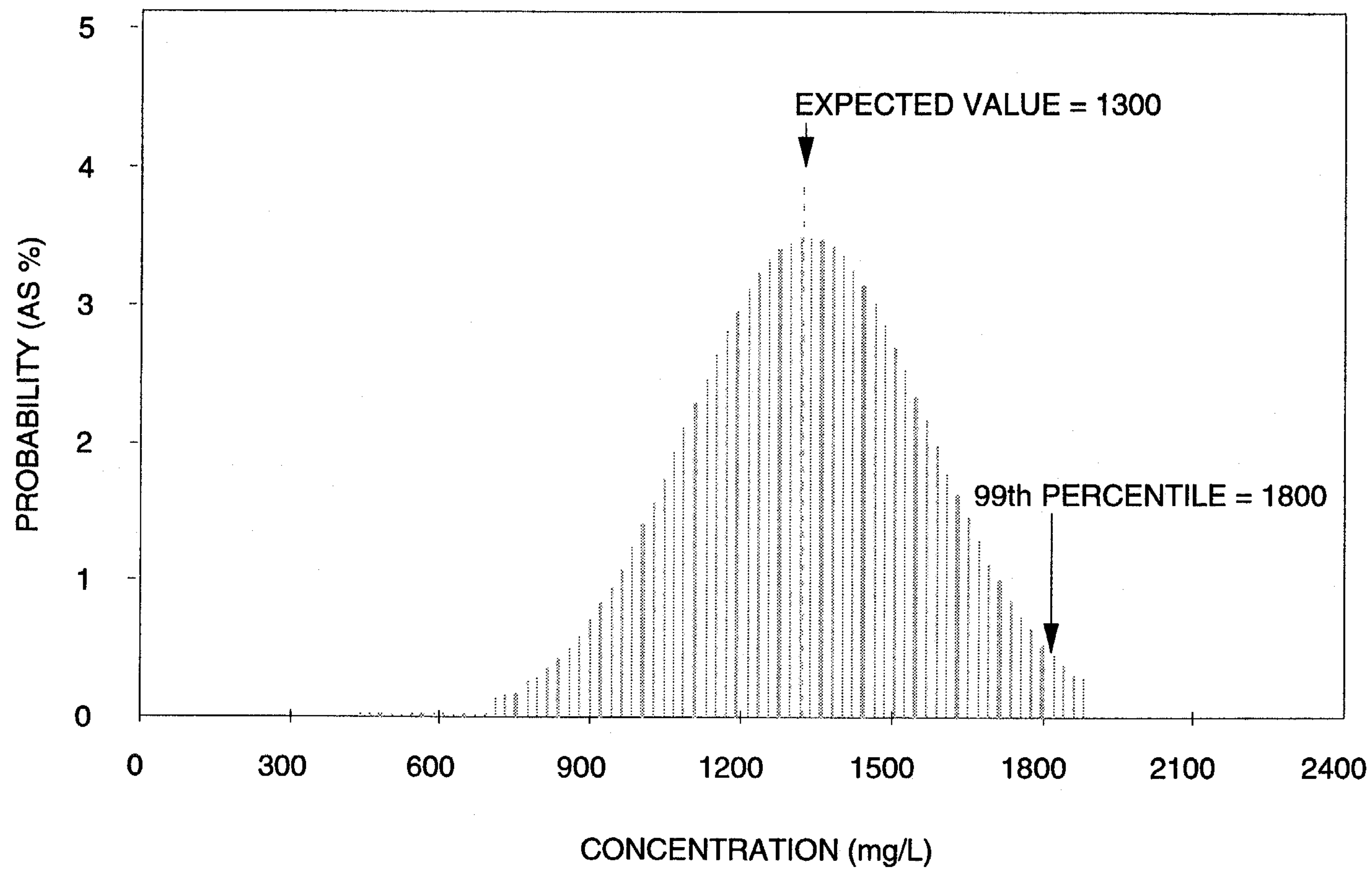

FIGURE 4.4
PROBABILITY DISTRIBUTION OF SULFATE CONCENTRATIONS
SLICK ROCK, COLORADO, NC SITE

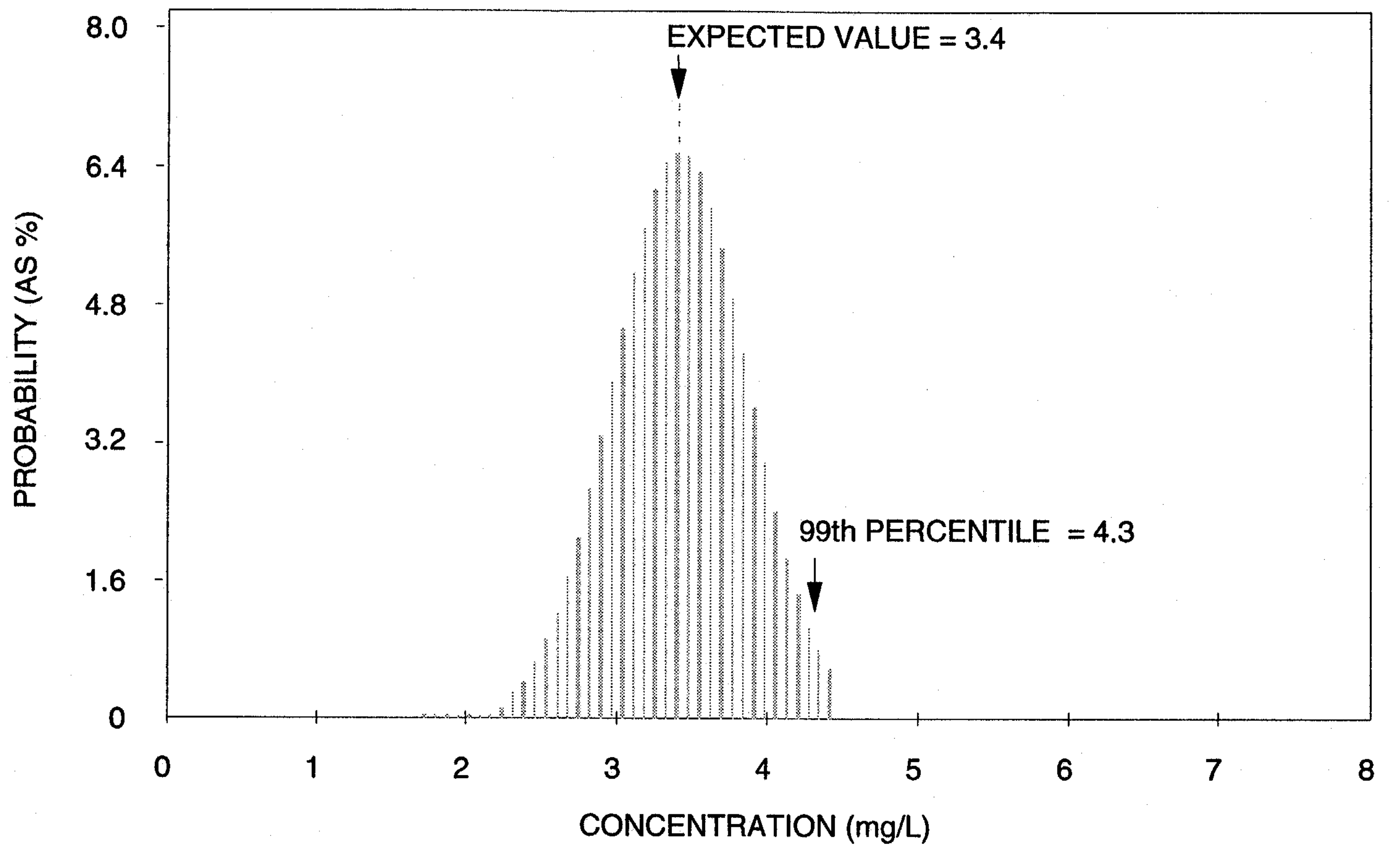

FIGURE 4.5
PROBABILITY DISTRIBUTION OF URANIUM CONCENTRATIONS
SLICK ROCK, COLORADO, NC SITE

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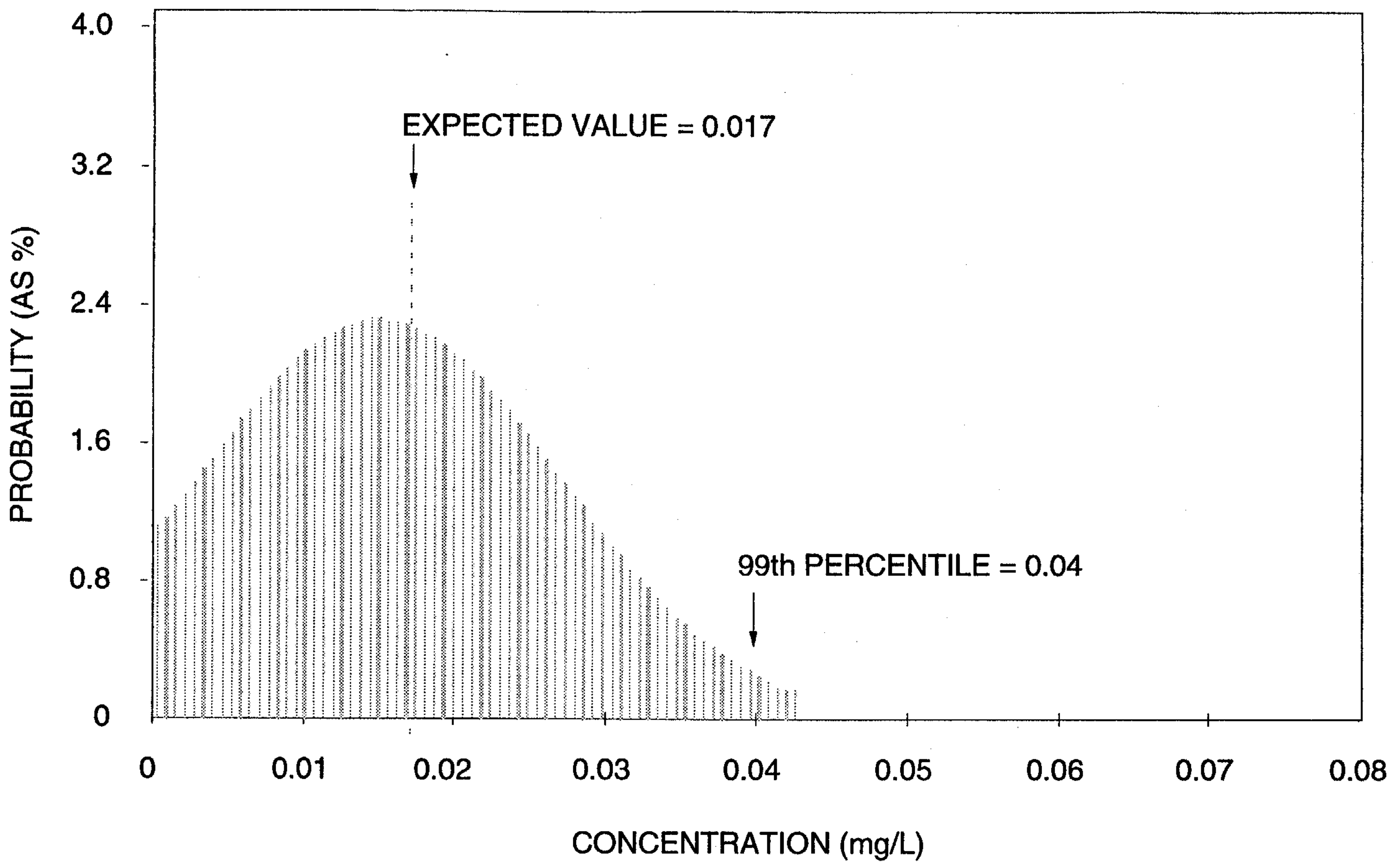

FIGURE 4.6
PROBABILITY DISTRIBUTION OF CADMIUM CONCENTRATIONS
SLICK ROCK, COLORADO, UC SITE

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CADCONUC.DRW

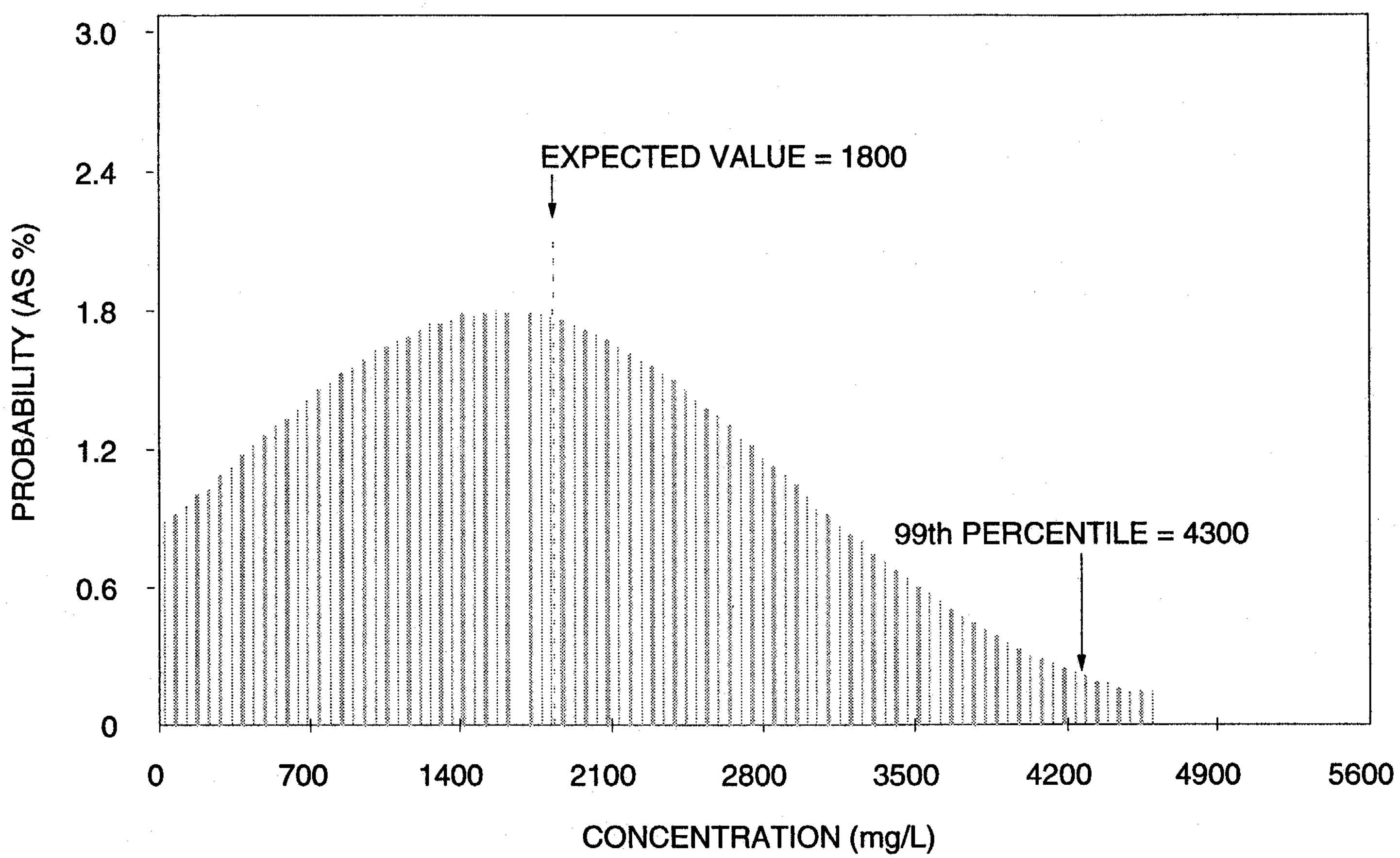

FIGURE 4.7
PROBABILITY DISTRIBUTION OF CHLORIDE CONCENTRATIONS
SLICK ROCK, COLORADO, UC SITE

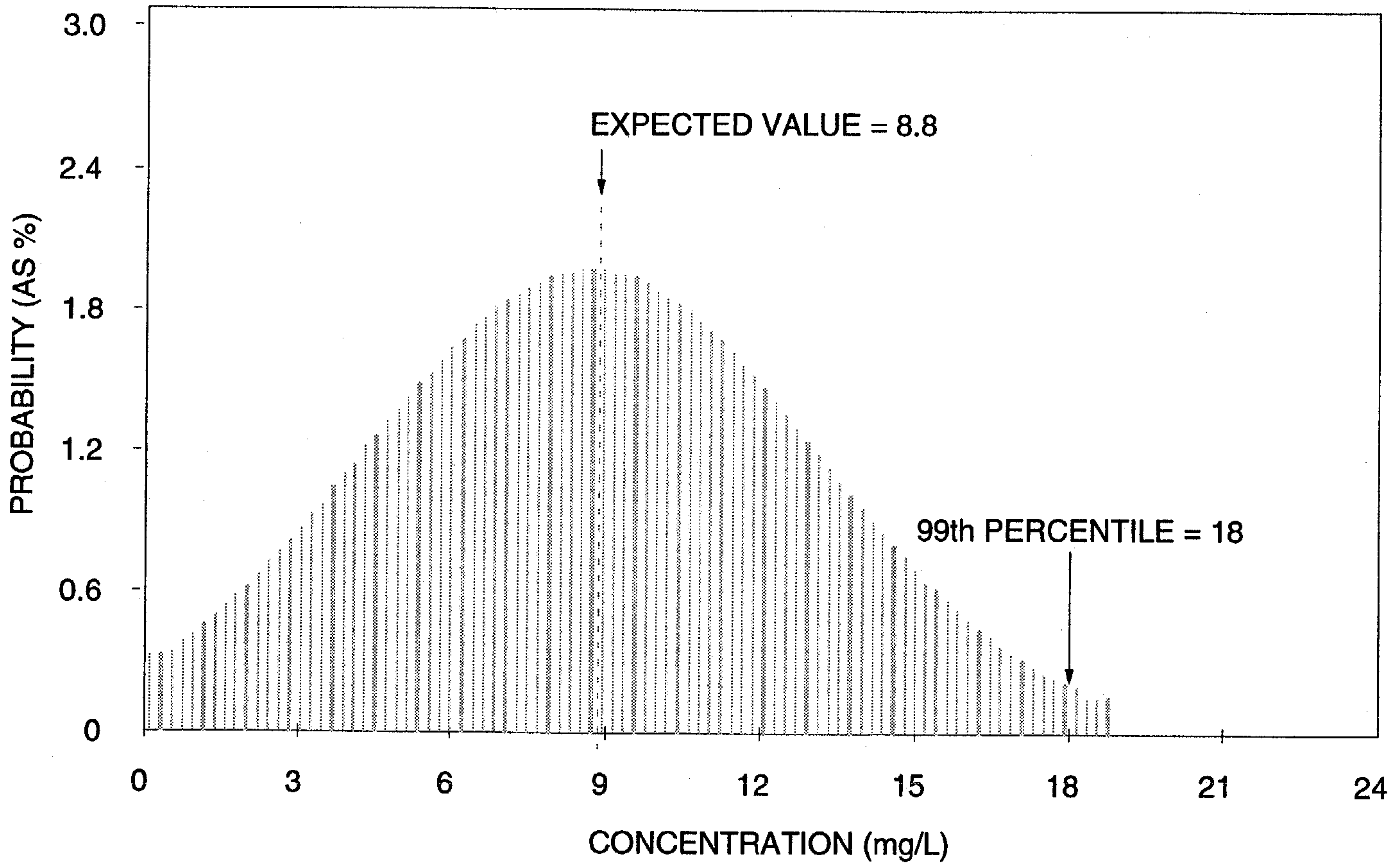

FIGURE 4.8
PROBABILITY DISTRIBUTION OF IRON CONCENTRATIONS
SLICK ROCK, COLORADO, UC SITE

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IROCON.DRW

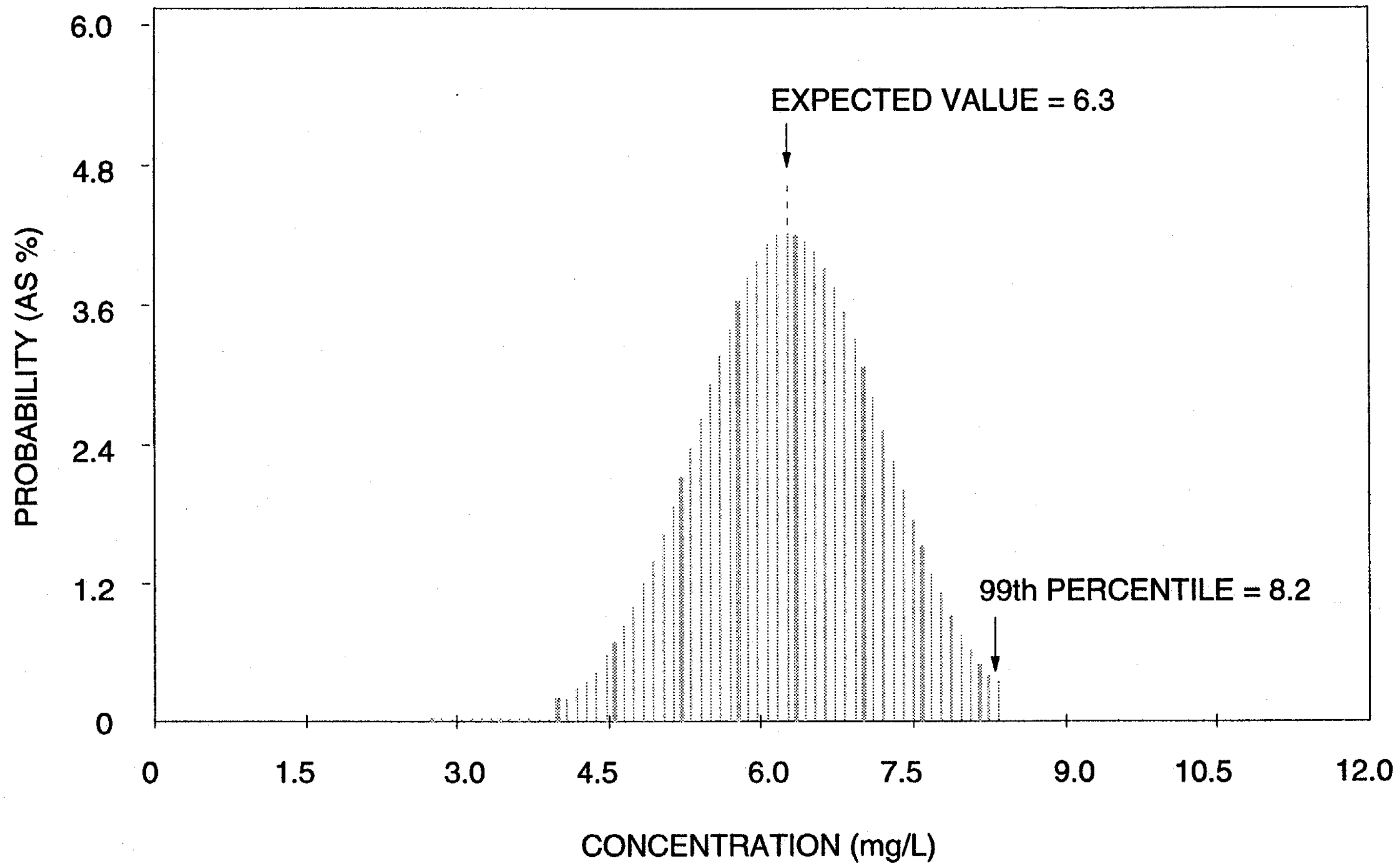

FIGURE 4.9
PROBABILITY DISTRIBUTION OF MANGANESE CONCENTRATIONS
SLICK ROCK, COLORADO, UC SITE

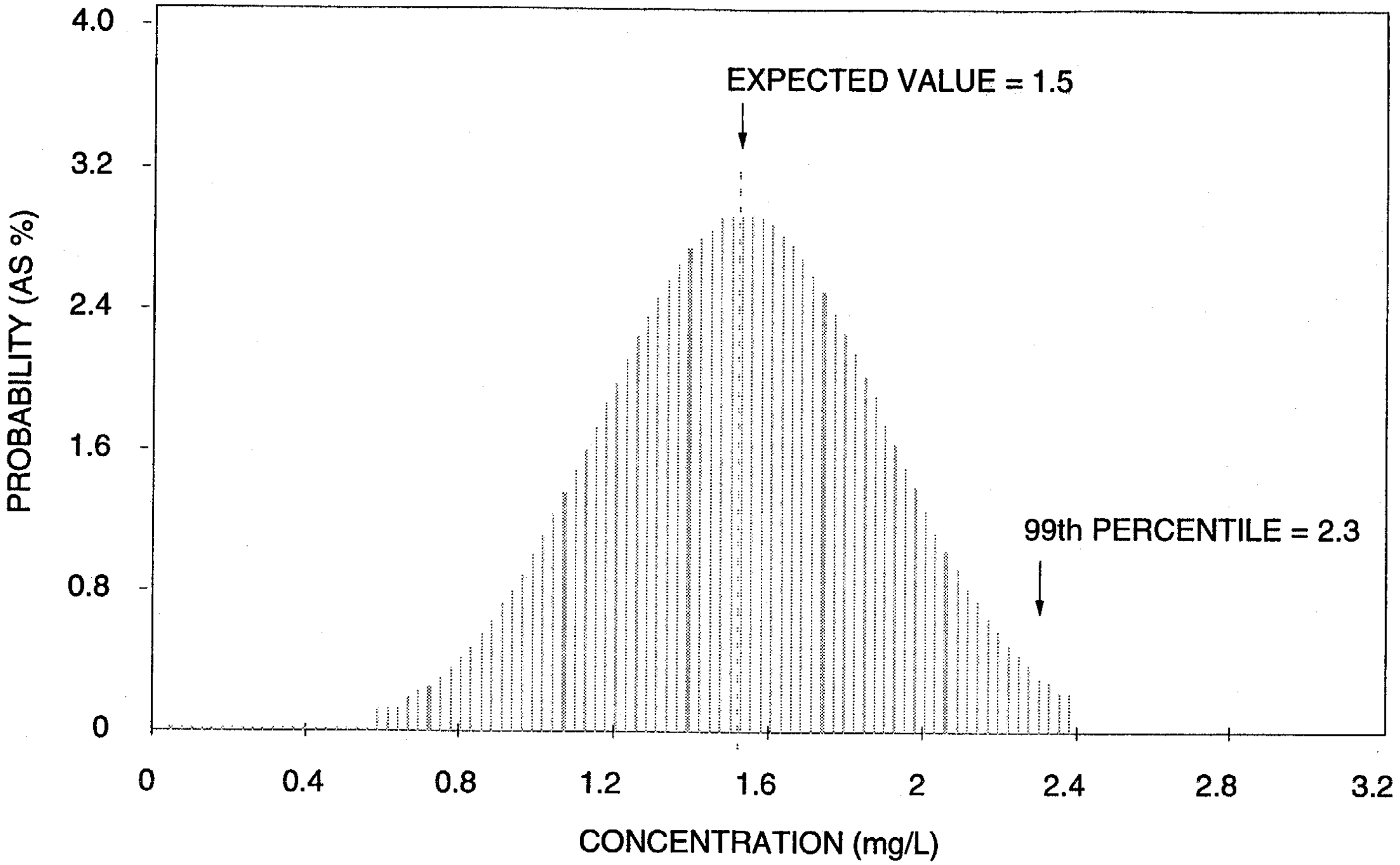

FIGURE 4.10
PROBABILITY DISTRIBUTION OF MOLYBDENUM CONCENTRATIONS
SLICK ROCK, COLORADO, UC SITE

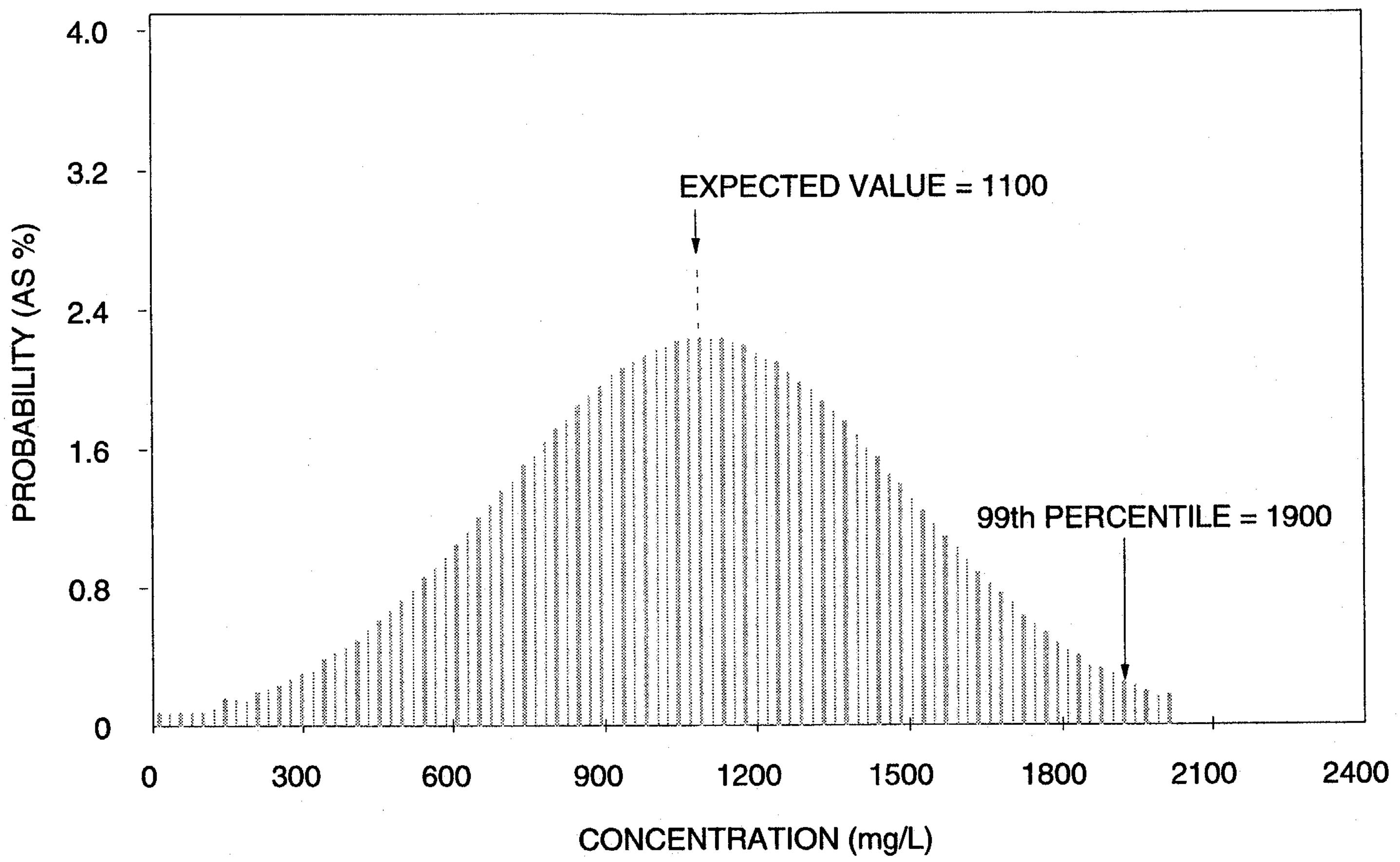

FIGURE 4.11
PROBABILITY DISTRIBUTION OF NITRATE CONCENTRATIONS
SLICK ROCK, COLORADO, UC SITE

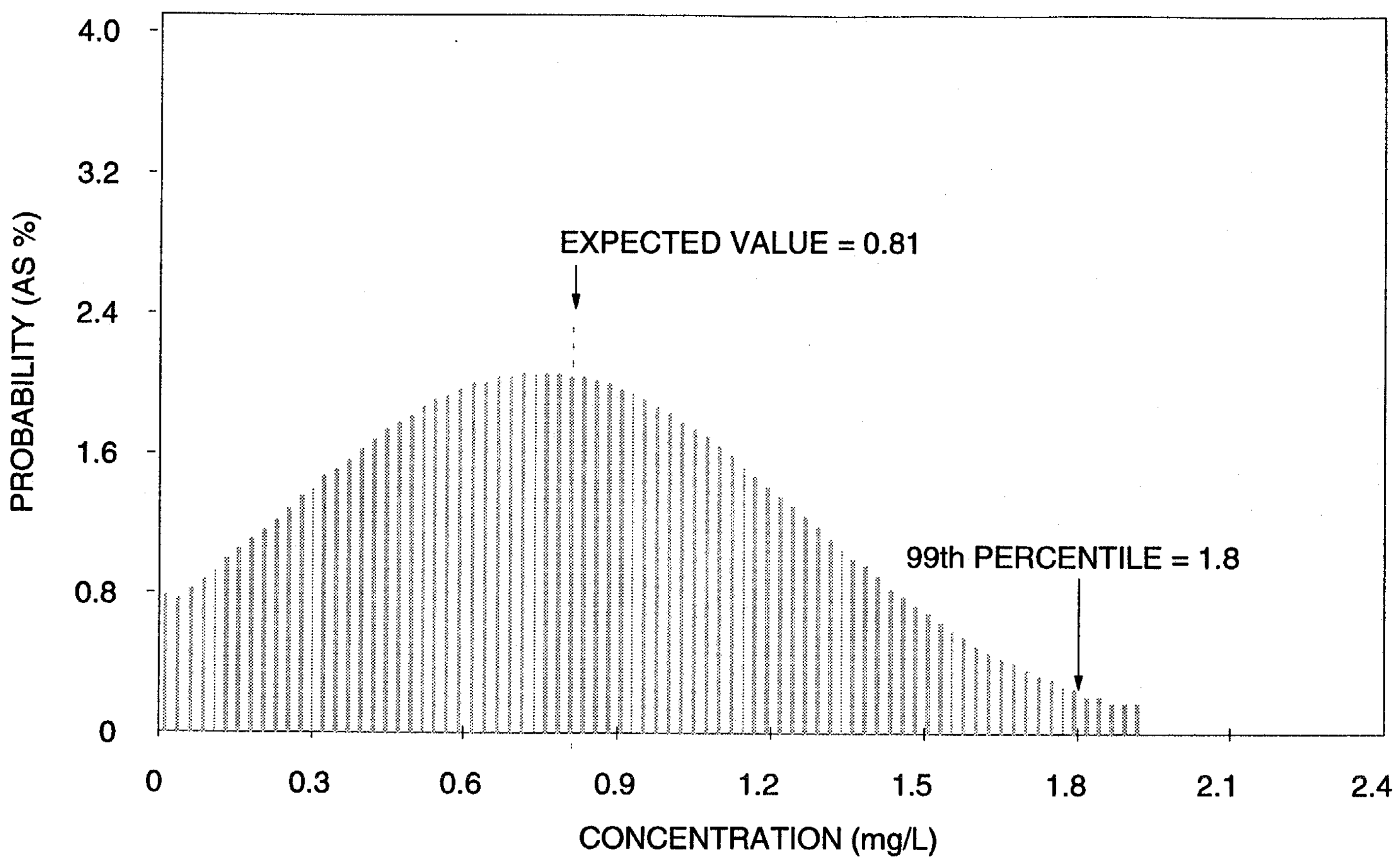

FIGURE 4.12
PROBABILITY DISTRIBUTION OF SELENIUM CONCENTRATIONS
SLICK ROCK, COLORADO, UC SITE

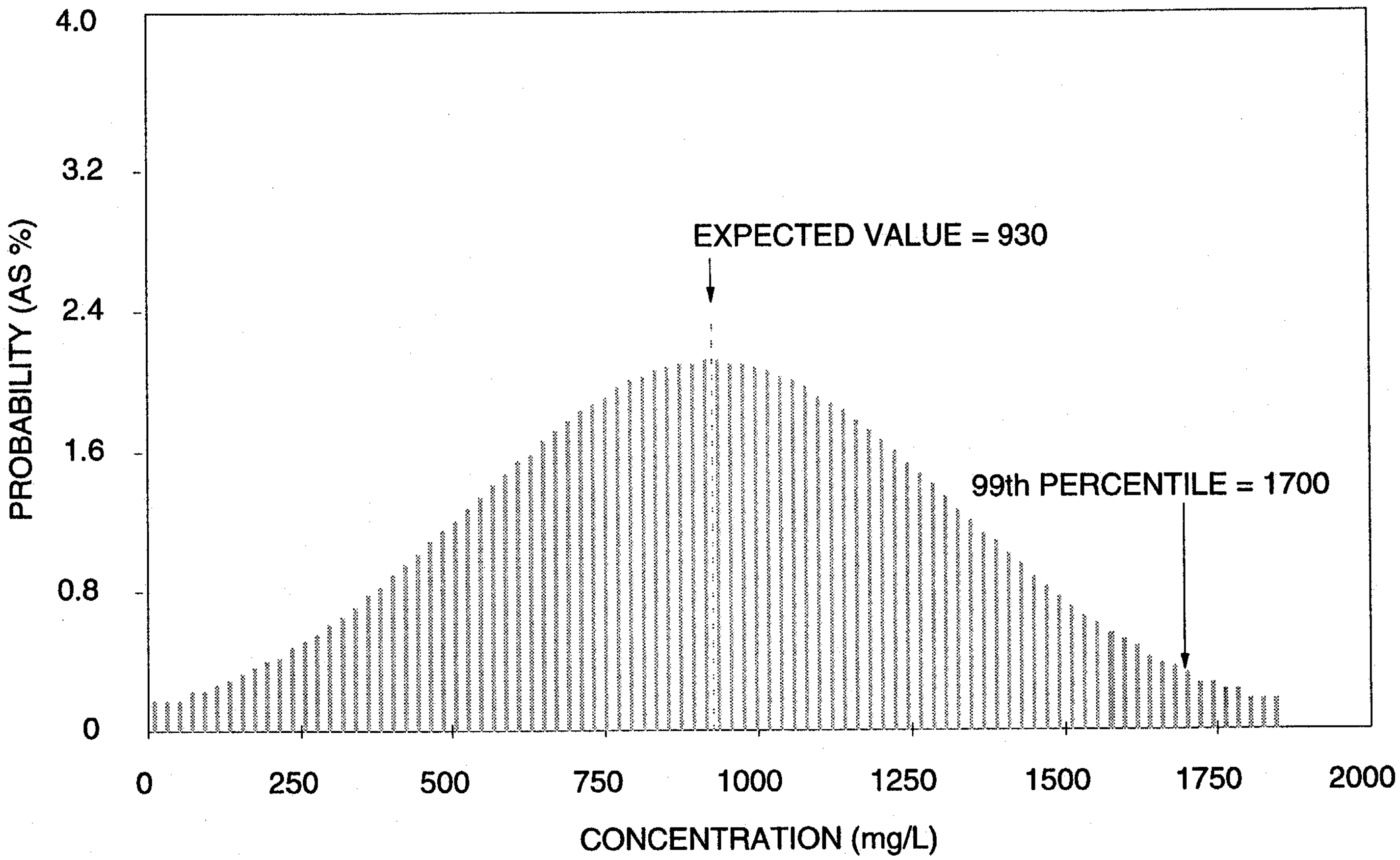

FIGURE 4.13
PROBABILITY DISTRIBUTION OF SODIUM CONCENTRATIONS
SLICK ROCK, COLORADO, UC SITE

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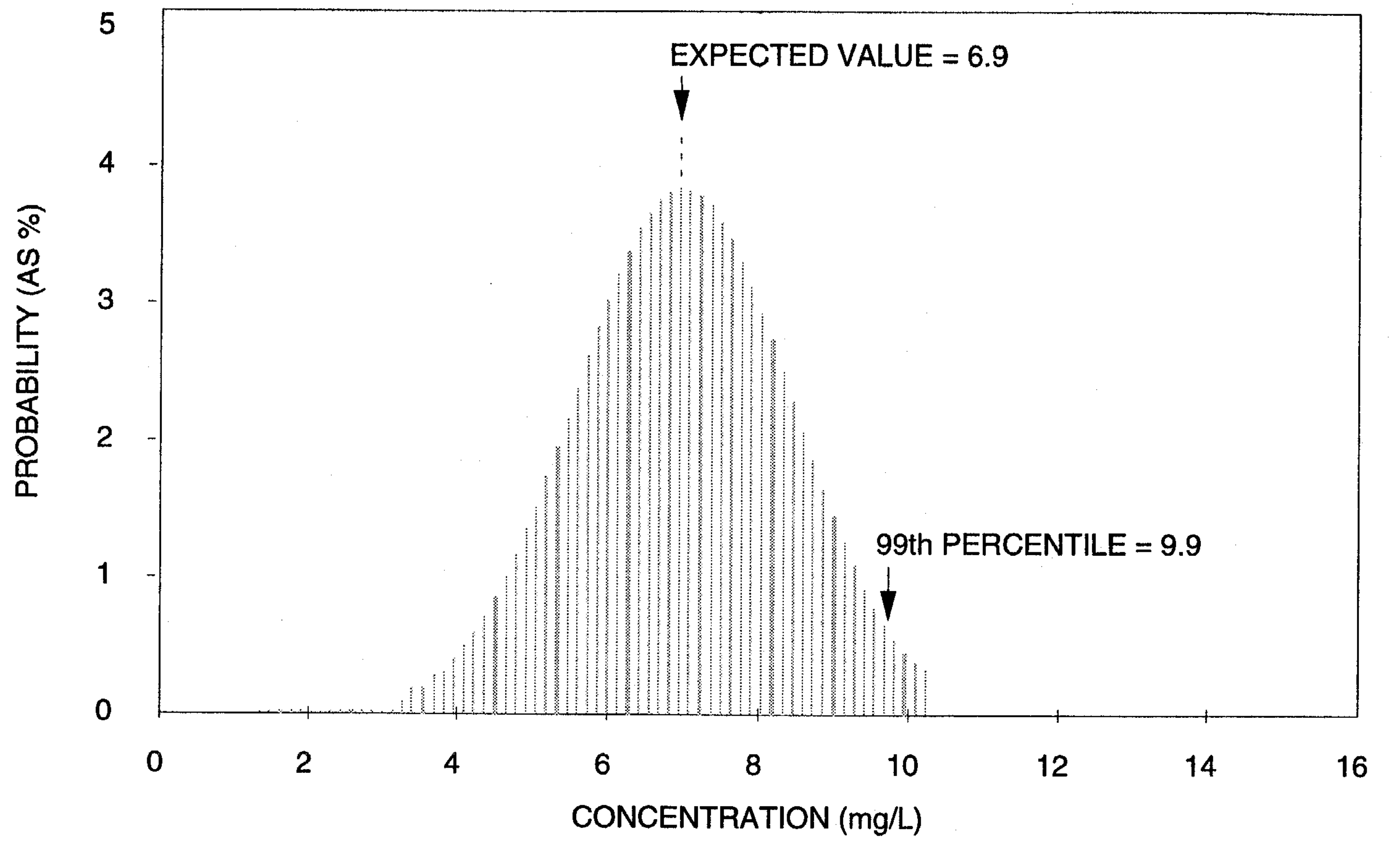

FIGURE 4.14
PROBABILITY DISTRIBUTION OF STRONTIUM CONCENTRATIONS
SLICK ROCK, COLORADO, UC SITE

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STROCON.DRW

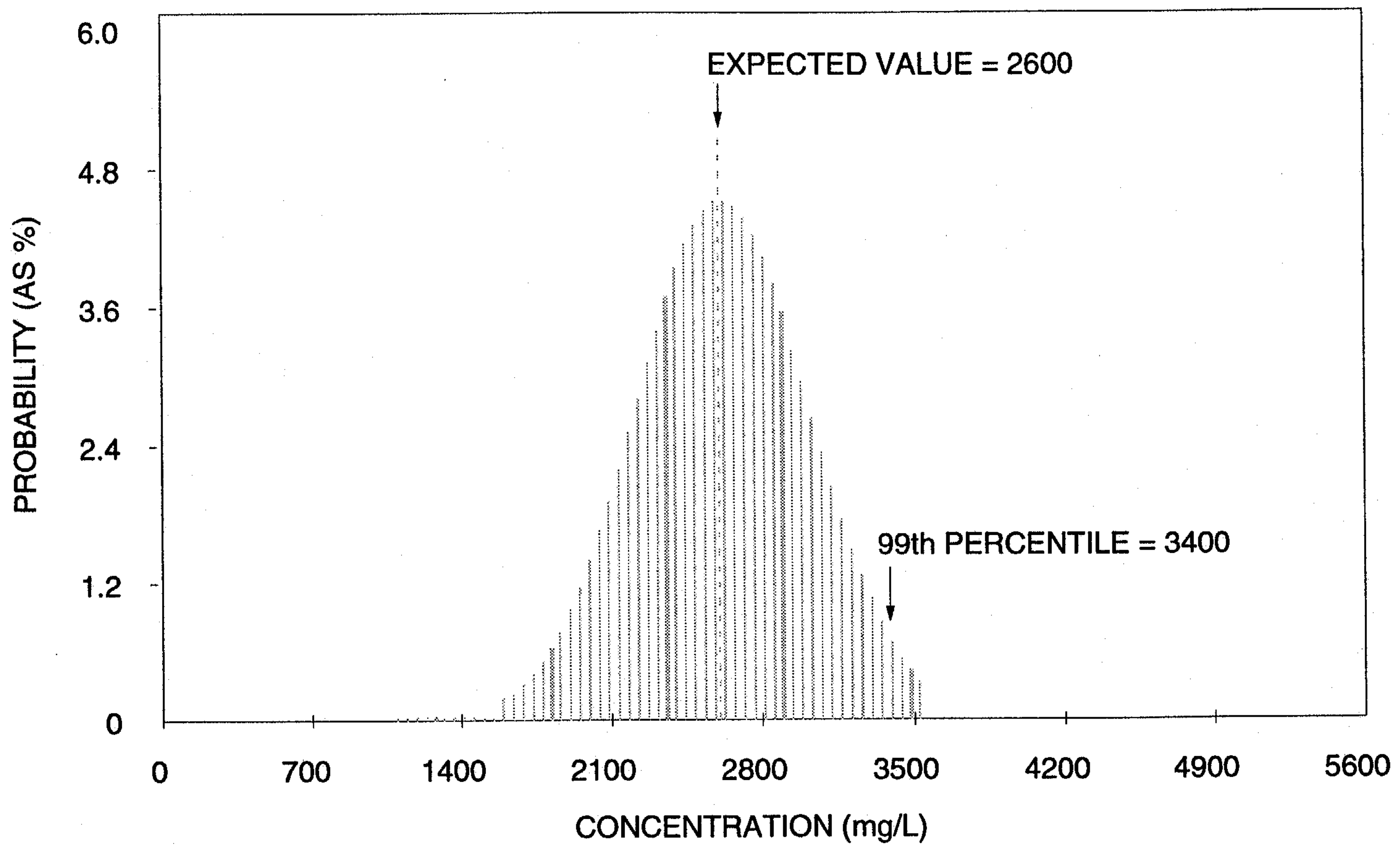

FIGURE 4.15
PROBABILITY DISTRIBUTION OF SULFATE CONCENTRATIONS
SLICK ROCK, COLORADO, UC SITE

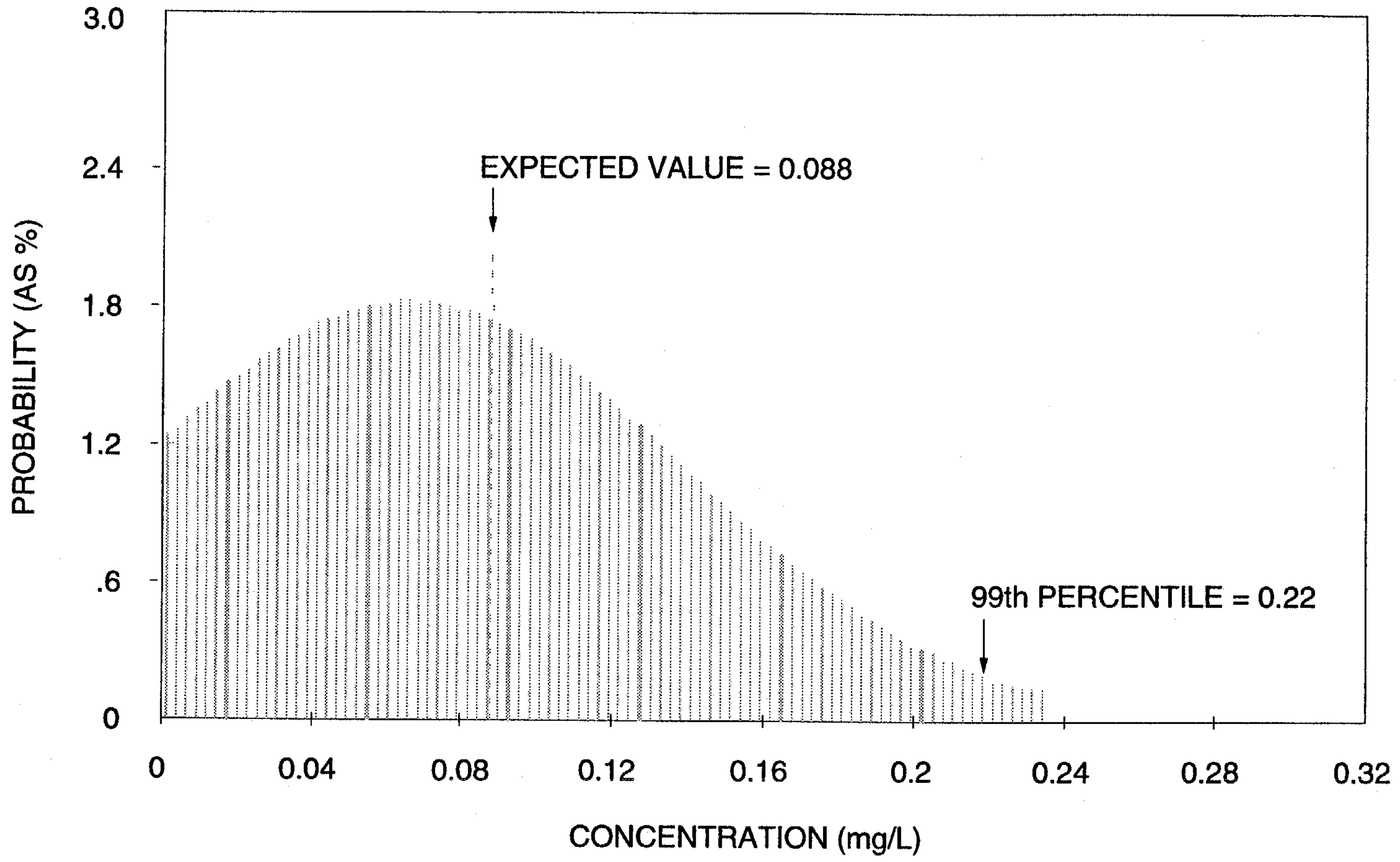

FIGURE 4.16
PROBABILITY DISTRIBUTION OF URANIUM CONCENTRATIONS
SLICK ROCK, COLORADO, UC SITE

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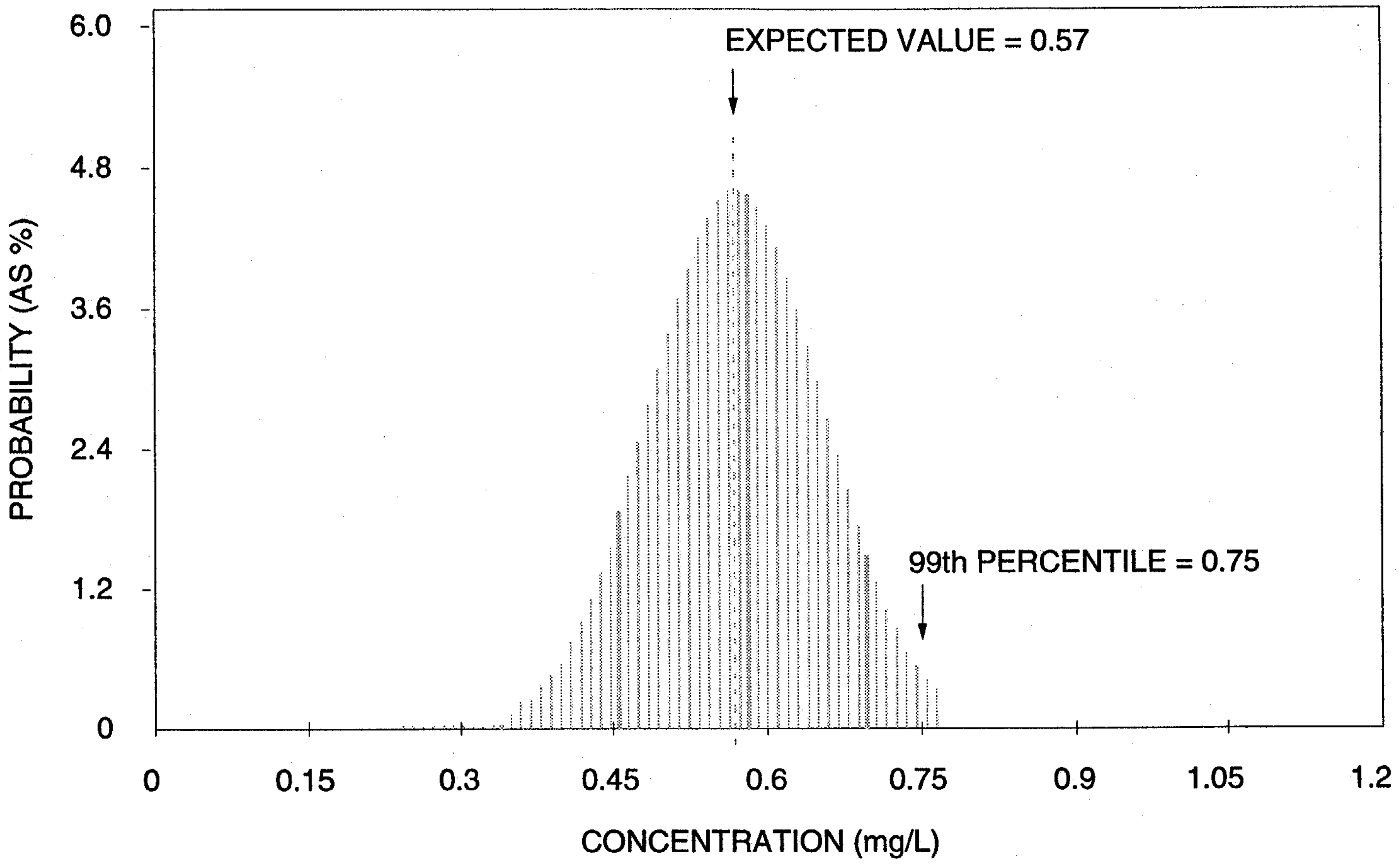

FIGURE 4.17
PROBABILITY DISTRIBUTION OF VANADIUM CONCENTRATIONS
SLICK ROCK, COLORADO, UC SITE

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VANUCCON.DRW

of body weight. For probability distributions of noncarcinogens, chronic daily intake is calculated as follows:

$$\underset{(\text{mg/kg-day})}{\text{Intake}} = \frac{\underset{(\text{mg/L})}{\text{Concentration}} \times \underset{(\text{L/day})}{\text{ingestion rate}} \times \underset{(\text{days/year})}{\text{exposure frequency}} \times \underset{(\text{years})}{\text{exposure duration}}}{\underset{(\text{kg})}{\text{Body weight}} \times \underset{(\text{days/year})}{365} \times \underset{(\text{years})}{\text{exposure duration}}}$$

Potential carcinogenicity is thought to increase with total intake over time, instead of with average daily intake as for noncarcinogens. Body weight is relatively insignificant in determining risk from exposure to carcinogens. The carcinogens identified as contaminants of potential concern at the Slick Rock sites are the radionuclides lead-210, polonium-210, radium-226, thorium-230, and uranium. Therefore, only calculations for radionuclide carcinogens are presented here. Carcinogenic radionuclide intake is quantified as total exposure to radioactivity throughout the residence period of an individual:

$$\underset{(\text{pCi/lifetime})}{\text{Intake}} = \underset{(\text{pCi/L})}{\text{Concentration}} \times \underset{(\text{L/day})}{\text{ingestion rate}} \times \underset{(\text{days})}{\text{exposure frequency}} \times \underset{(\text{years})}{\text{exposure duration}}$$

Average daily intake

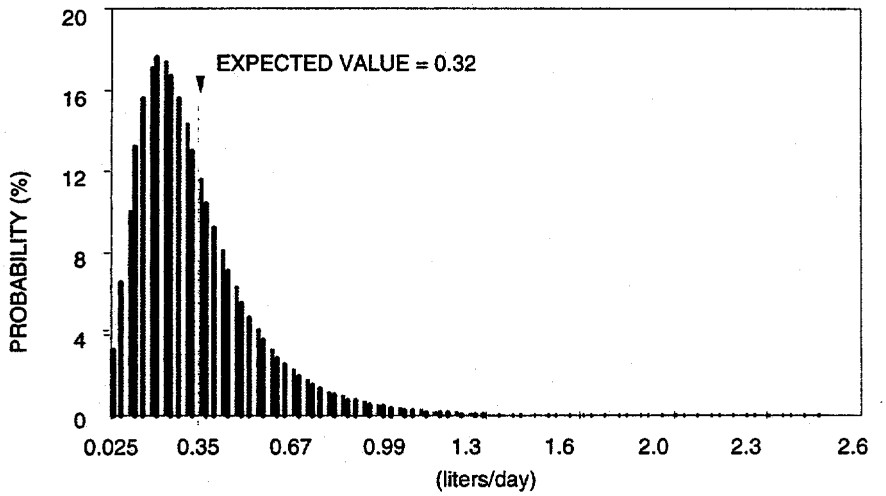
Lognormal probability distributions were used to describe variation in average daily tap water intake (in liters per day) for the population evaluated in this report (Roseberry and Burmaster, 1992). These distributions were developed from data collected during the 1977-78 National Food Consumption Survey conducted by the U.S. Department of Agriculture. Total tap water consumption during a 3-day period was recorded for 26,081 survey participants nationwide (Figure 4.18).

Body weight

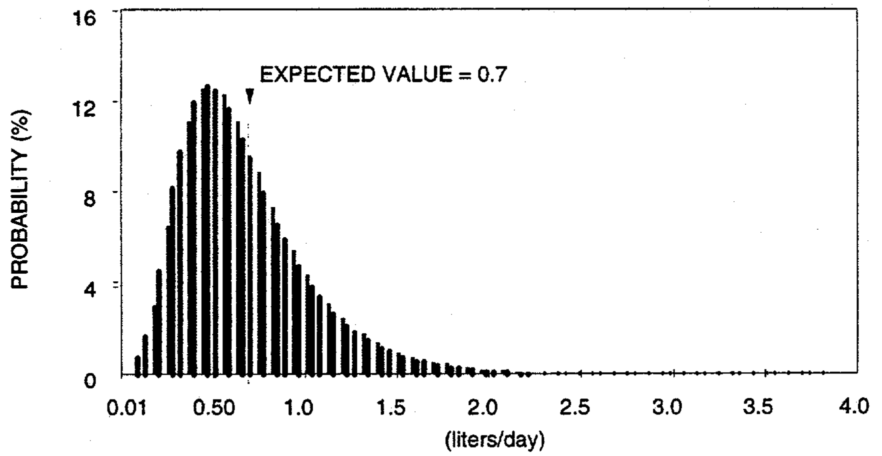
Extensive national data on weights (in kilograms) of males and females, by age, were collected for the National Health and Nutrition Survey between 1976 and 1980. These data were used to develop lognormal probability distributions for body weight by age and by sex. The distributions for males and females then were combined using census data on the national ratio of males to females within each age group (Figure 4.19).

Exposure duration

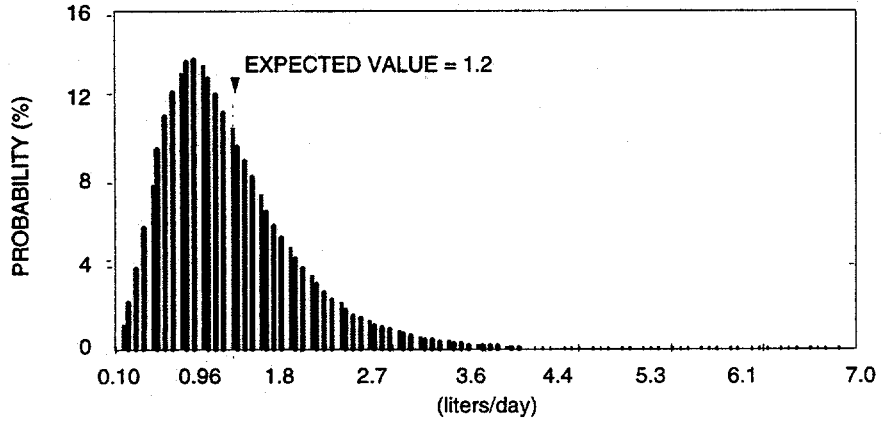
A fixed lifetime exposure time of 70 years was used to model lifetime cancer risks. Because the radionuclide concentrations in ground water at the Slick Rock sites are expected to decrease over time, risk evaluations based on this exposure duration combined with historic and current maximum radionuclide concentrations should yield conservative estimates of carcinogenic risks for these sites.



DAILY WATER INGESTION RANGES -- 0-1 YR OLDS



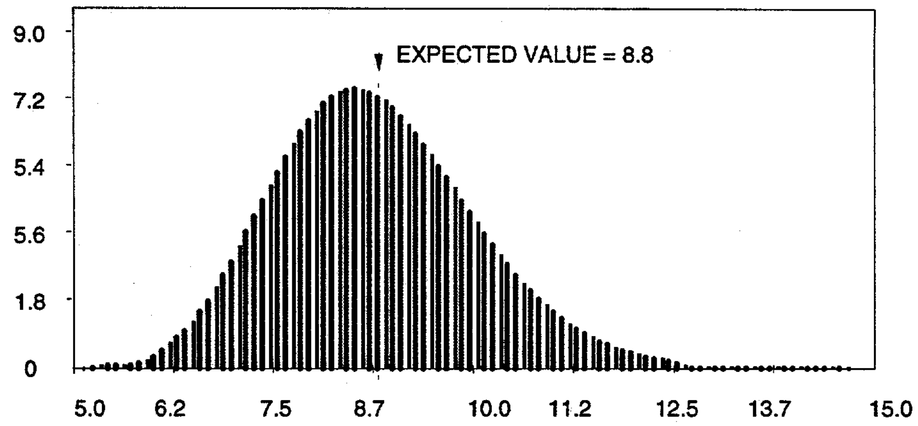
DAILY WATER INGESTION RANGES -- 1-10 YR OLDS



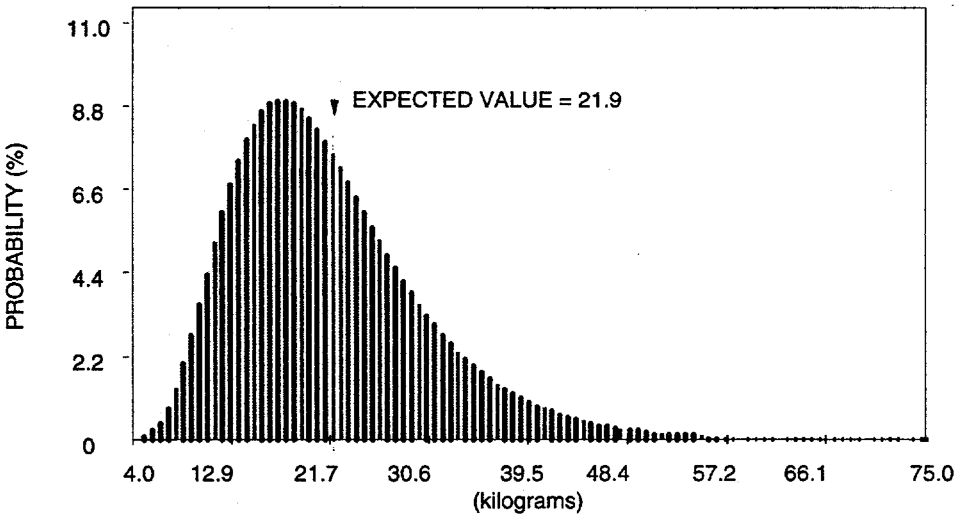
DAILY WATER INGESTION RANGES -- 11-64 YR OLDS

FIGURE 4.18
PROBABILITY DISTRIBUTIONS FOR TAP WATER INGESTION RATES

BODY WEIGHT RANGES -- 0-1 YR OLDS



BODY WEIGHT RANGES -- 1-10 YR OLDS



BODY WEIGHT RANGES -- 11-64 YR OLDS

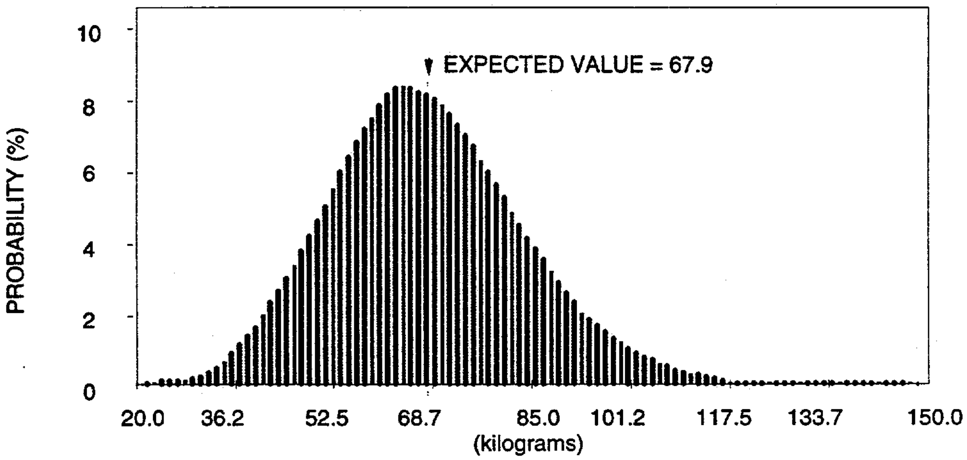


FIGURE 4.19
PROBABILITY DISTRIBUTIONS FOR BODY WEIGHT

Using the exposure concentration distribution (Section 4.3) and the intake parameter distributions described here, total intake distributions derived for the three age groups were generated for uranium. Intake distributions for these age groups were generated for the NC site only because the uranium concentration detected was highest at this site. Figure 4.20 illustrates the different age group characterization from daily uranium intake (for noncarcinogic effects). This figure shows intake is greatest in the 1- to 10-year age group, although the intake for the 0- to 1-year age group is very similar. Therefore, the 1- to 10-year age group is used in this risk evaluation unless one of the other age groups has demonstrated increased sensitivity to a particular constituent. The 0- to 1-year age group is the most sensitive to nitrate and sulfate toxicity. Therefore, the intake distribution for this age is used to evaluate nitrate and sulfate exposure. Simulated intake distributions for the contaminants of potential concern at the NC site are presented in Figures 4.21 through 4.24, and the intake distributions for the UC site are presented in Figures 4.25 through 4.36.

4.5 EXPOSURE ASSESSMENT UNCERTAINTIES

Several potential sources of error may arise in all phases of the exposure assessment, including the following more significant sources of uncertainty:

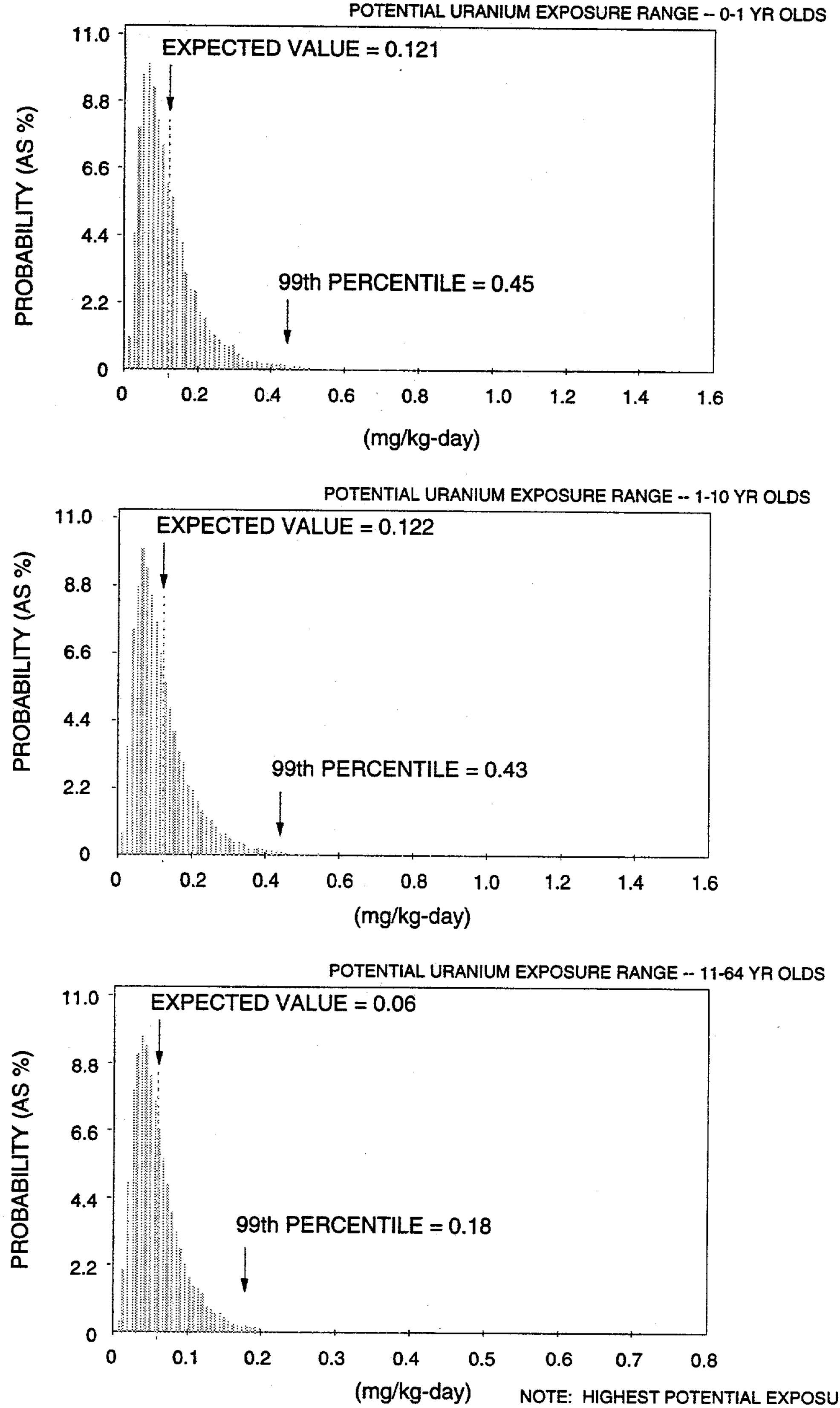
- Uncertainties resulting from the lack of thorough environmental sampling data (ground water, surface water, sediment, and biota), which could lead to an underestimate or overestimate in the exposure analysis.

- Uncertainties arising from the assumption that the ground water contaminant source term at the site has reached a steady state and that constituent concentrations at the exposure point will remain constant for chronic periods of exposure (generally greater than 7 years). Because the sources of contamination at the Slick Rock sites will be removed, the assumption of a constant source will probably lead to an overestimation of risk.

- Uncertainties associated with the model used to estimate uptake of constituents into plants for the irrigated garden produce pathway used to screen pathways. Site-specific plant uptake factors could vary substantially from the default literature estimates. As with environmental sampling, the net effect of this uncertainty on risk estimates cannot be predicted.

- Uncertainties with bioconcentration factors (BCF) and meat transfer coefficients for the milk and meat ingestion pathways. Site-specific BCFs and transfer coefficients could vary substantially from the default literature values.

- Uncertainties associated with the relationship of an applied dose (used in this assessment) and absorbed dose or effective toxic dose.



NOTE: HIGHEST POTENTIAL EXPOSURE OCCURS IN CHILDREN AGE 1-10 (AVERAGE POTENTIAL EXPOSURE OF 0.122 mg URANIUM/kg BODY WEIGHT/DAY).

FIGURE 4.20
COMPARISON OF DISTRIBUTIONS OF POTENTIAL URANIUM EXPOSURES AS A RESULT OF DRINKING CONTAMINATED GROUND WATER FOR THE THREE AGE GROUPS EXAMINED NC AND UC SITES, SLICK ROCK, COLORADO

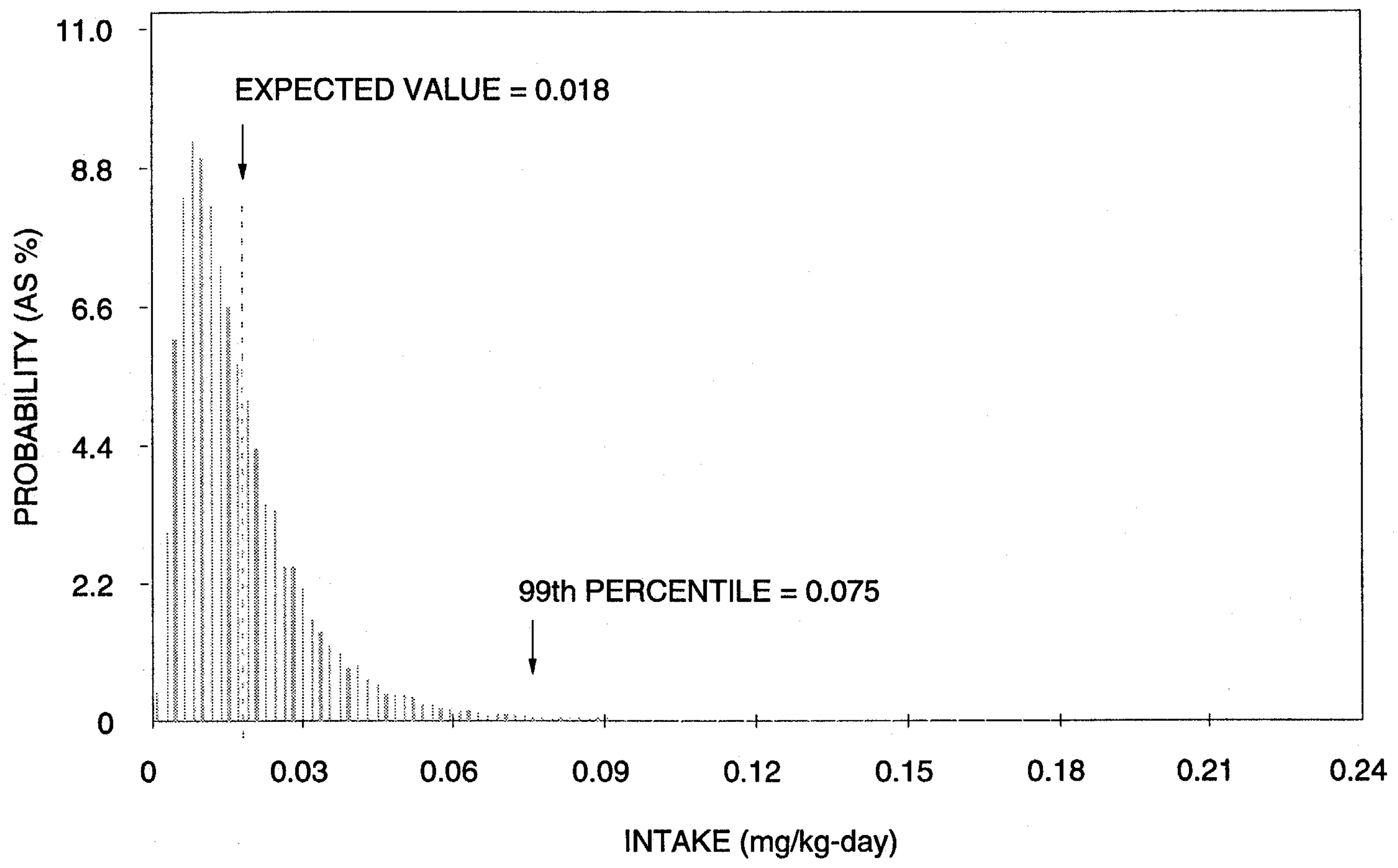


FIGURE 4.21
PROBABILITY DISTRIBUTION OF MANGANESE INTAKES
SLICK ROCK, COLORADO, NC SITE

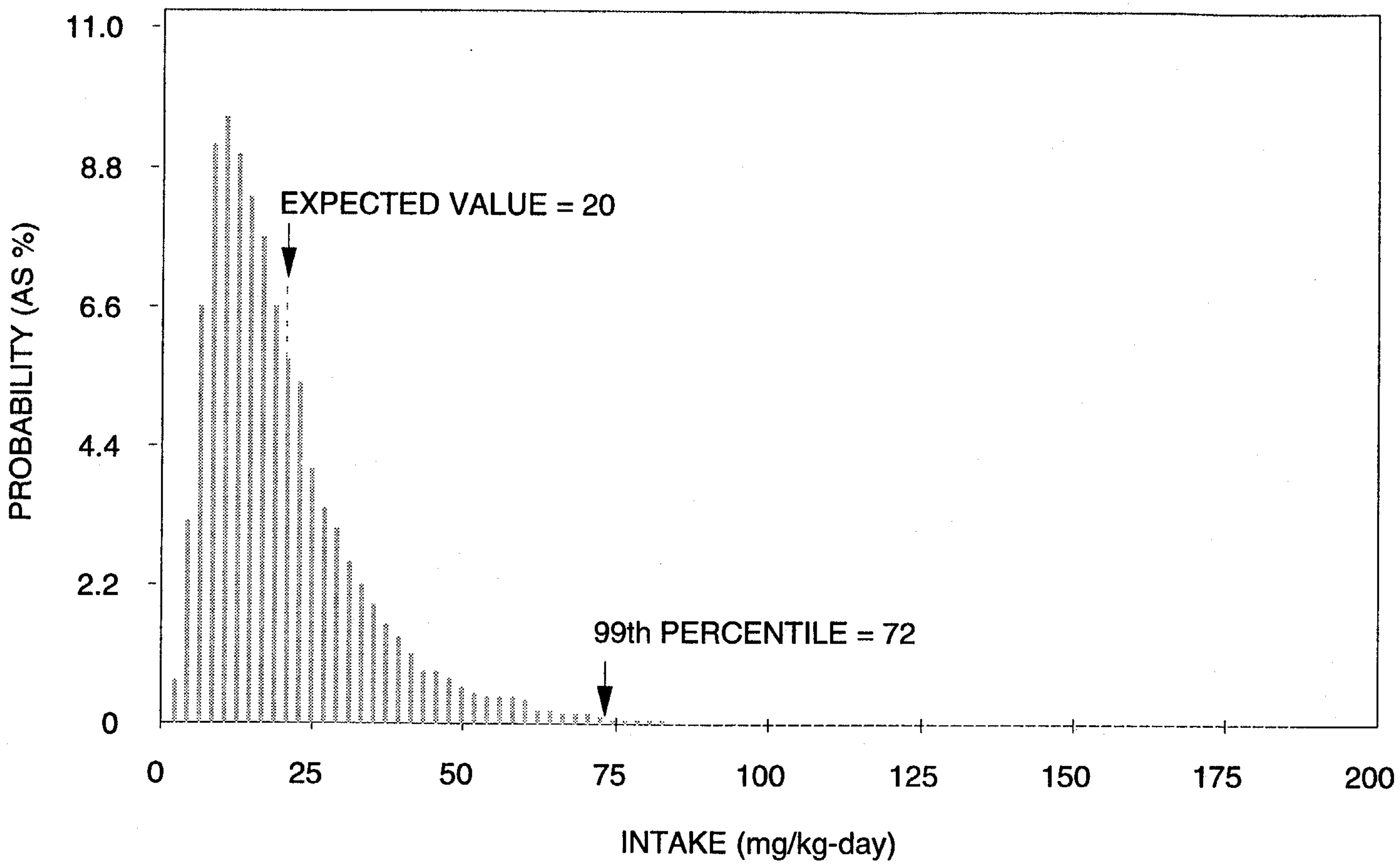


FIGURE 4.22
PROBABILITY DISTRIBUTION OF SODIUM INTAKES
SLICK ROCK, COLORADO, NC SITE

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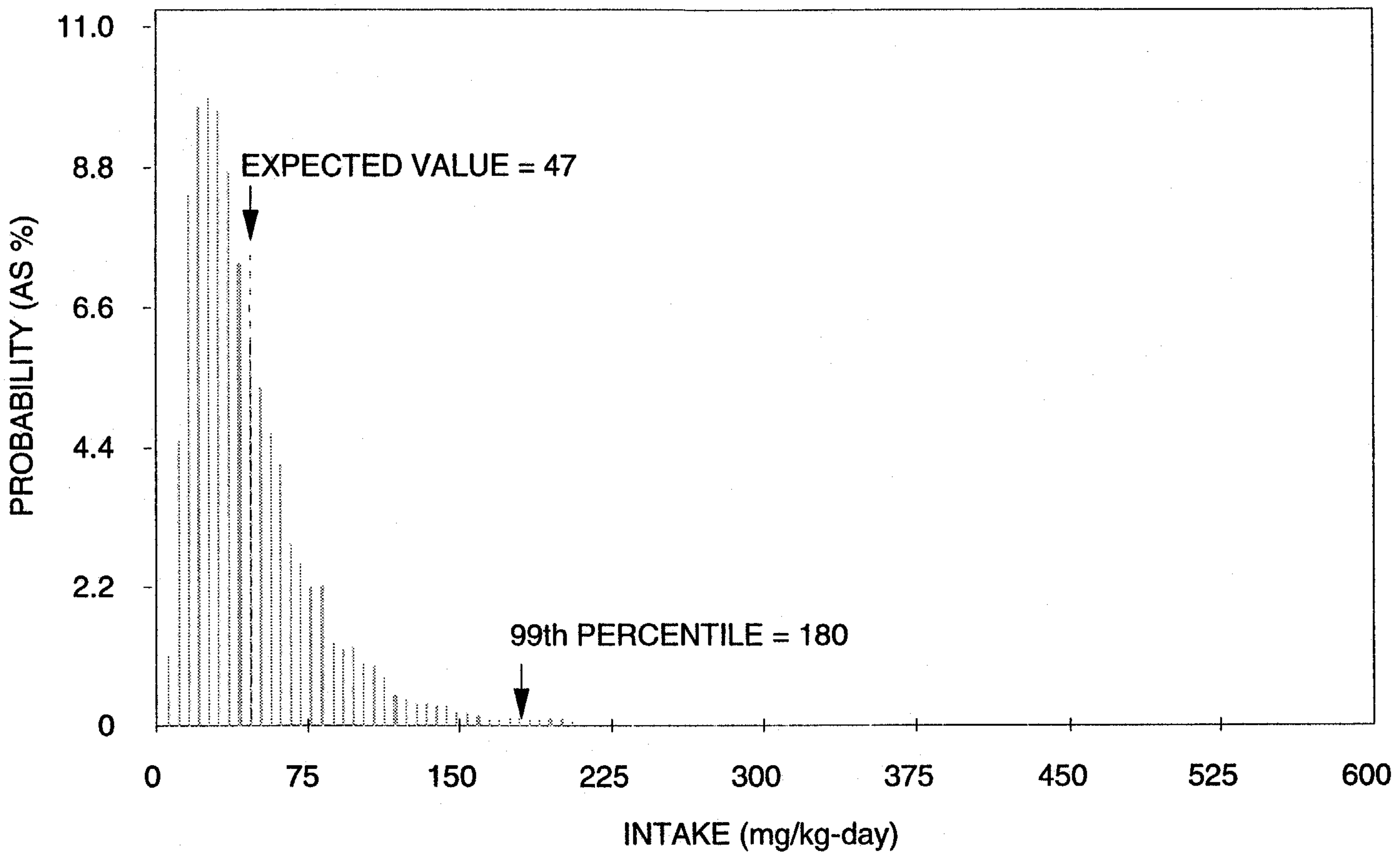

FIGURE 4.23
PROBABILITY DISTRIBUTION OF SULFATE INTAKES
SLICK ROCK, COLORADO, NC SITE

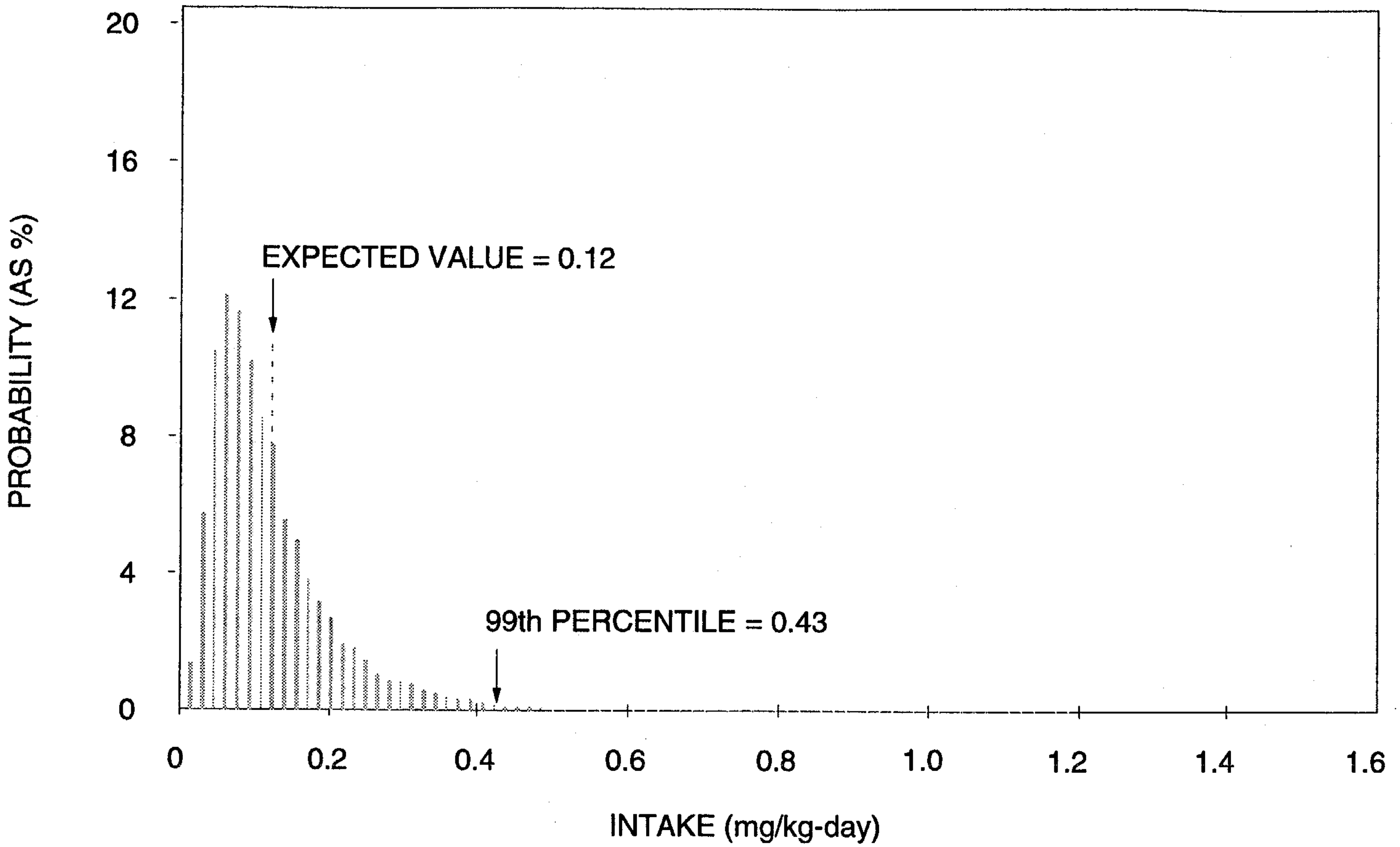

FIGURE 4.24
PROBABILITY DISTRIBUTION OF URANIUM INTAKES
SLICK ROCK, COLORADO, NC SITE

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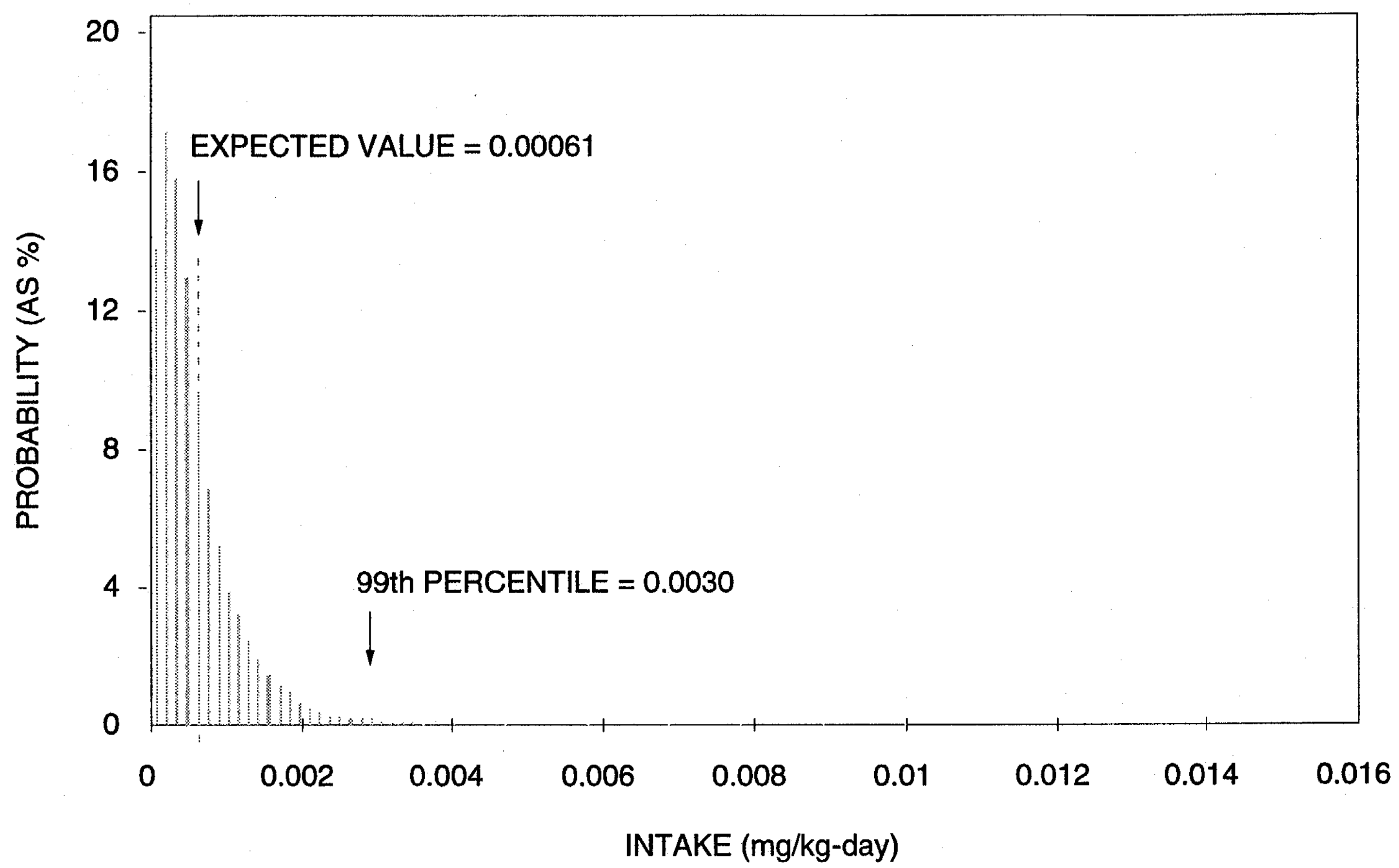

FIGURE 4.25
PROBABILITY DISTRIBUTION OF CADMIUM INTAKES
SLICK ROCK, COLORADO, UC SITE

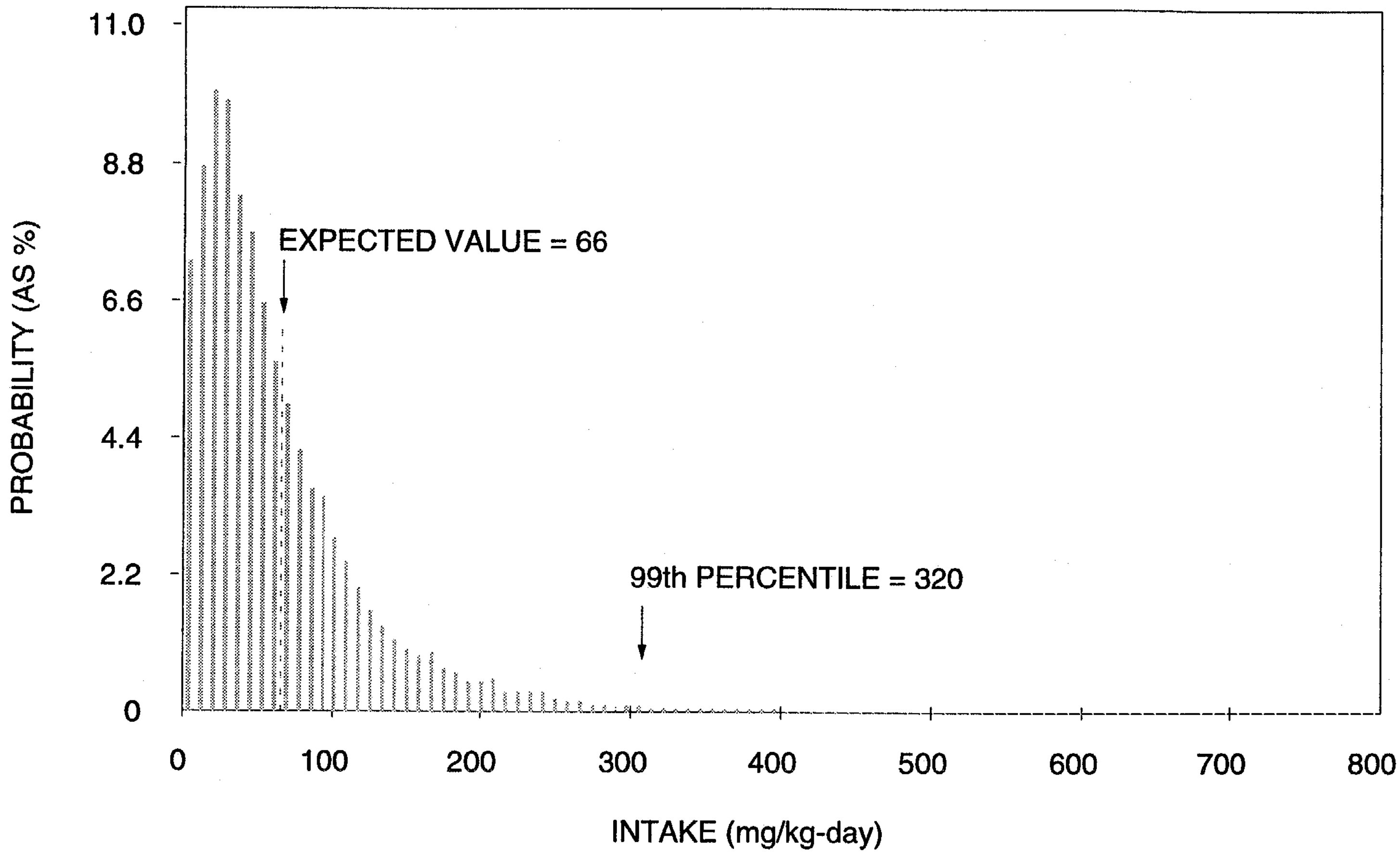

FIGURE 4.26
PROBABILITY DISTRIBUTION OF CHLORIDE INTAKES
SLICK ROCK, COLORADO, UC SITE

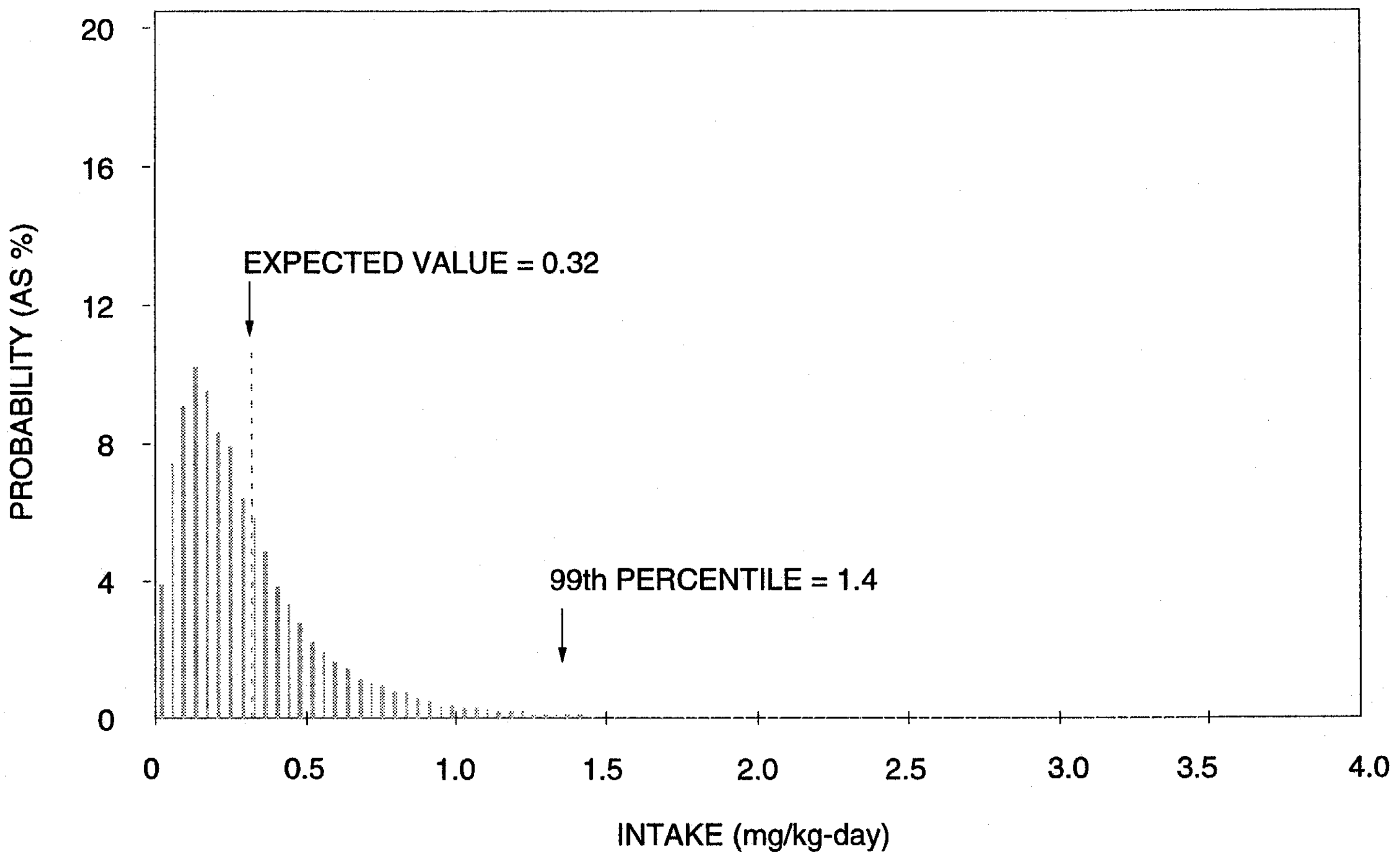

FIGURE 4.27
PROBABILITY DISTRIBUTION OF IRON INTAKES
SLICK ROCK, COLORADO, UC SITE

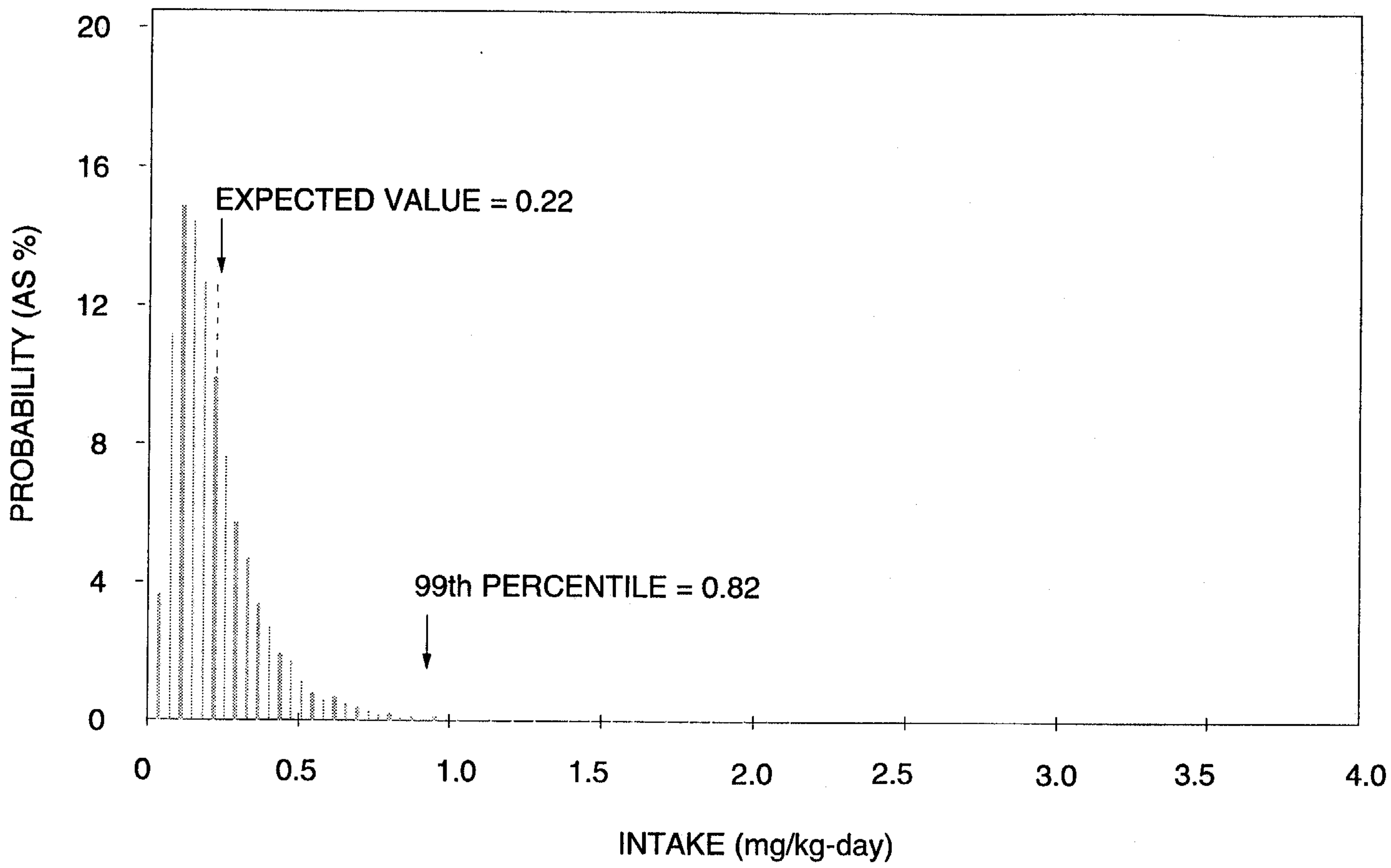

FIGURE 4.28
PROBABILITY DISTRIBUTION OF MANGANESE INTAKES
SLICK ROCK, COLORADO, UC SITE

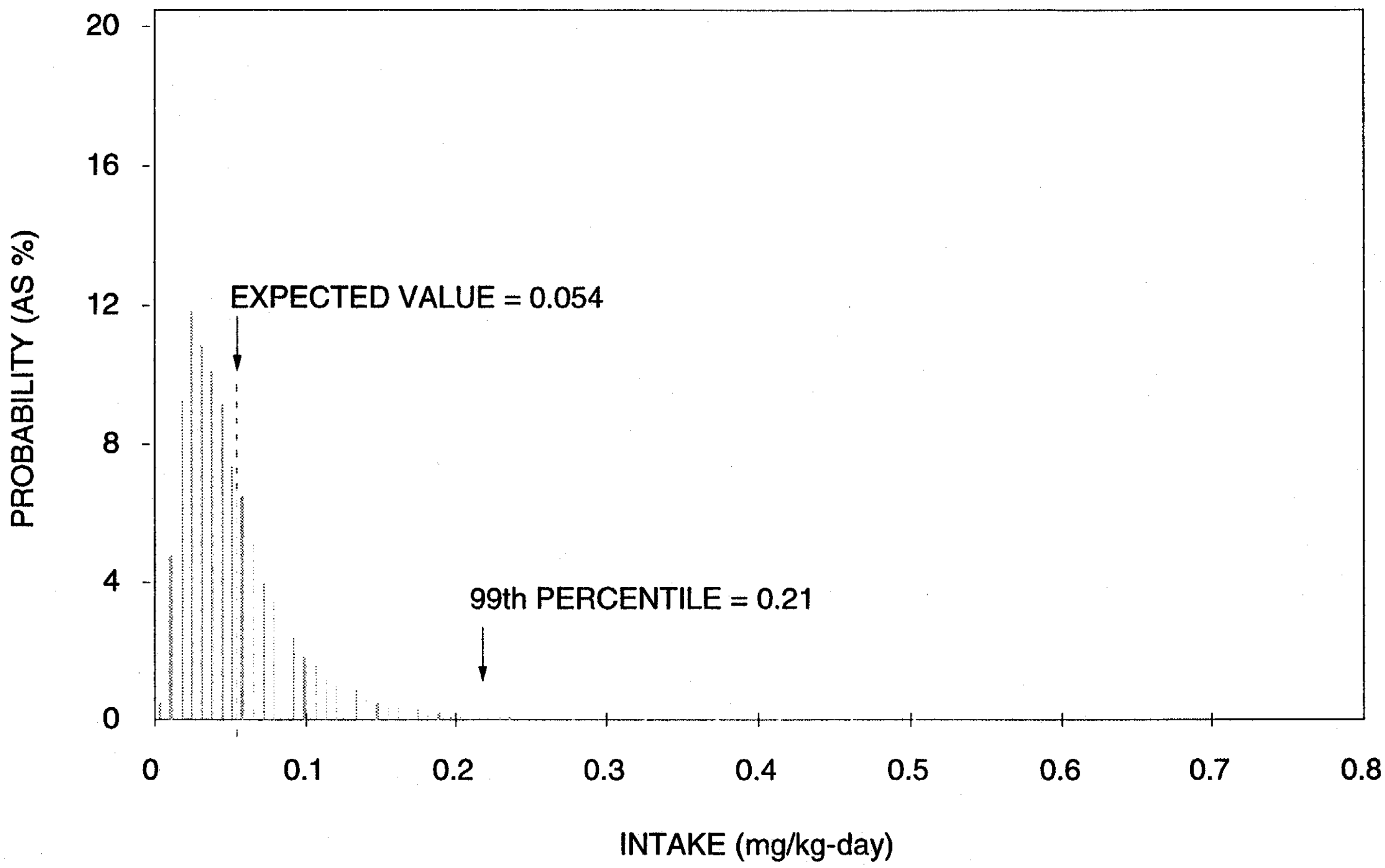

FIGURE 4.29
PROBABILITY DISTRIBUTION OF MOLYBDENUM INTAKES
SLICK ROCK, COLORADO, UC SITE

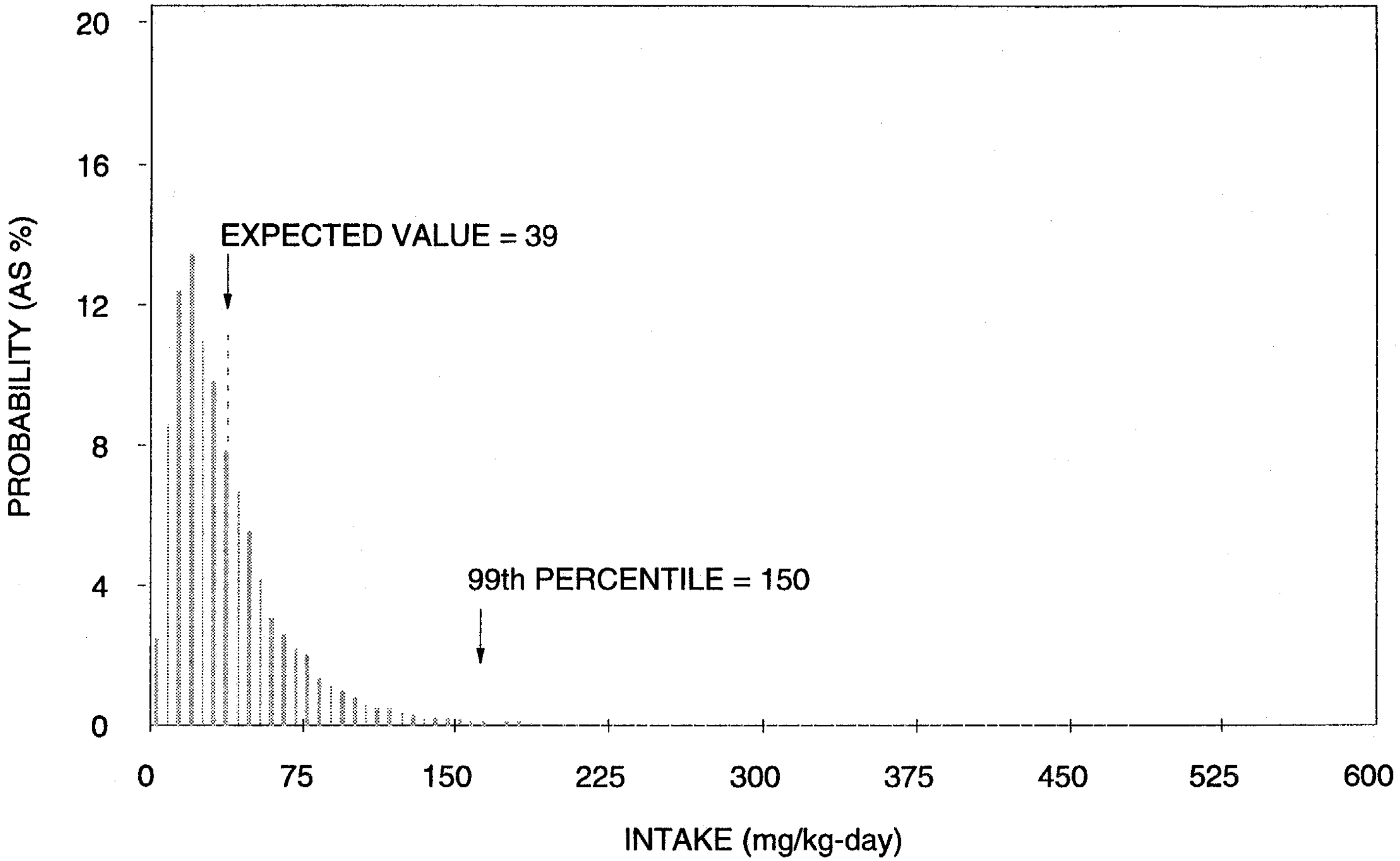

FIGURE 4.30
PROBABILITY DISTRIBUTION OF NITRATE INTAKES
SLICK ROCK, COLORADO, UC SITE

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NITINT.DRW

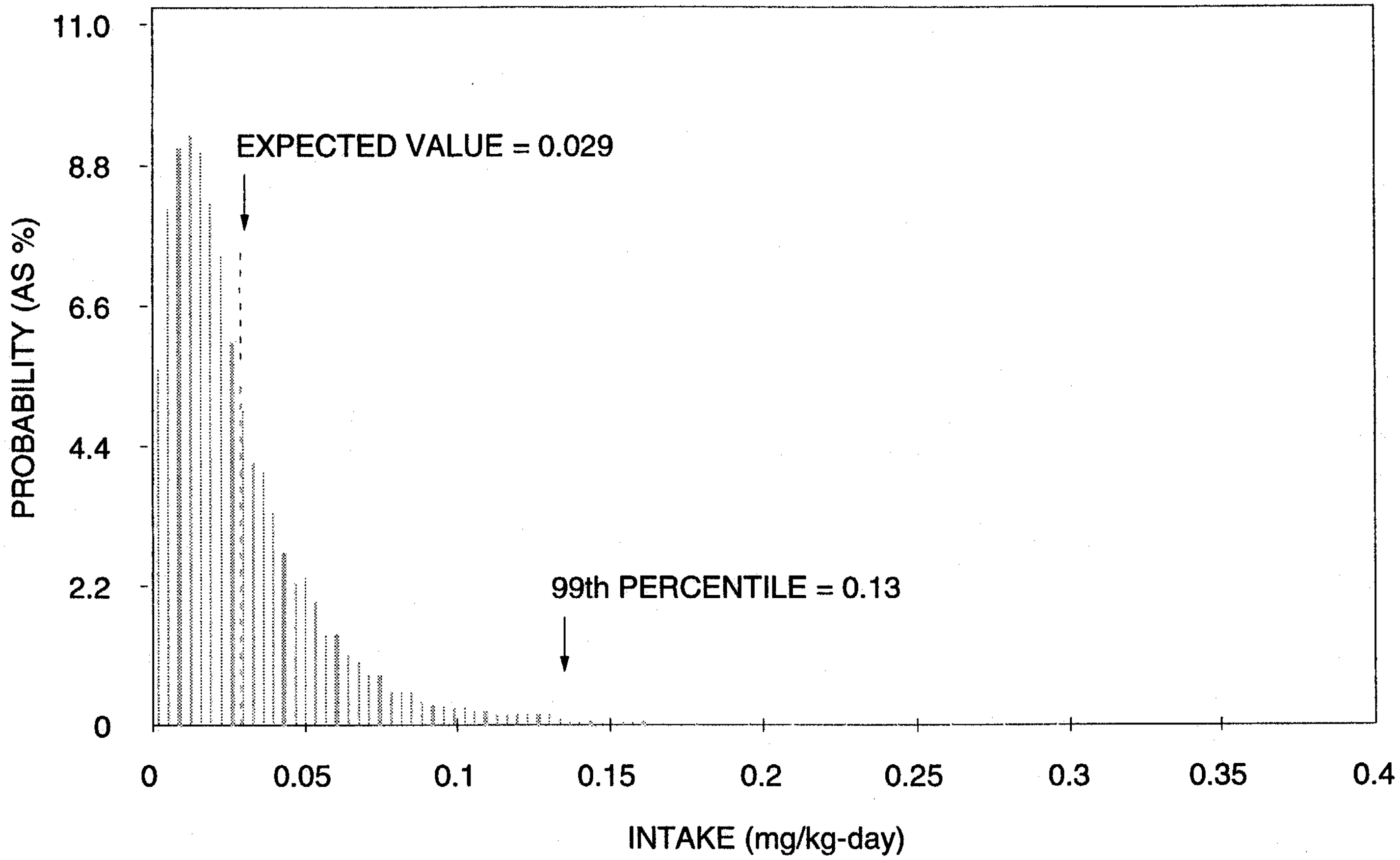

FIGURE 4.31
PROBABILITY DISTRIBUTION OF SELENIUM INTAKES
SLICK ROCK, COLORADO, UC SITE

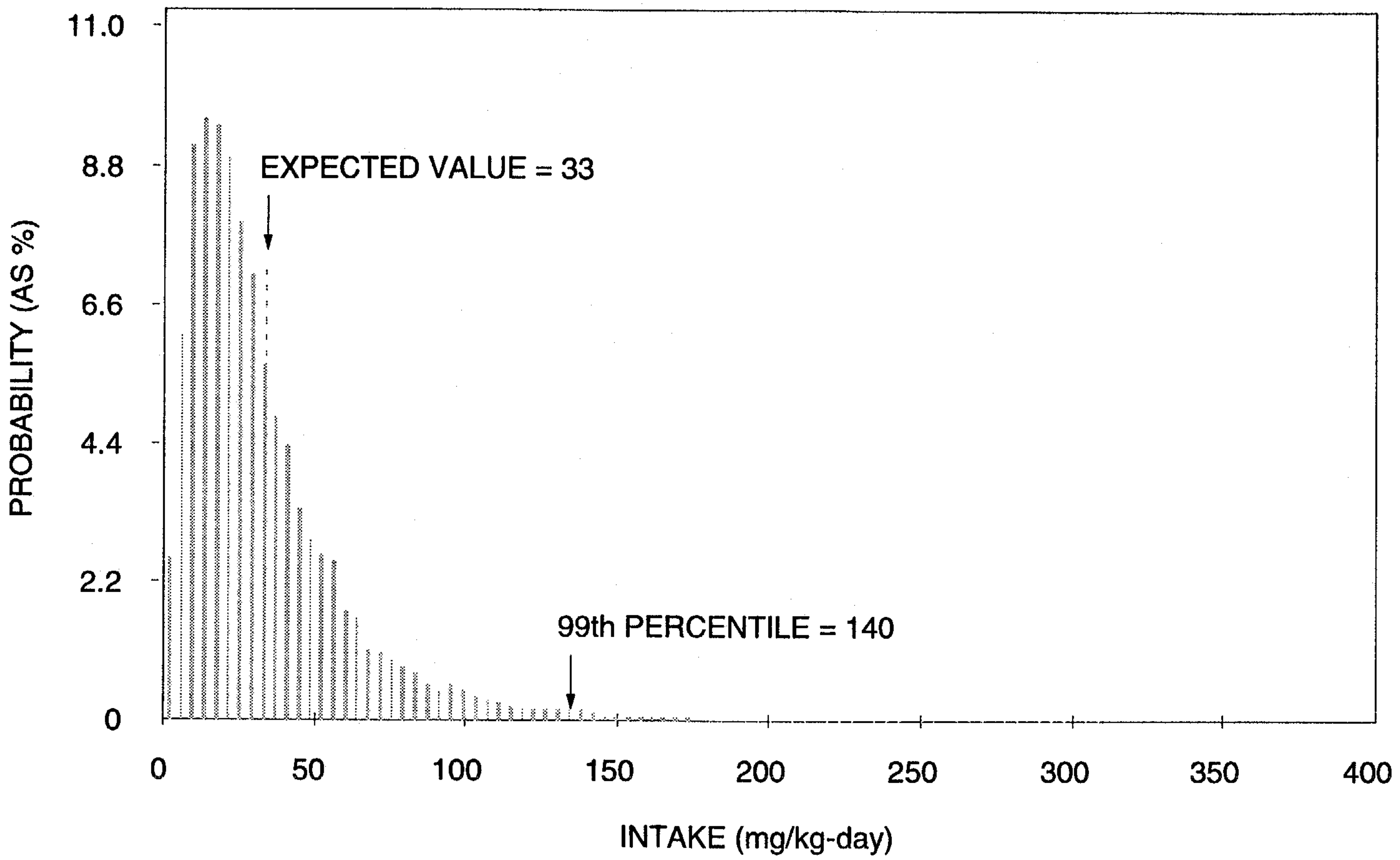

FIGURE 4.32
PROBABILITY DISTRIBUTION OF SODIUM INTAKES
SLICK ROCK, COLORADO, UC SITE

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SODUCINT.DRW

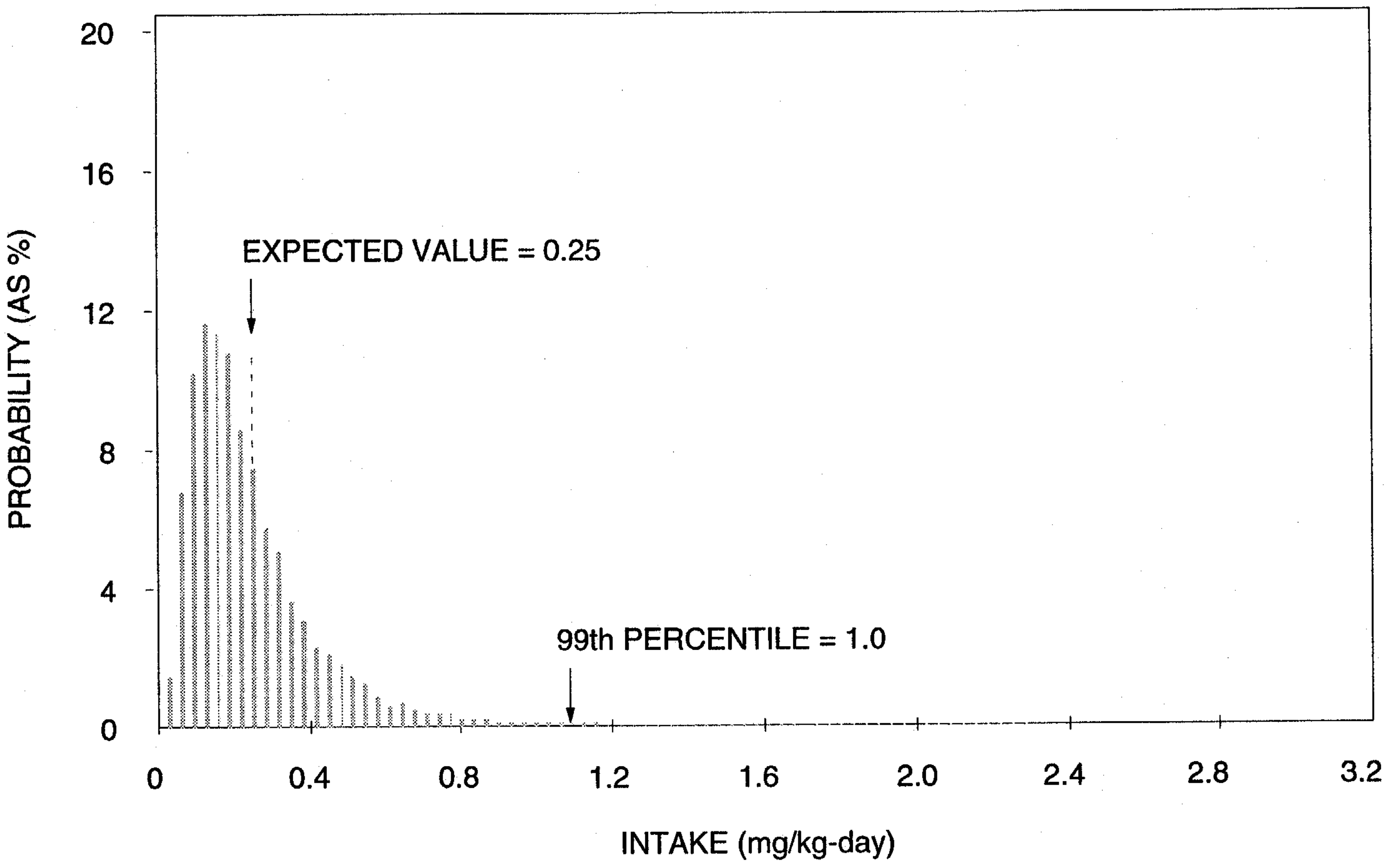

FIGURE 4.33
PROBABILITY DISTRIBUTION OF STRONTIUM INTAKES
SLICK ROCK, COLORADO, UC SITE

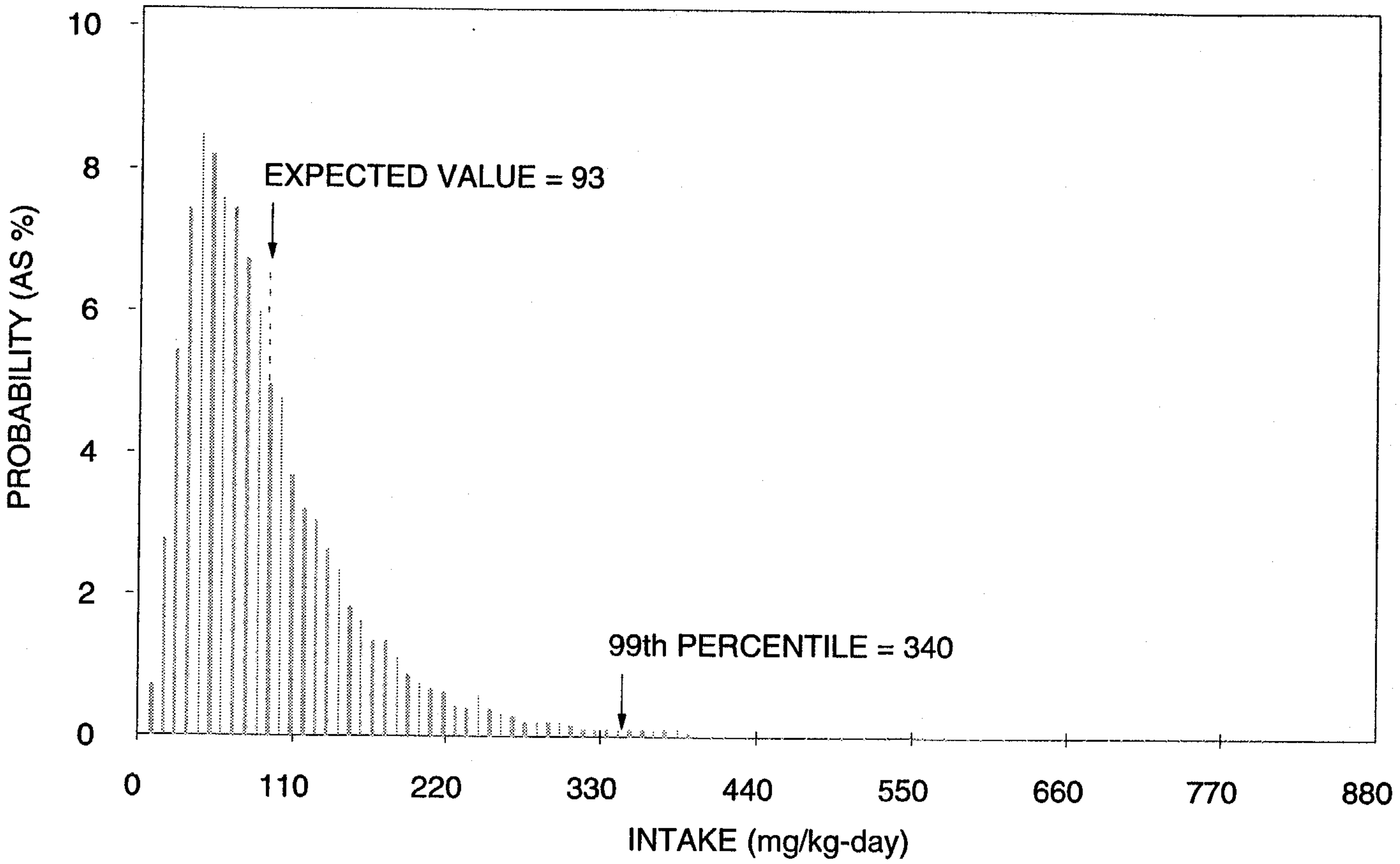

FIGURE 4.34
PROBABILITY DISTRIBUTION OF SULFATE INTAKES
SLICK ROCK, COLORADO, UC SITE

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SULUCINT.DRW

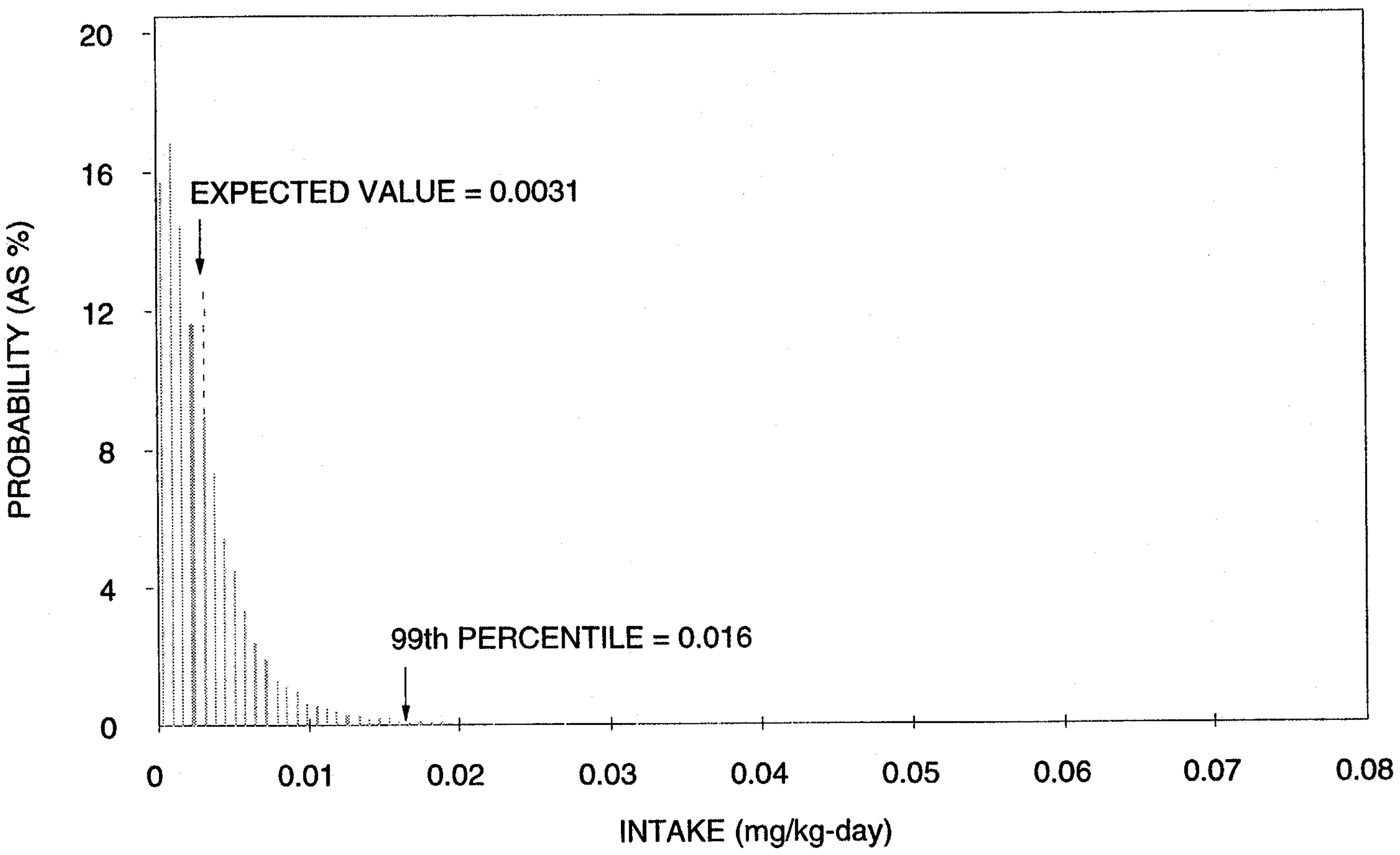


FIGURE 4.35
PROBABILITY DISTRIBUTION OF URANIUM INTAKES
SLICK ROCK, COLORADO, UC SITE

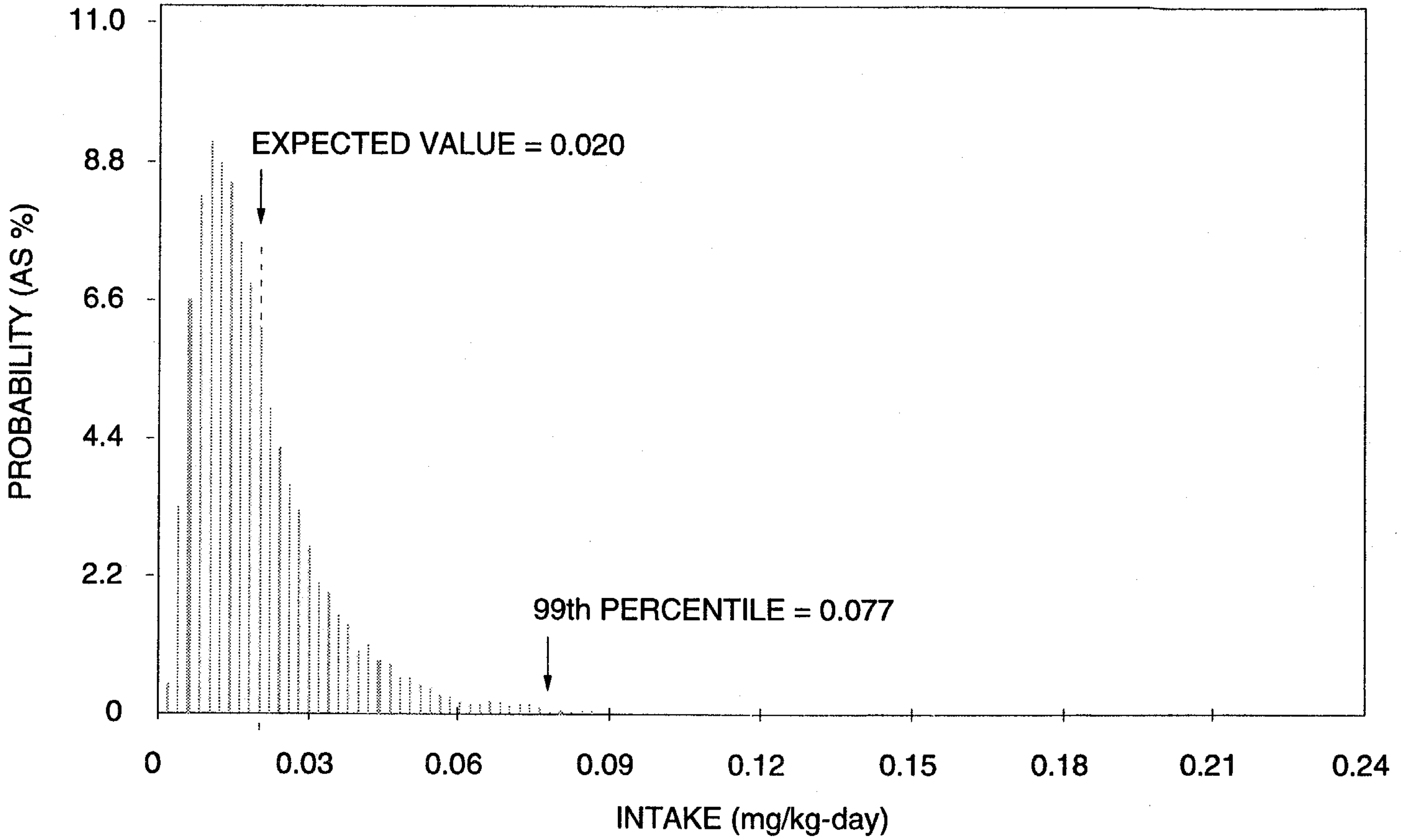


FIGURE 4.36
PROBABILITY DISTRIBUTION OF VANADIUM INTAKES
SLICK ROCK, COLORADO, UC SITE

PATH I:\FL3.01\SRKBRA

VANUCINT.DRW

- Uncertainties associated with different sensitivities of subpopulations, such as individuals with chronic illnesses, that could alter predicted responses to contaminants.

Despite these uncertainties, probability distributions that incorporate all definable sources of variability should provide a representative picture of the potential range of exposures.

5.0 TOXICITY ASSESSMENT

Several constituents that have the potential to cause adverse human health effects have been detected in ground water at the NC and UC sites. The toxicological effects of the chemicals and carcinogenic potentials of the radionuclides are discussed below. The following source materials were used in developing these toxicological profiles: the EPA's Integrated Risk Information System (IRIS) (EPA, 1994a); the *Agency for Toxic Substances Disease Registry Toxicological Profiles*, published by the Department of Health and Human Services (DHHS); and the *Handbook on the Toxicology of Metals* (Friberg et al., 1986). When these review documents were not available, peer-reviewed scientific literature was used. Basing toxicity information on the standardized review documents cited above ensures risks evaluation for UMTRA Project sites is consistent with evaluations at sites regulated by different legislation.

The toxicity profiles presented here focus on drinking water source material in humans, including animal data only when human data are not available. Toxicity range graphs graphically illustrate toxicity ranges. Animal information is presented on the graphs by widely-spaced dotted lines. Uncertainty about the beginning or ending points of an exposure range that produces specific toxic effects are noted by closely-spaced dots on the line denoting range.

5.1 CONTAMINANT TOXICITY SUMMARIES

The basic toxicokinetics and toxicity of the twelve noncarcinogenic contaminants of potential concern at the Slick Rock sites are cadmium, chloride, iron, manganese, molybdenum, nitrate, selenium, sodium, strontium, sulfate, uranium, and vanadium. Although these constituents have a wide range of toxic effects depending on the exposure levels, the following discussions focus on toxic effects observed in the exposure range most relevant to contamination at the Slick Rock sites.

5.1.1 Cadmium

Absorption

Humans absorb approximately 5 percent of ingested cadmium in water, although this figure can increase substantially following exposure to other metals (such as calcium or iron) or with increased protein intake (Friberg et al., 1986). The amount of cadmium absorbed from food sources is about half the amount absorbed from water. Absorption also substantially increases in individuals with low iron stores (Flanagan et al., 1978). Once absorbed, cadmium binds to protein, primarily metallothionein. The ability of many metals to increase the concentration of metallothionein is the likely basis for interactions in absorption, tissue concentrations, and toxicity of combined exposures to metals.

Tissue accumulation and clearance

Humans with low-level exposure to cadmium show 50 percent of the body burden in the kidneys, 15 percent in the liver, and 20 percent in muscle (Kjellström, 1979). The kidney concentration will increase with continued exposure only to about age 50, but the concentration in muscle will increase throughout life. Only 0.01 to 0.02 percent of the total body burden of cadmium is excreted daily, resulting in continuously increasing body burdens with prolonged exposure. The biological half-life of cadmium, or the time necessary to eliminate 50 percent of the cadmium in the body at a given time, is 10 to 30 years in humans (Nordberg et al., 1985).

Environmental sources of cadmium

The normal cadmium content of food and water in nonpolluted areas results in 0.01 to 0.06 mg per day intake of cadmium (0.0001 to 0.0009 milligrams per kilogram per day [mg/kg-day]) (Elinder, 1985). Cadmium occurs naturally with zinc and lead; therefore, it is often present as an impurity in products using these metals, such as solders and galvanized metals. These sources lead to contact with water supplies in water heaters and coolers, in some pipes, and in taps.

Toxicity of cadmium

Acute exposure to high concentrations of cadmium (15 mg/L in water) results in acute gastrointestinal effects, including abdominal cramps, diarrhea, and vomiting (0.07 mg/kg). These gastrointestinal effects have not been reported in any chronic environmental exposure.

The primary toxic effect of long-term cadmium exposure is disturbance of reabsorption in the proximal tubules of the kidney. This effect is first observed by an increase of low molecular-weight proteins in the urine. This initial effect is observed following a daily intake of 0.0075 mg/kg-day. Progressive disruption of kidney function will lead to an increase in amino acids, glucose, phosphate, and protein in the urine. Because of already compromised kidney function, diabetics and the elderly can be more susceptible to cadmium toxicity (Buchet et al., 1990). Long-term exposure can also disturb calcium metabolism, leading to osteoporosis and osteomalacia. A combination of these two effects is known as *Itai-itai* disease and was seen in epidemic proportions in a cadmium-contaminated region in Japan in the 1950s (Friberg et al., 1986). Chronic cadmium exposure to humans through diet produces no observable adverse effects at exposure levels from 0.001 to 0.002 mg/kg-day (DHHS, 1993). Figure 5.1 summarizes these health effects as a function of dose.

Cadmium has been classified as a probable human carcinogen by the EPA (EPA, 1994a) and International Agency for Research on Cancer (IARC, 1987). Although chronic inhalation of cadmium oxide has been related to increased lung and prostate cancers in workers, evidence linking cadmium to cancer in humans

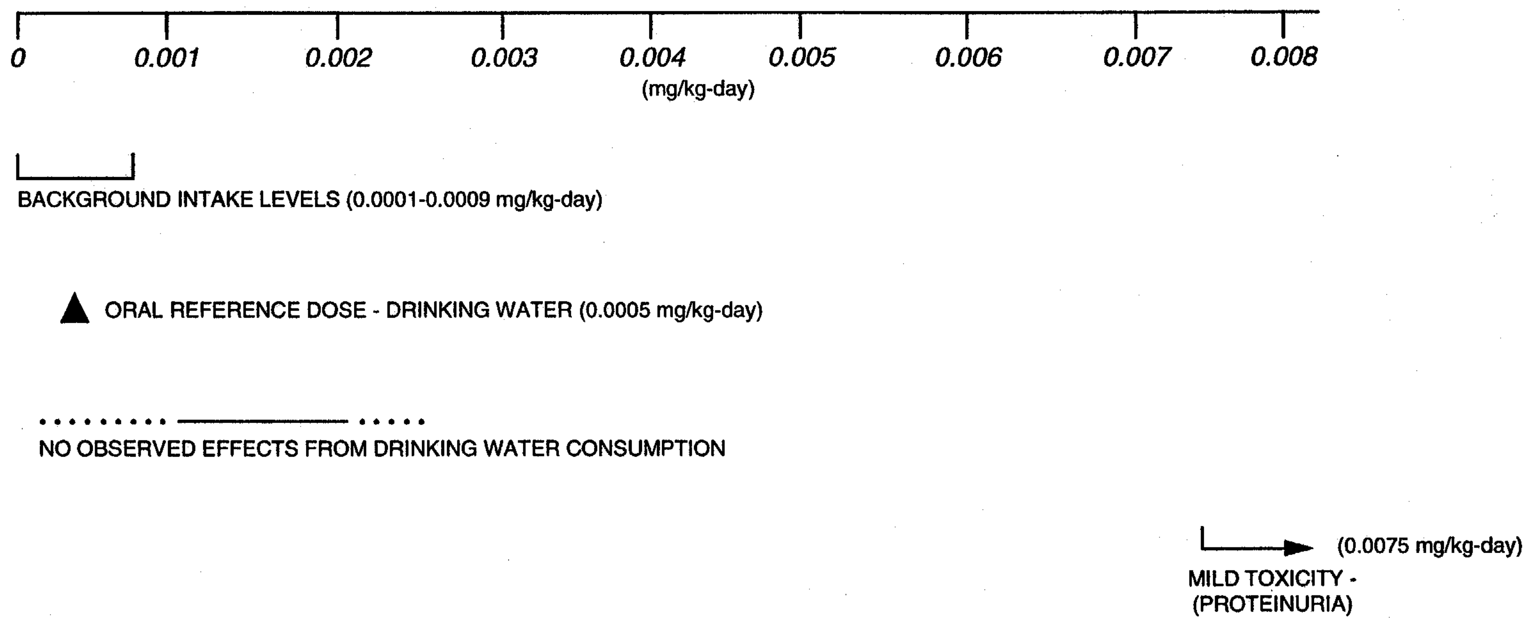


FIGURE 5.1
CADMIUM TOXICITY RANGES

is inconclusive at this time because of other known carcinogens present in the workplace and small statistical differences in tumor incidences (DHHS, 1993). No data, however, link oral cadmium ingestion to cancer in humans or animals (DHHS, 1993).

5.1.2 Chloride

Absorption

Chloride is rapidly and fully absorbed from the gastrointestinal tract.

Tissue accumulation and clearance

The chloride concentration in the human body is approximately 2000 mg/kg of fat-free body mass in the newborn and 1920 mg/kg in the adult (NAS, 1980). It occurs in plasma at concentrations of 96 to 106 milliequivalents per liter (mEq/L) (3400 to 3800 mg/L), and in more concentrated form in cerebrospinal fluid and gastrointestinal secretions (National Research Council, 1989). Its concentration in most cells is low. A daily chloride turnover in adults (intake/output) ranges from between 3000 and 8900 mg. Chloride excretion is mainly urinary, with appreciable amounts also excreted in feces, sweat, and tears.

Environmental sources of chloride

Dietary chloride comes almost entirely from sodium chloride (National Research Council, 1989). Much smaller amounts are supplied from potassium chloride. Thus, dietary sources of chloride are essentially the same as those for sodium; processed foods are the major source of chloride. Rich sources of chloride are salt, cereals, breads, dried skim milk, teas, eggs, margarine, salted butter, bacon, ham, corned beef, salted snack food, and olives. Dietary chloride intake varies largely with salt intake. Estimates range from 2,400 to 14,400 mg chloride per day from sodium chloride (equivalent to 34 to 206 mg/kg-day for a 70-kg man).

Human milk contains 11 mEq of chloride per liter (391 mg/L). A similar level has been recommended by the American Academy of Pediatrics for infants formulas (National Research Council, 1989).

Chloride is found in all natural waters. Surface water contains only a few milligrams of chloride per liter, whereas streams in arid or semiarid regions contain several hundred milligrams per liter, especially in drained areas where chlorides occur in natural deposits or are concentrated from soils through evaporation. Contamination with sewage increases the chloride content of river waters. Ground water usually contains larger quantities of chloride than surface water. Some public supply wells may contain 100 mg chloride/L (about 3 mg/kg-day, assuming 2 L consumption and 70-kg body weight) (NAS, 1980).

A typical chloride concentration in drinking water is about 21 mg/L, which would contribute 0.6 mg chloride/kg-day (assuming 2 L per day consumption rate and 70-kg body weight). This concentration contributes about 2 percent of the lower estimates of total chloride intake.

The recommended drinking water level for chloride is 250 mg/L (equivalent to 7 mg chloride/kg-day for a 70-kg man consuming 2 L of water per day) (NAS, 1980). This amount of chloride in drinking water causes a salty taste, which may be unpalatable. The taste threshold for the chloride anion in water varies from 210 to 310 mg/L.

Toxicity of chloride

Chloride is the most important inorganic anion in the extracellular fluid compartment. It is essential in maintaining fluid and electrolyte balance and is a necessary component of gastric juice.

Chloride loss from the body generally parallels that of sodium. Thus, conditions associated with sodium depletion (e.g., heavy, persistent sweating, chronic diarrhea or vomiting, trauma, renal disease) will also cause chloride loss, resulting in hypochloremic metabolic alkalosis.

Although the essentiality of the chloride ion is generally recognized, recommended dietary allowance (RDA) has not been determined. The estimated chloride minimum requirement for good health ranges from 180 mg per day for infants to 750 mg per day for adults (National Research Council, 1989).

The toxicity of salts containing the chloride ion depends primarily on the characteristic of the cation (NAS, 1980; National Research Council, 1989).

High chloride intake may cause increased chloride plasma concentration and decreased bicarbonate plasma concentration, with an acidifying effect. This results in hyperkalemic metabolic acidosis (NAS, 1980). When metabolic acidosis develops, potassium leaves cells and is excreted by the kidney (Brater, 1992).

The only known dietary hyperchloremia results from water-deficiency dehydration. Sustained high chloride ingestion (as salt) is associated with hypertension in sensitive individuals and in animal models. Although the level of chloride attributable to hypertension has not been determined, it may be estimated based on the level of sodium intake (from sodium chloride) causing hypertension in approximately 15 percent of adults (Freis, 1976). This indirect estimate, associated with hypertension in sensitive individuals, would be in the range of 36 to 180 mg/kg-day. Figure 5.2 summarizes chloride toxicity as a function of dose.

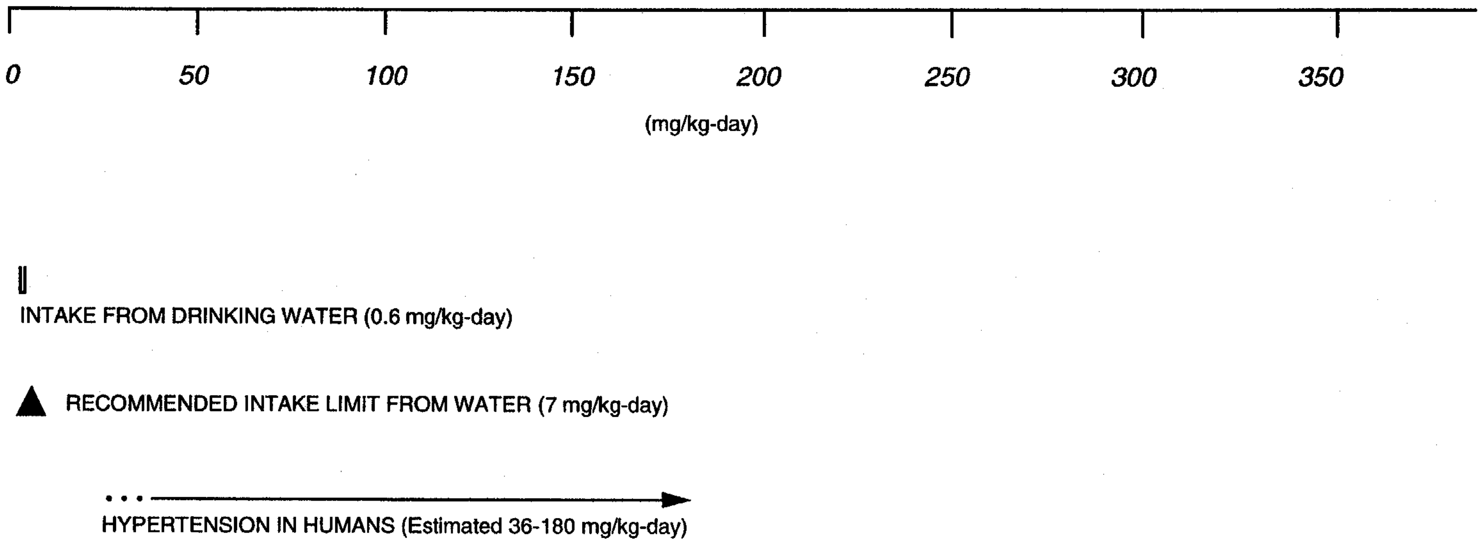


FIGURE 5.2
CHLORIDE TOXICITY RANGES

5.1.3 Iron

Absorption

The percentage of dietary iron that is absorbed ranges from 2 percent in individuals with diseases of the gastrointestinal tract to 35 percent in rapidly growing, healthy children (Goyer, 1991; Whitney et al., 1990). Normally, 10 to 15 percent of dietary iron is absorbed, but this percentage varies to compensate for the level of iron in the body (Elinder, 1986). For example, patients with iron-deficiency anemia can absorb as much as 60 percent of an oral dose of iron (Josephs, 1958).

Iron absorption also is influenced by factors such as the source and chemical form of the ingested iron, other substances in the diet, and the condition of the gastrointestinal tract (Elinder, 1986). Very little is known about the absorption of iron from water and about the chemical species of iron in drinking water from the tap. Although the amount of ferric ion (Fe^{3+}), ferrous ion (Fe^{2+}), and organic complexes of iron in water that are absorbed by humans is unknown, a reducing agent such as ascorbic acid clearly increases iron absorption from food (National Research Council, 1980). Ferrous ion appears to have better availability than does ferric ion. Humans absorb iron from animal sources more effectively than from vegetables and grains. Soluble forms of iron such as iron sulfate are taken up more readily than insoluble forms such as iron oxide. The presence of other metals also affects iron absorption. Absorption decreases in the presence of high levels of phosphate, cobalt, copper, and zinc (Elinder, 1986). Excess manganese can significantly decrease iron absorption by impairing hemoglobin regeneration in the blood (National Research Council, 1980).

Tissue accumulation and clearance

Iron absorption from the gastrointestinal tract occurs in two steps: first, ferrous ions from the intestinal lumen are absorbed into the mucosal cells. Second, they are transferred from the mucosal cells to plasma, where they are bound to transferrin for transfer to storage sites. As ferrous ion is released into plasma, it is oxidized by oxygen in the presence of ferroxidase (Goyer, 1991).

Normally, the adult human body contains 3 to 5 grams of iron. Two-thirds of this amount is in the blood, bound to hemoglobin. Less than 10 percent of body iron is found in myoglobin and iron-requiring enzymes. About 20 to 30 percent of the remaining iron in the body pool binds to iron-storage proteins in the liver, bone marrow, and spleen (Elinder, 1986).

Under normal conditions, only 0.6 to 1.0 mg of iron per day, or roughly 0.01 percent of the body stores, is eliminated from the body. Approximately 0.2 to 0.5 mg of elemental iron per day is eliminated through the feces, 0.1 to 0.3 mg per day in urine, and the remainder through normal dermal losses in sweat, hair, and nails. Based on these elimination rates, the biological half-life of iron in the body is 10 to 20 years (Elinder, 1986).

Environmental sources of iron

The iron concentrations of liver, kidney, beef, ham, egg yolk, and soybeans are on the order of 30 to 150 mg/kg fresh weight. Grains and fruits are low in iron, usually ranging from 1 to 20 mg/kg. In both human and cow's milk, iron concentration is about 0.5 mg/L (Elinder, 1986).

Average daily intakes of iron range from 9 to 35 mg per day (0.1 to 0.5 mg/kg-day) (Elinder, 1986). Approximately 35 percent of dietary iron comes from meat, fish, and eggs, while 50 percent is supplied by cereals, root vegetables, and other foods of plant origin (National Research Council, 1980).

Iron concentrations in water vary greatly. In the United States, the iron concentrations of freshwater and public water supplies range from 0.01 to 1.0 mg/L (Elinder, 1986). Assuming a 2 L per day consumption of water by a 70-kg (body weight) adult, this range would result in an intake of 0.0003 to 0.03 mg/kg-day of iron from drinking water.

The RDA for iron is 10 mg (approximately 0.14 mg/kg-day) for adult males and 18 mg (approximately 0.25 mg/kg-day) for females of reproductive age (National Research Council, 1980).

Toxicity of iron

Iron intoxication is most frequent in children aged 1 to 3 years. This generally occurs when children eat adult iron supplements in the form of ferrous sulfate tablets with candy-like coatings. Severe poisoning in children may occur following ingestion of more than 0.5 gram (approximately 22 mg/kg) of iron or about 2.5 grams (approximately 110 mg/kg) as ferrous sulfate. Acute iron poisoning has occurred in children who ingested as few as six iron tablets (Whitney et al., 1990). The iron damages the lining of the gastrointestinal tract, producing vomiting as the first symptom. Bleeding of the damaged gastrointestinal tissue frequently results in blood in the vomit and black stools (Goyer, 1991). Shock and metabolic acidosis can develop. If the patient survives the initial crisis, liver damage with hepatitis and coagulation defects often occur within a couple of days. Renal failure and cirrhosis of the liver may occur as delayed effects (Elinder, 1986).

Long-term iron intake in a form that is readily absorbed and in doses exceeding 50 to 100 mg of iron per day (0.7 to 1.4 mg/kg-day for a 70-kg adult male) (Elinder, 1986) results in an increased body burden of iron because iron is removed from the body at a much slower rate than it is absorbed. As the body burden of iron increases to between 20 and 40 grams (roughly 10 times the normal level), hemosiderin production (the iron-binding protein) increases and results in a condition known as hemochromatosis. This condition starts with increased pigmentation of the skin and higher concentrations of iron in the liver, pancreas, endocrine organs, and heart. This increased tissue iron can produce cirrhosis of the liver, disturbances in endocrine and cardiac function, and diabetes mellitus (Goyer, 1991).

Chronic iron toxicity in adults can be caused by genetic factors, excess dietary iron, excessive ingestion of tonics or medicines containing iron, or multiple blood transfusions. The pathologic consequences of iron overload are similar regardless of cause (Goyer, 1991). Figure 5.3 summarizes the toxic effects and doses for iron.

5.1.4 Manganese

Absorption

Following ingestion, manganese absorption is homeostatically controlled: the absorption rate depends on both the amount ingested and tissue levels of manganese. Adults absorb approximately 3 to 4 percent of dietary manganese (Saric, 1986). Manganese can be absorbed following exposure by inhalation, ingestion, and dermal contact. Available data indicate that humans absorb only 3 percent of an ingested dose of manganese chloride (Mena et al., 1969). The absorption rate is influenced by iron and other metals. In states of iron deficiency, manganese is actively absorbed from the intestine. Individuals with anemia can absorb more than twice the percentage of an ingested dose. However, in states of excess iron, manganese absorption is by diffusion only (Saric, 1986). High levels of dietary calcium and phosphorus are shown to increase manganese requirements in several species (Lönnerdal et al., 1987).

Tissue accumulation and clearance

Manganese is widely distributed throughout the body. The highest concentrations are found in the liver and kidney and, to a lesser extent, the hair. The biological half time in humans is 2 to 5 weeks, depending on body stores. Manganese readily crosses the blood-brain barrier and clears more slowly from brain than from other tissues (Goyer, 1991). Normal concentrations in the brain are low, but the half time in the brain is longer and the metal may accumulate in the brain with excessive absorption (National Research Council, 1973).

Absorbed manganese eliminates rapidly from the blood and concentrates in mitochondria. Initial concentrations are greatest in the liver. Manganese penetrates the placental barrier in all species and is more uniformly distributed throughout the fetus than in adult tissues. It is secreted into milk.

Absorbed manganese is almost totally secreted in bile and reabsorbed from the intestine as needed to maintain body levels. At excessive exposure levels, other gastrointestinal routes may participate. Excess manganese is eliminated in the feces; urinary excretion is negligible (Goyer, 1991; Saric, 1986).

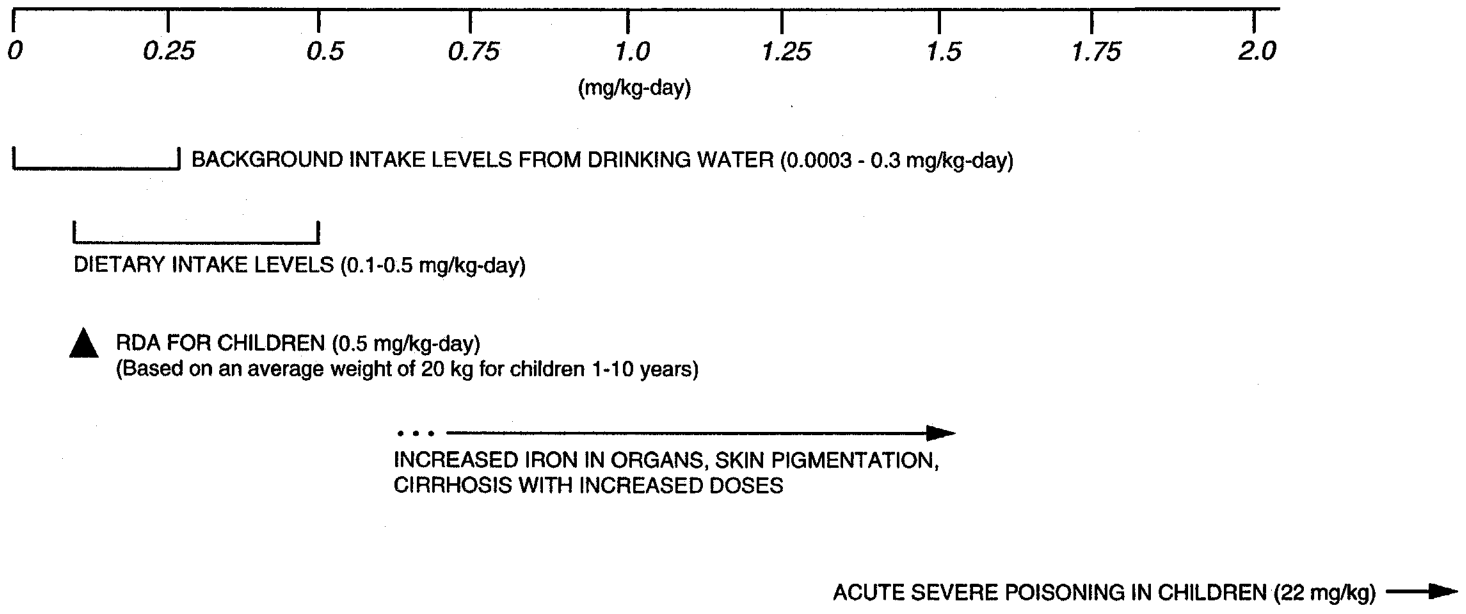


FIGURE 5.3
IRON TOXICITY RANGES

Environmental sources of manganese

On the whole, food constitutes the major source of manganese intake for humans. The highest manganese concentrations are found in plants, especially wheat and rice. Drinking water generally contains less than 0.1 mg/L. Manganese levels in soil range from 1 to 7000 mg/kg, with an average of 600 to 900 mg/kg. Mining and natural geological background variation can contribute to this variability. Manganese bioaccumulates in marine mollusks up to 12,000-fold, and there is evidence for toxic effects in plants (phytotoxicity) and plant bioaccumulation. The Illinois Institute for Environmental Quality recommends a criterion of 1 to 2 mg/kg for manganese in soil and 200 mg/kg in plants (Saric, 1986).

Variations in manganese intake can be explained to a large extent by differences in nutritional habits. In populations consuming cereals and rice as main food sources, manganese intake will be higher than in areas where meat and dairy products are a larger part of the diet. The average daily intake has been estimated to be 2.0 to 8.8 mg per day (0.03 to 0.13 mg/kg-day) (EPA, 1994a), but intakes as high as 12.4 mg (about 0.2 mg/kg-day) are reported in countries with high cereal intake (Saric, 1986).

Drinking water generally results in an intake of less than 0.2 mg (0.003 mg/kg-day), although some mineral waters can increase this amount by more than threefold (Saric, 1986). One study from Greece reported manganese concentrations in drinking water exceeded 2 mg/L, resulting in daily intakes of 0.06 to 0.07 mg/kg-day (EPA, 1994a).

Toxicity of manganese

Manganese is an essential nutrient. Estimated safe and adequate daily dietary intakes for adults range from 0.03 to 0.07 mg/kg-day (Saric, 1986). The EPA no-adverse-effect level for drinking water is set at 0.005 mg/kg-day while the lowest-observed-adverse-effect level for drinking water is 0.06 mg/kg-day. The EPA reference dose (RfD) for drinking water is 0.005 mg/kg-day. The RfD for food ingestion is 0.14 mg/kg-day. Manganese may be more bioavailable (i.e., more readily absorbed) in drinking water than in dietary food sources, resulting in toxic effects at lower ingested doses in drinking water than in food (EPA, 1994a).

Manganese inhalation in industrial settings has provided the largest source of data on chronic manganese toxicity. These data indicate excess manganese can result in a central nervous system disorder consisting of irritability, difficulty in walking, speech disturbances, and compulsive behavior that may include running, fighting, and singing. With continued exposure, this condition can progress to a mask-like face, retropulsion or propulsion, and a Parkinson-like syndrome. The condition reverses slowly with removal of manganese exposure. Metal chelating agents are ineffective in treatment, but L-dopa is effective in treatment (Goyer, 1991).

Information is limited on the effects of manganese ingestion. Because effects from drinking water seem to differ from those from food sources, only studies on water consumption will be considered here. A Japanese study of 25 people drinking well water with manganese concentrations of 14 mg/L (0.4 mg/kg-day estimated intake) reported symptoms of intoxication, including a mask-like face, muscle rigidity and tremors, and mental disturbances. In two cases (8 percent), deaths occurred among the intoxicated people. A Greek study of more than 4000 individuals drinking water with manganese concentrations varying from 0.081 to 2.3 mg/L (estimated intake at 2 L per day for a 70-kg individual range from 0.002 to 0.07 mg/kg-day) showed varying degrees of neurological effects in individuals drinking from 0.007 to 0.07 mg/kg-day, but no effects in individuals drinking less than 0.005 mg/kg-day (Kondakis et al., 1989).

The chemical form of manganese has complex effects on its toxicity. Although more soluble forms are more readily absorbed from the gastrointestinal tract, they also appear to be more rapidly cleared. Exposure to insoluble forms results in lower manganese absorption but higher chronic tissue levels and therefore greater toxicity (EPA, 1994a). Information is limited on the effects of various forms of manganese.

Few data are available on manganese toxicity in infants, but infants are probably more susceptible to toxicity due to greater absorption and greater penetration into the central nervous system (EPA, 1994a; Saric, 1986). Figure 5.4 summarizes manganese toxicity as a function of dose.

5.1.5 Molybdenum

Absorption

Molybdenum absorption in the gastrointestinal tract depends on the species of the metal. Both inorganic and hexavalent forms such as molybdenum trioxide, sodium molybdate, and ammonium molybdate are readily absorbed from both food and water, whereas molybdenite is not. Human absorption rates of 40 to 70 percent have been observed for molybdenum (Tipton et al., 1969; Robinson et al., 1973; Alexander et al., 1974).

Tissue accumulation and clearance

In humans, the highest concentrations of molybdenum occur in the liver, kidney, and adrenals (Casarett and Doull, 1991). With normal dietary intake, molybdenum levels in the body slowly increase until approximately age 20, then begin to decline steadily. Urine is the principal route of excretion in humans. Human studies indicate the biological half-life in humans is considerably longer than in animals and may be as long as 2 weeks (Rosoff and Spencer, 1964).

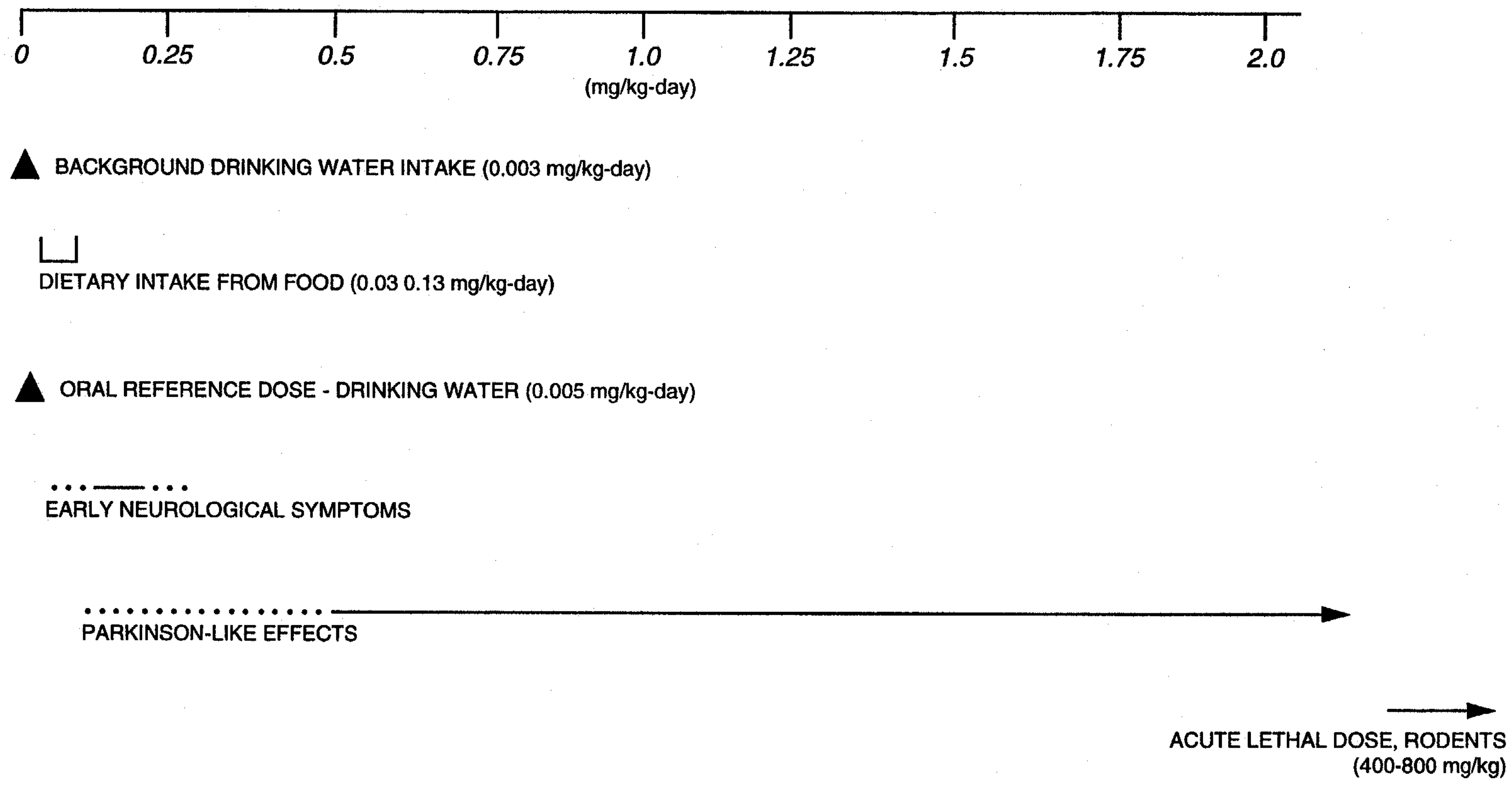


FIGURE 5.4
MANGANESE TOXICITY RANGES

MAC: SITE/SRK/BRA/MAN-GEN

Environmental sources of molybdenum

Molybdenum naturally occurs in combination with other metals, including uranium, lead, iron, cobalt, and calcium. Native soil concentrations can vary by as much as 2 orders of magnitude, from 0.1 to 10 mg/kg, leading to large variations in the molybdenum concentrations in plant materials. Natural concentrations in ground water have been reported from 0.00011 mg/L to 0.0062 mg/L. Human dietary intake of molybdenum has been estimated at 0.05 to 0.24 mg per day (0.0007 to 0.003 mg/kg-day). The drinking water contribution is estimated to range from 0 to 95 percent. The nutritional intake for molybdenum ranges from 0.0015 to 0.0054 mg/kg-day. No symptoms of molybdenum deficiency have been reported in humans. Nonetheless, molybdenum is an essential trace element that functions as a necessary constituent of several enzymes, including xanthine oxidase (which is involved in the metabolism of uric acid) and nitrate reductase (Friberg et al., 1986).

Toxicity of molybdenum

Acute toxic effects have not been reported for molybdenum. No adverse health effects have been reported with chronic intake of less than 0.008 mg/kg-day of molybdenum. The primary toxicity of molybdenum is related to its interactions with copper and sulfur, leading to altered excretion patterns for these elements. Increased molybdenum levels also increase the levels of xanthine oxidase, which is responsible for the production of uric acid. High levels of uric acid can accumulate in joints and lead to symptoms of gout and other joint disorders.

Intake of 0.008 to 0.022 mg/kg-day of molybdenum can produce mineral imbalance as a result of increased copper excretion. Copper excretion has been reported to double with molybdenum intakes at the upper end of this range. Copper is an essential nutrient important in many metabolic pathways, including the synthesis and function of hemoglobin. A copper deficiency resulting from excess excretion will impair the oxygen-carrying capacity of the blood, and severe copper deficiencies can lead to hypochromic microcytic anemia. Gout-like symptoms and joint deformities were reported in humans in regions of Russia where elevated soil concentrations of molybdenum and subsequent increased molybdenum concentrations in food led to molybdenum intake ranging from 0.14 to 0.21 mg/kg-day. Figure 5.5 summarizes the health effects of molybdenum as a function of dose.

5.1.6 Nitrate

Absorption

Ingested nitrate is converted in the gut to the toxic nitrite ion, which is readily absorbed. The conversion rate depends on both gut flora and pH, with a more rapid conversion in a higher pH environment. Infants have a higher gut pH, which is more conducive to bacteria growth. Therefore, the combination of an alkaline environment and increased bacterial conversion increases the production

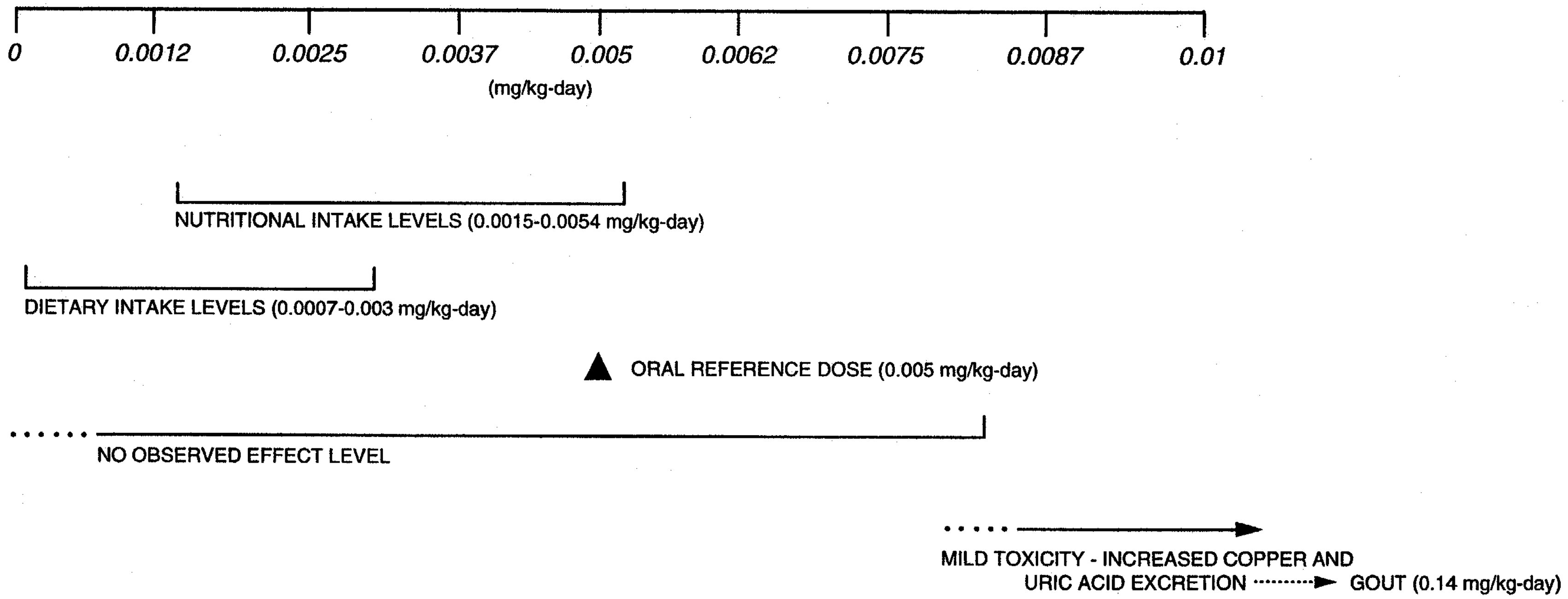


FIGURE 5.5
MOLYBDENUM TOXICITY RANGES

MAC: SITE/SRK/BRA/MOL-GEN

of nitrite from nitrate in infants, resulting in higher blood nitrite levels for a given dose of nitrate. In healthy adults, nitrates are rapidly absorbed from the upper intestine. This rapid absorption reduces the contact time with gut flora, thereby reducing the conversion to nitrite and the resultant toxicity.

Tissue accumulation and clearance

After absorption, the nitrite ion binds to hemoglobin in the blood and oxidizes it, thereby reducing the oxygen-carrying capacity of the blood and decreasing the rate of oxygen release. The oxidized hemoglobin is called methemoglobin and can be reduced back to normal hemoglobin enzymatically by methemoglobin reductase. Infants are more sensitive to these effects because of 1) the presence of fetal hemoglobin, which is more sensitive to oxidation by nitrite, and 2) lower activity of methemoglobin reductase, meaning the methemoglobin remains oxidized for a longer period. Certain individuals have a rare genetic deficiency in methemoglobin reductase and therefore exhibit higher levels of circulating methemoglobin. Although these individuals develop alternate metabolic pathways to maintain adequate levels of circulating hemoglobin in the normal state, exposure to high nitrate levels can result in excessive levels of methemoglobin in these individuals.

In healthy adults, the estimated half time for methemoglobin reductase conversion of methemoglobin back to hemoglobin ranges from 6 to 24 hours for theoretical methemoglobin levels (Bolyai et al., 1972).

Environmental sources of nitrate

Nitrates accumulate in soils from the application of fertilizers, human and animal waste, bacterial nitrogen fixation, mineral dissolution, and plant and animal tissue breakdown. These nitrates can filter through the soil into ground water. Concentrations of nitrate in well water exceeded 440 mg/L, or 10 times the current regulatory levels (Lee, 1970).

Bioaccumulation of nitrates from soil and water to plants results in a wide range of nitrate concentrations in fresh fruits and vegetables, with levels as high as 2000 mg/kg reported in beets and 9000 mg/kg in radishes (Kamm et al., 1965; Smith, 1966). Nitrate accumulation in plant material increases with drought, high temperatures, cloudiness, and insect and herbicide damage to plants. Nitrates and nitrites are used to preserve meats, especially corned or smoked products.

Toxicity of nitrate

The primary toxicity of nitrate is methemoglobinemia, which is a function of the balance between circulating levels of nitrite and methemoglobin reductase activity. A very high acute dose can produce the same toxicity as a lower dose that slowly increases the concentration of methemoglobin over time. Therefore, the acute and chronic toxicities of nitrate are summarized together. For easier comparison between ingested doses of nitrate and ground water levels at the UC site, dose ranges are presented as nitrate intake; nitrate exposure levels are frequently converted to the nitrogen concentration in the nitrate by dividing the nitrate number by 4.4. Therefore, 44 mg/L nitrate is equivalent to 10 mg/L nitrate-nitrogen.

Symptoms of methemoglobinemia can be correlated with the percentage of methemoglobin in the blood as follows: less than 10 percent methemoglobin produces no symptoms in individuals; more than 25 percent methemoglobin produces weakness, rapid pulse, and tachypnea (rapid breathing); more than 50 to 60 percent methemoglobin can be fatal (EPA, 1994a). These symptoms reflect the progressive decrease in available oxygen. Infants are more sensitive to the production of methemoglobin and therefore are considered the most sensitive population. The exposure route for infants is contaminated water used for formula.

Toxicity symptoms have not been reported in infants with nitrate intakes below 7 mg/kg-day. Mild symptoms such as weakness, rapid pulse, and rapid breathing occur with intakes from 7 to 30 mg/kg-day. The severity of these symptoms increases as increased nitrate intake results in greater levels of methemoglobin and therefore reduced availability of oxygen. Cyanosis, or a blue appearance to the skin, is followed by unconsciousness as oxygen availability is further reduced. The lowest reported fatal dose of chronic nitrate is 35 mg/kg-day for an infant and 116 mg/kg (acute intake) for an adult. A wide range of nitrate intake can produce similar symptoms among individuals because of net differences in gut pH, bacterial activity, and methemoglobin reductase activity. Figure 5.6 summarizes these health effects in infants as a function of dose.

Nitrate toxicity data are based primarily on epidemiologic studies of human adults and infants who report to hospitals with symptoms of methemoglobinemia. Exposure doses were back-calculated from sampling their drinking water, in most cases. Therefore, these data do not represent well controlled studies with readily defined dosage ranges. Many of the water sources in these clinical studies showed contamination with bacteria, leading to the possibility that this bacterial exposure is a necessary cofactor in the development of methemoglobinemia. One laboratory study indicated that healthy infants could drink nitrate at 24 mg/kg-day in solutions free of bacteria and show no symptoms of methemoglobinemia (EPA, 1994a).

Gastrointestinal distress has also been suggested as a cofactor in the development of methemoglobinemia. Infants with colic are more susceptible than healthy infants to nitrate-induced methemoglobinemia (EPA, 1994a).

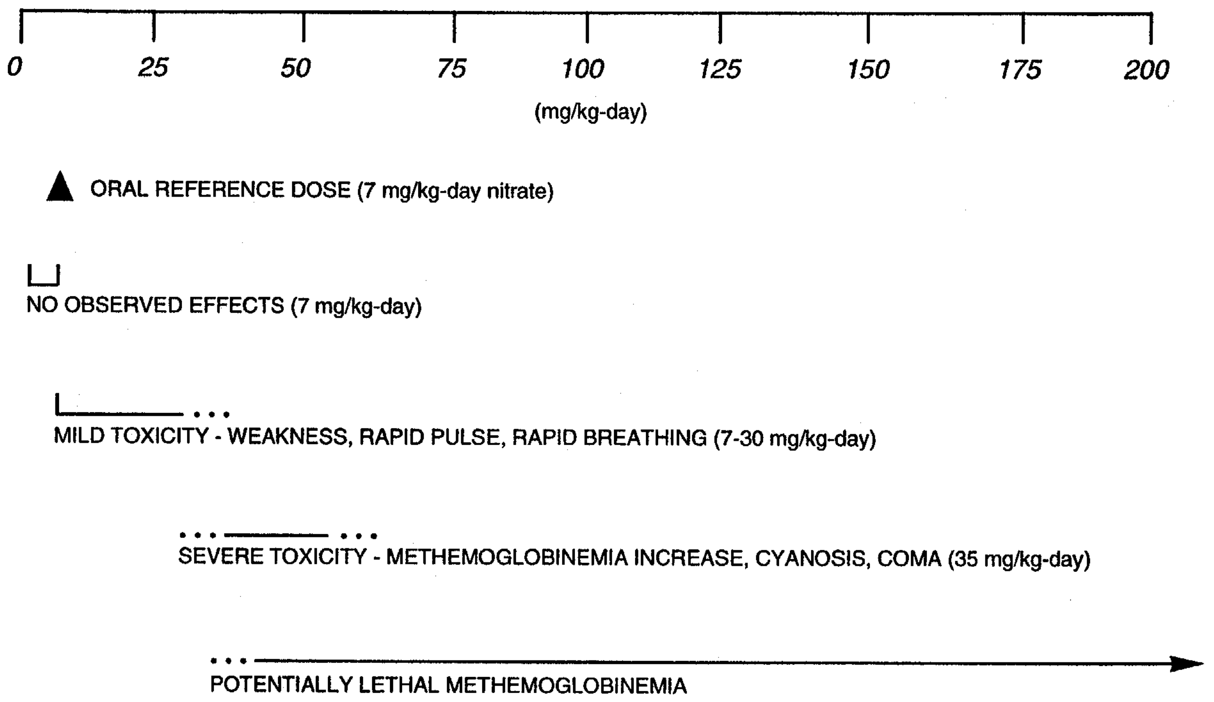


FIGURE 5.6
NITRATE TOXICITY RANGES FOR INFANTS

MAC: SITE/SRK/BRA/NIT-GEN

5.1.7 Selenium

Absorption

Although approximately 90 percent of the water-soluble forms of selenium (such as selenite) are absorbed in the gastrointestinal tract in rats, humans show lower absorption (40 to 80 percent) (Bopp et al., 1982). Absorption by ruminants is only 30 to 35 percent, probably due to bacterial reduction in the rumen. Absorption of the less soluble elemental selenium or selenium sulfide is poor in rats (Medinsky et al., 1981; Cummins and Kimura, 1971).

Tissue accumulation and clearance

Human studies suggest similar distributions of selenium between humans and laboratory animals (Bopp et al., 1982). At low intake levels, selenium is retained and accumulates in the reproductive organs, brain, and thymus, with only transient accumulation in other organs. Selenite-derived selenium accumulates in the liver and kidneys more rapidly than selenium derived from selenate (Millar et al., 1973). There is some indication that organically bound forms of selenium exist in a separate, more bioavailable pool than either selenite and selenate.

Although urinary excretion is the primary elimination route under normal dietary conditions (67 percent), in deficiency states fecal excretion is the major pathway. At toxic doses, the major excretion route is through expired air as dimethylselenide (50 to 60 percent) (Friberg et al., 1986). Although these data were obtained from rats, other data suggest human excretion is similar (Bopp et al., 1982). Selenium elimination in humans follows three phases with the following half times: 1, 8 to 20, and 65 to 116 days.

Environmental sources of selenium

Seafood, meat, and grains are the main source of selenium for the general population. Dietary intake of selenium in the United States ranges from 0.0007 to 0.0029 mg/kg-day. Selenium concentrations in ground water and surface water range from 0.00006 to 0.400 mg/L, with highs of 6 mg/L reported by Friberg et al. (1986). Concentrations in U.S. public water supplies rarely exceed 0.010 mg/L (EPA, 1980). High selenium concentrations occur in volcanic rock (0.120 mg per gram) and in sandstone uranium deposits (1.0 mg per gram). The soil content of selenium varies widely, as does the rate of accumulation by plants. Although grasses and grains do not accumulate selenium in concentrations greater than 50 mg/kg, some plants grown in high-selenium regions can accumulate as much as 10,000 mg/kg. These high-accumulating plants are generally not used as food sources but can produce toxic effects if consumed by livestock.

Toxicity of selenium

Selenium is an essential nutrient. The adult RDA is 0.0006 to 0.0011 mg/kg-day. Although some biochemical alterations, including prolonged prothrombin time and reduced blood glutathione concentrations, can be observed with selenium intakes from 0.0107 to 0.0121 mg/kg-day, no clinical signs of selenosis are observed with these intakes. Mild toxicity, including hair loss or breakage, thickening and brittle nails, and a garlic odor in dermal excretions and breath, were reported in human populations with dietary selenium intakes of 0.015 mg/kg-day. However, selenium intake as low as 0.013 mg/kg-day can produce symptoms of selenosis such as hair and nail loss in susceptible populations.

Persistent clinical symptoms of selenosis are caused by chronic dietary selenium intake in human populations in areas of China where selenium concentrations in soil range from 7 mg/kg to 12 mg/kg. Estimated selenium dietary intake was reported to be 0.018 mg/kg-day for adult women and 0.021 mg/kg-day for adult men (Yang et al., 1989a; 1989b). The average blood-selenium concentration associated with this intake was 1.3 mg/L (ranging from 1.05 to 1.85 mg/L). Symptoms of chronic selenosis with hair and nail loss and below-normal hemoglobin levels were reported in the same study at selenium intakes of 0.071 mg/kg-day. A serious outbreak of selenium poisoning, including the possible occurrence of neurotoxic effects such as peripheral anesthesia, acroparesthesia, and pain in the extremities, was observed with a selenium intake of 0.54 mg/kg-day in both women and men. It is important to note that protein intake by members of this population is unknown. Figure 5.7 summarizes these health effects as a function of dose.

Adults ingesting 350 to 4300 mg (5 to 61 mg/kg) of selenium experience vomiting, diarrhea, abdominal cramps, numbness in arms, marked hair loss, and irregular menstrual bleeding in women. Higher intakes can result in unsteady gait, cyanosis of mucous membranes, labored breathing, and sometimes death.

Symptoms of alkali disease and blind staggers were seen in grazing livestock feeding long-term on selenium-accumulating plants in areas with high soil selenium levels (Rosenfeld and Beath, 1964). These symptoms include neurological dysfunctions such as impaired vision, ataxia, disorientation, and respiratory distress.

5.1.8 Sodium

Absorption

Sodium is rapidly and fully absorbed from the intestinal tract. The skin and lungs also absorb sodium rapidly by simple diffusion and ion exchange. Sodium travels in the blood, where it ultimately passes through the kidneys. The kidneys filter out all the sodium. Then, the adrenal hormone aldosterone maintains sodium concentration in the bloodstream at the amount needed (National Research Council, 1980).

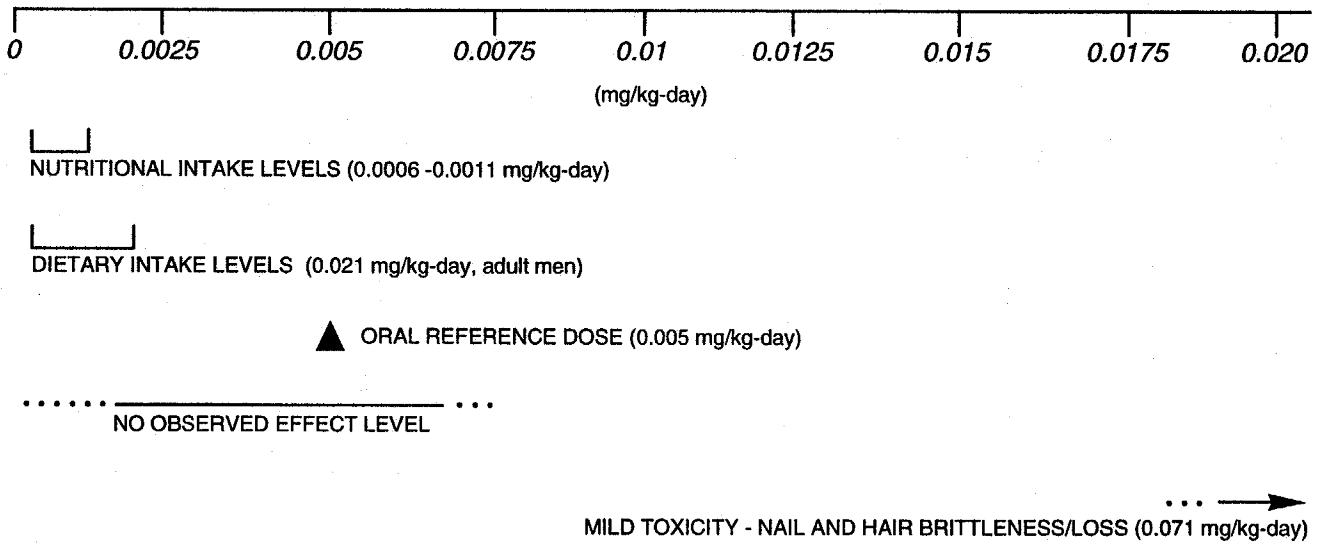


FIGURE 5.7
SELENIUM TOXICITY RANGES

Tissue accumulation and clearance

Sodium is the major extracellular ion. The sodium ion is essential to regulation of the acid-base balance and is an important contributor to extracellular osmolarity. It is an essential constituent in the electrophysiological functioning of cells and is required for impulse propagation in excitable tissues. Furthermore, sodium is essential for active nutrient transport, including the active transport of glucose across the intestinal mucosa. About 30 to 40 percent of the body's sodium is thought to be stored on the surfaces of the bone crystals, where it is easily recovered if the blood-sodium level drops.

Sodium excretion is mainly urinary, with appreciable amounts also excreted in feces, sweat, and tears (Venugopal and Luckey, 1978). Mammalian renal sodium excretion is a two-phase process involving glomerular filtration and reabsorption in the proximal tubules; of about 600 grams of sodium involved in 24-hour glomerular filtration, approximately 99.5 percent is reabsorbed in human adults. A homeostatic mechanism for sodium functions at the renal excretory level.

Environmental sources of sodium

The total sodium intake is influenced mainly by the extent to which salt (sodium chloride) is added to food, the inherent salt content of the foods consumed, and the intake of other sodium salts in the diet and medication. Sodium is a natural constituent of both vegetable and animal products in varying concentrations. Other sodium sources are medications, drinking water, cooking water, soft drinks, and alcoholic beverages.

At 2 months, infants consume approximately 300 mg of sodium per day; at 12 months, approximately 1400 mg per day. Human milk contains 161 mg/L and cow's milk contains approximately 483 mg/L (Carson et al., 1986).

The National Research Council recommends limiting daily sodium intake to less than 2400 mg (34 mg/kg-day). A healthy person requires about 115 mg sodium daily (1.6 mg/kg-day), yet sodium dietary intake is estimated at 57 to 85 mg/kg-day. However, dietary sodium intake levels as high as 134 mg/kg-day have been reported (National Research Council, 1980). The American Heart Association recommends limiting sodium intake to 3000 mg daily (about 43 mg/kg for a 70-kg individual).

The sodium content of drinking water is extremely variable. Sodium concentrations in 630 water supply systems nationwide ranged from less than 1 to 402 mg/L (resulting in drinking water ingestion rates from less than 0.03 to 11 mg/kg-day). More than 42 percent of these systems reported levels greater than 20 mg/L and 3 percent greater than 200 mg/L (Carson et al., 1986).

Toxicity of sodium

In healthy adult males, acute sodium chloride symptoms of toxicity accompanied by visible edema may occur with an intake of 35 to 40 grams of salt per day (200 to 220 mg sodium/kg-day, because sodium is 39 percent of the weight of sodium chloride) (Meneely and Battarbee, 1976). The mean lethal dose of sodium for humans was reported to be 3230 mg/kg (Venugopal and Luckey, 1978).

Epidemiological studies indicate that long-term excessive sodium intake is one of many factors associated with hypertension in humans. A high sodium/potassium ratio in the diet may be detrimental to persons susceptible to high blood pressure. Some adults, however, tolerate chronic intake above 40 grams of sodium chloride per day (equivalent to 220 mg/kg-day) (Carson et al., 1986).

Research shows critical levels of sodium ingestion can increase blood pressure (with age) and hypertension in some people. Freis (1976) reports that with sodium intake below 227 mg/day (3 mg/kg-day for a 70-kg adult), hypertension is absent. In the range of 227 to 1591 mg per day (3 to 23 mg/kg-day for a 70-kg adult), a few cases of hypertension may occur, while in the range of 1590 to 8000 mg per day (23 to 114 mg/kg-day for a 70-kg adult), approximately 15 percent of adults will exhibit hypertension. When sodium intake rises above 8000 mg/day, hypertension occurs in about 30 percent of the population.

Because sodium chloride is present in nearly all processed and packaged foods, it is difficult to limit dietary sodium intake. Average daily dietary intakes in the United States are often within the range of hypertensive effects. Drinking water generally contains relatively low sodium levels; therefore, it does not contribute significantly to the total intake, unless sodium is at higher-than-average levels in the water supply. However, people on sodium-restricted diets can obtain a significant portion of daily sodium from drinking water. Because the kidney is the major organ involved in regulating sodium balance, individuals with compromised kidney function may be placed on a low-sodium diet. In addition, other individuals may be on low-sodium diets to control hypertension. Because of the high prevalence of such individuals in our society, the American Heart Association has proposed that public drinking water supplies in the United States adopt a standard of 20 mg/L sodium to protect individuals on low sodium diets (Calabrese and Tuthill, 1977). This level would limit the sodium intake from drinking water to approximately 0.6 mg/kg-day for a 70-kg adult. Figure 5.8 summarizes the potential health effects of sodium as a function of dose.

5.1.9 Strontium

The strontium isotopes present at UMTRA Project sites are all natural, stable isotopes. The radioactive element strontium-90 is not naturally occurring and is produced only as a product of fission reactions. Therefore, no radiation

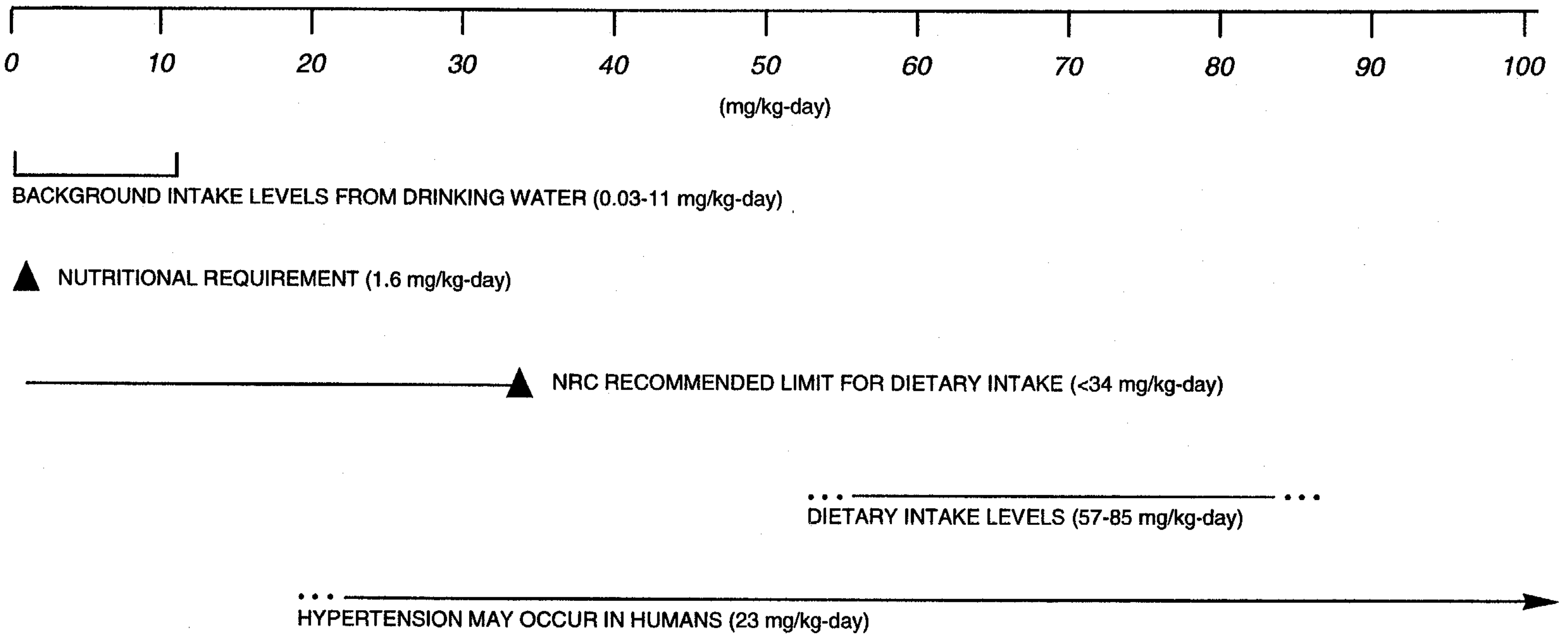


FIGURE 5.8
SODIUM TOXICITY RANGES

MAC: SITE/SRK/BRA/SOD-GEN

exposures are associated with the presence of strontium at UMTRA Project sites.

Absorption

Humans absorb 14 to 50 percent of an orally administered dose of strontium, with peak blood levels occurring within 4 hours. Absorption is proportional to dose, although large doses may overwhelm homeostatic mechanisms. Strontium is absorbed by passive diffusion from the intestinal lumen (Comar and Wasserman, 1964). Because of their chemical resemblance, strontium can effectively displace calcium. Where dietary calcium is deficient, strontium is absorbed to a higher degree. The bioavailability of ingested strontium is estimated to be 20 percent but it depends on age, species, form of strontium, and dietary levels of phosphorus, vitamin D, and calcium.

Tissue accumulation and clearance

Because of its strong similarity to calcium, 99 percent of the body burden of strontium is found in bone. The average adult body burden of strontium is estimated to be 320 mg (Snyder et al., 1975). Absorbed strontium is cleared primarily through urine and feces. Humans eliminate 12 to 13 percent of an intravenous dose in the feces. Urinary excretion accounts for nearly 60 percent of an intravenous dose and 4 to 18 percent of an oral dose (EPA, 1990). Although strontium is filtered by the kidney at a rate 3.5 times greater than calcium, calcium reabsorbs more efficiently than strontium, resulting in a more rapid clearance of strontium.

Environmental sources of strontium

Normal dietary intake of strontium in adult humans ranges from 0.013 to 0.021 mg/kg-day. Stable strontium was reported in drinking water supplies in Wisconsin and Ohio at concentrations ranging from 0.02 to 34.5 mg/L (Curzon, 1985). Strontium has been used medicinally since 1884, although its medicinal use has steadily declined.

Toxicity of strontium

Data are not available on the acute toxicity of stable strontium in humans. Lethal doses for orally administered strontium vary across species from a lethal dose of 1826 mg/kg for 50 percent of experimental mice (LD_{50}) to an LD_{50} of 7500 mg/kg in rabbits (EPA, 1990). Death resulted from respiratory failure. Intravenous administration decreased the toxic dose by as much as 1 order of magnitude (148 mg/kg in mice).

Good data are not available for estimating the toxic effects of long-term intake of excess stable strontium. Strontium was administered in the treatment of osteoporosis at a dose of 24 mg/kg-day for as long as 3 years. Although no side effects were observed, the bone loss occurring in these patients makes it difficult to compare their response to what might be observed in a healthy population.

In rat studies, strontium toxicity is related to its displacement of calcium in bone; this toxicity differs with the developmental stage of the animals. The lowest intake level that produced toxicity in young rats was 380 mg/kg-day of strontium carbonate. This dose inhibited calcification of the epiphyseal plate after 3 weeks of exposure. In adult rats, this dose had no effect, but a much larger epiphyseal plate was observed following intake of 750 or 1500 mg/kg-day in the adult animals (Storey, 1961). Intake of 190 mg/kg-day was not toxic in the young rats. In weanling rats, drinking 633 mg/kg-day of strontium chloride in water resulted in slower mineralization of the bone, slower calcification, and defective long-bone growth (Marie et al., 1985). Toxicity was not observed in weanling animals at 525 mg/kg-day intake of strontium chloride. Figure 5.9 summarizes these health effects as a function of dose.

5.1.10 Sulfate

Absorption

Sulfate absorption from the gastrointestinal tract is similar in humans and other animals. Generally, greater than 90 percent absorption is reported for sulfate doses below 150 mg/kg, decreasing to 50 to 75 percent as the dose increases into the grams-per-kilogram range.

Tissue accumulation and retention

Ingesting high levels of sulfate results in transient increases in both blood and urine concentrations. Approximately 50 percent of a 75 mg/kg-sulfate dose is excreted over 72 hours. The urinary excretion mechanism is transport-limited and can therefore become saturated at high sulfate doses. Excess sulfate is also excreted in feces in its inorganic form. To date, no data indicate sulfate accumulates, even with chronic ingestion of above-normal levels. However, extremely high chronic doses have not been examined in humans.

Sulfate is used to biosynthesize collagen, cartilage, and dentin and to form sulfate esters of both endogenous compounds (such as lipids and steroids) and exogenous compounds (such as phenols). Sulfation is important in detoxication pathways because it increases the solubility of these compounds, which enhances their excretion in the urine. Exposure to high concentrations of compounds that are conjugated with sulfate and excreted can produce a transient decrease in plasma sulfate concentrations.

Environmental sources of sulfate

Drinking water sulfate concentrations in the western United States in 1978 ranged from 0 to 820 mg/L, with a mean concentration of 99 mg/L. The EPA estimates a normal sulfate intake range of 0.00023 to 0.0064 mg/kg-day from

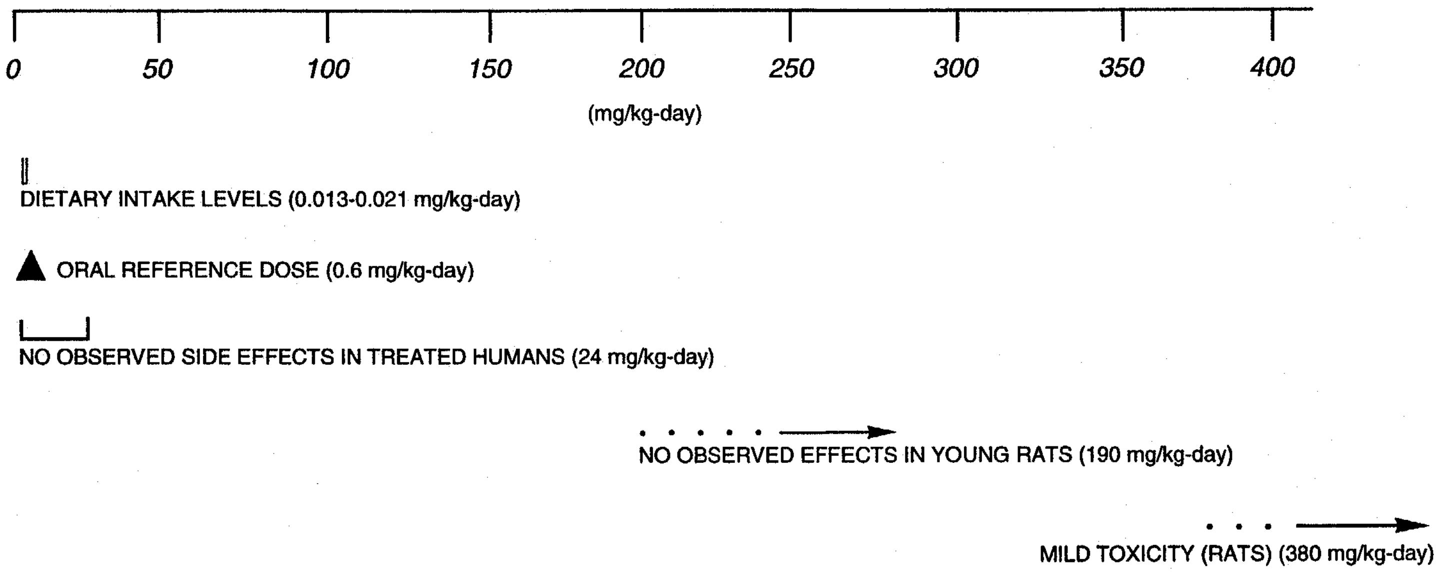


FIGURE 5.9
STRONTIUM TOXICITY RANGES

air and up to 2.9 mg/kg-day from drinking water in the western United States. No estimates are available on sulfate intake from food.

Toxicity of sulfate

As with nitrate toxicity, the acute and chronic effects of sulfate toxicity differ more in severity than in symptoms or mechanisms. Therefore, this discussion combines acute and chronic toxicities. No data indicate sulfate bioaccumulation with chronic exposure. Sulfate salts of magnesium and sodium are used medicinally as cathartics. High concentrations of unabsorbed sulfate salts in the gut can pull large amounts of water into the gut, greatly increasing the normal volume of feces. This is the basis of the toxic effects as well.

Toxicity in humans manifests primarily in diarrhea; the severity of the diarrhea is dose-dependent. Chronic sulfate ingestion can result in persistent diarrhea, leading to ionic imbalance and dehydration similar to that seen with extremely high acute doses. Serious gastroenteritis is reported in some infants and adults drinking water containing 400 to 1000 mg/L sulfate (EPA, 1992a). When drinking water is contaminated with sulfate, the taste of the water may make it unpalatable and reduce consumption. However, this is not necessarily the case. In regions (such as Saskatchewan) with high sulfate concentrations in the drinking water, residents have adapted to the taste (EPA, 1992a). A lower water intake could compound the dehydration effects of the diarrhea. Extreme dehydration can lead to death. As with nitrate toxicity, infants seem to be the most susceptible population for sulfate-induced diarrhea. Also, some data indicate diabetic and elderly populations with compromised kidney function may be more sensitive than healthy adults to the effects of sulfates (EPA, 1992a). Figure 5.10 summarizes these health effects as a function of dose.

In cattle, high sulfate intake results in sulfhemoglobinemia, a condition similar to the methemoglobinemia induced by nitrate ingestion (EPA, 1992a). Sulfhemoglobinemia has not been reported following ingestion of sulfate by humans, although the condition has been reported in humans following inhalation of hydrogen sulfide.

As with nitrate, data on sulfate toxicity are based primarily on epidemiologic studies of human adults and infants who report to hospitals with symptoms of sulfate exposure. Most exposure doses were back-calculated by sampling their drinking water. Therefore, these data do not represent well controlled studies with readily defined dosage ranges.

5.1.11 Uranium

The uranium that occurs naturally at UMTRA Project sites consists of three radioactive isotopes: uranium-234, uranium-235, and uranium-238. More than 99 percent of natural uranium occurs in the form of uranium-238 (Cothern and Lappenbusch, 1983). Uranium-238 undergoes radioactive decay by emitting alpha particles to form uranium-234, thorium-230, radium-226, radon 222,

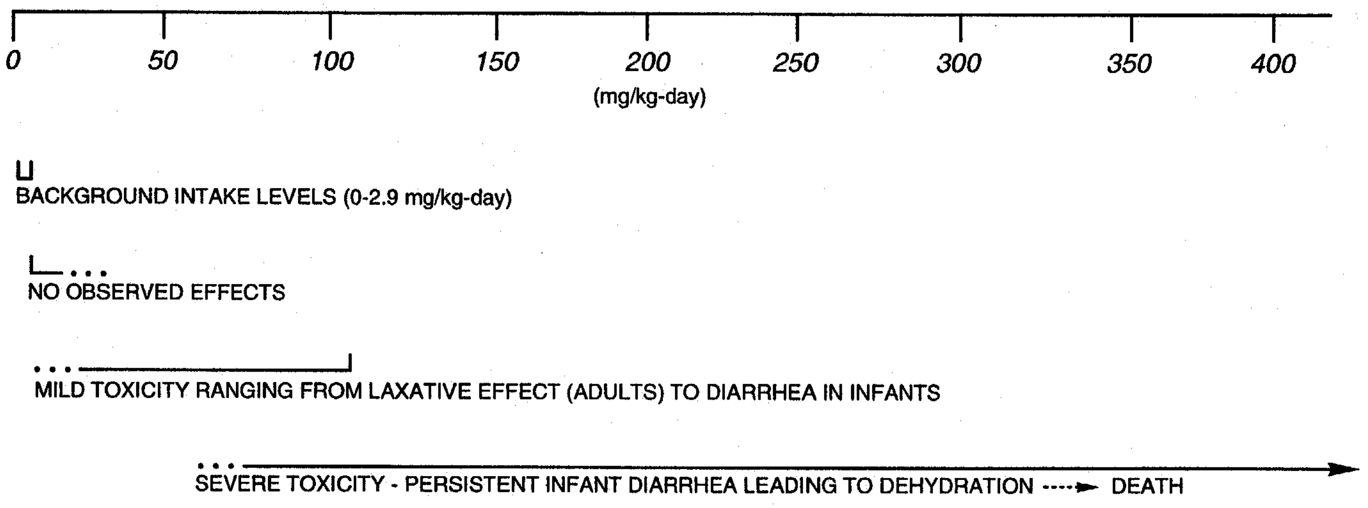


FIGURE 5.10
SULFATE TOXICITY RANGES

polonium-210, and other radioisotopes. The radioactive decay chain of uranium-238 and uranium-234 is summarized in Figure 5.11. As all natural uranium isotopes are radioactive, the hazards of high uranium intake are from both its chemical toxicity and potential radiological damage. The chemical toxicity of natural uranium is discussed below; the carcinogenic potential associated with exposure to radioactive isotopes of natural uranium is discussed in Section 5.3.

Absorption

Uranium absorption in the gastrointestinal tract depends on the solubility of the uranium compound. Hexavalent uranium compounds, especially the uranyl salts, are water soluble, while tetravalent compounds generally are not (Weigel, 1983). Even with soluble compounds, only a small fraction is absorbed. Human gastrointestinal absorption rates of 0.76 to 7.8 percent have been determined (Wrenn et al., 1985).

Tissue accumulation and clearance

In humans exposed to background levels of uranium, the highest concentrations were found in the bones, muscles, lungs, liver, and kidneys (Fisenne et al., 1988). Uranium retention in bone consists of a short retention half time of 20 days, followed by a long retention half time of 5000 days for the remainder (Tracy et al., 1992).

In body fluids, uranium tends to convert into water-soluble hexavalent uranium (Berlin and Rudell, 1986). Approximately 60 percent of the uranium in plasma complexes with low-molecular-weight anions (e.g., bicarbonates, citrates), while the remaining 40 percent binds to the plasma protein transferrin (Stevens et al., 1980). Following oral exposure in humans, more than 90 percent of uranium is excreted in the feces and is not absorbed in the gastrointestinal tract. Animal studies indicate that, of the small percent absorbed (typically less than 5 percent), approximately 60 percent is excreted in the urine within 24 hours and 98 percent is excreted within 7 days (Ballou et al., 1986; Leach et al., 1984; Sullivan et al., 1986). A small portion of the absorbed uranium is retained for a longer period.

Environmental sources of uranium

Uranium is a ubiquitous element, present in the earth's crust at approximately 4 parts per million. Uranium concentrations in ground water and surface water averaged 1 pCi/L and 3 pCi/L, respectively (NCRP, 1984). The extent of absorption from the soil into plant tissues depends on the plant species and the depth of its root system (Berlin and Rudell, 1986). Plant uranium concentrations averaged 0.075 micrograms per kilogram (μg/kg) of fresh plant material (Tracy et al., 1983).

The main dietary source of natural uranium for the general population is food (e.g., potatoes, bakery products, meat, and fresh fish) which may contain

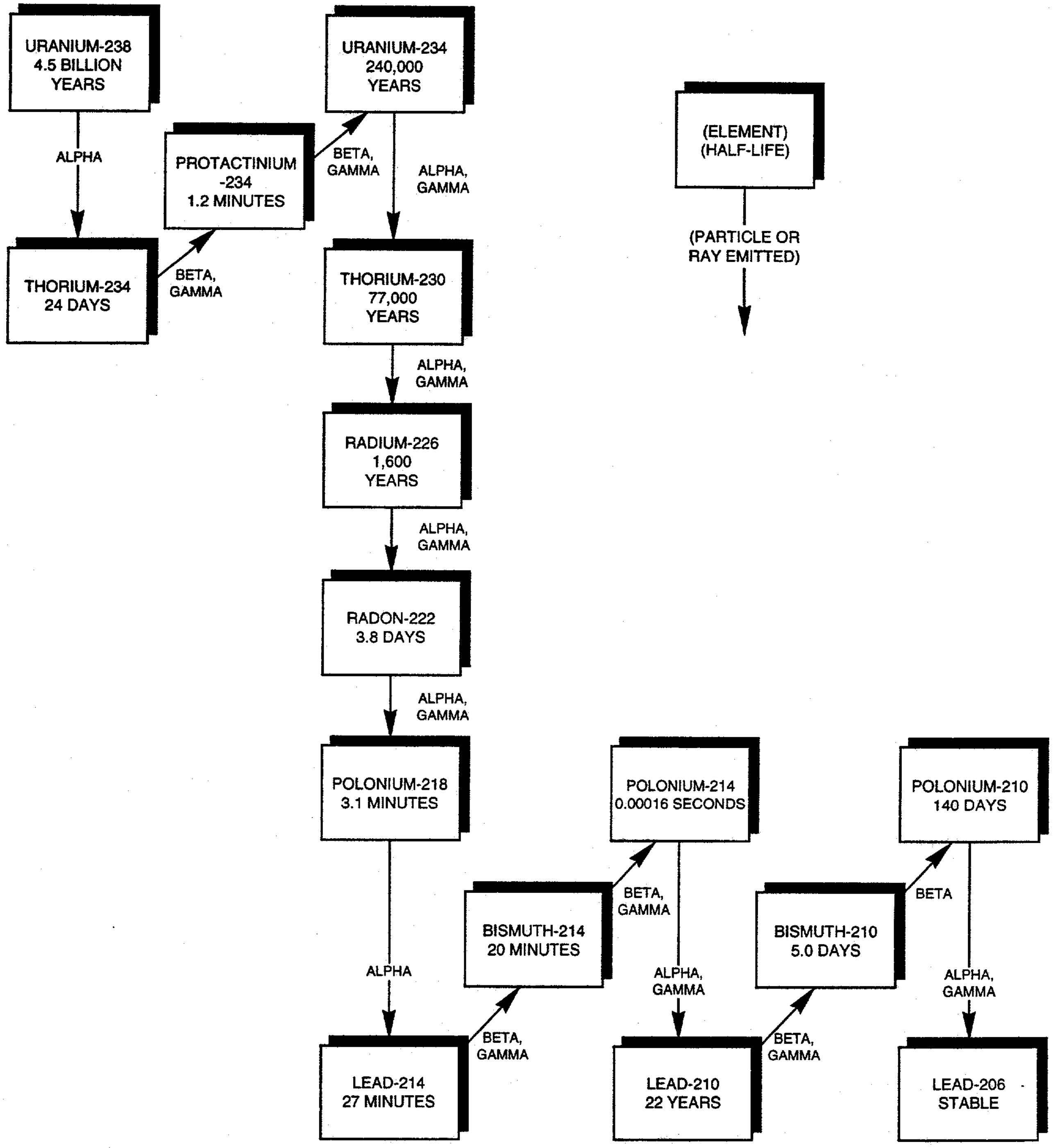


FIGURE 5.11
HALF-LIVES AND EMISSIONS FROM DECAY CHAIN OF URANIUM-238

uranium concentrations between 10 and 100 μg/kg (Prister, 1969). The total uranium dietary intake from the consumption of average foods is approximately 1 μg/kg per day; additionally, approximately 20 to 50 percent of that total can come from drinking water. Cereals and vegetables, particularly root crops, are likely to contribute most to daily uranium intake (Berlin and Rudell, 1986).

Toxicity of uranium

Exposure of the general public to natural uranium is unlikely to pose an immediate lethal threat to humans. No human deaths have been reported that are definitely attributable to uranium ingestion; therefore, no lethal dose has been determined for humans. Lethal doses of uranium ($LD_{50,23}$) in animals are reported to be as low as 14 mg/kg-day following 23-day oral exposures, depending on the solubility of the uranium compound tested (higher solubility compounds have greater toxicity), route of exposure, and animal species. High doses of uranium cause complete kidney and respiratory failure.

No chronic toxic effects are reported in humans following oral exposure to uranium. Data from populations occupationally exposed to high concentrations of uranium compounds through inhalation and information from studies on experimental animals indicate the critical organ for chronic uranium toxicity is the proximal tubule of the kidney (Friberg et al., 1986). In humans, chemical injury reveals itself by increased catalase excretion in urine and proteinuria. Dose-response data for the toxic effects of uranium on the human kidney are limited.

The lowest dose of uranyl nitrate that caused moderate renal damage was given to rabbits in diet at 2.8 mg/kg-day (Maynard and Hodge, 1949). Figure 5.12 summarizes the health effects for uranium as a function of dose.

5.1.12 Vanadium

Absorption

Vanadium absorption from the gastrointestinal tract is low. The International Commission on Radiological Protection (ICRP, 1960) estimates the absorption of soluble vanadium compounds is 2 percent, but the World Health Organization states that absorption of even very soluble forms of vanadium is less than 1 percent from the gastrointestinal tract (WHO, 1988). Limited human data (from three individuals) suggested as much as 10 percent of a repeated oral dose may be absorbed (Proescher et al., 1917; Tipton et al., 1969). Soluble vanadium compounds that are inhaled and deposited in the lungs are more readily absorbed (about 25 percent) (WHO, 1988). Although soluble forms of vanadium may be absorbed through the skin, absorption via this route is probably minimal (EPA, 1977; WHO, 1988).

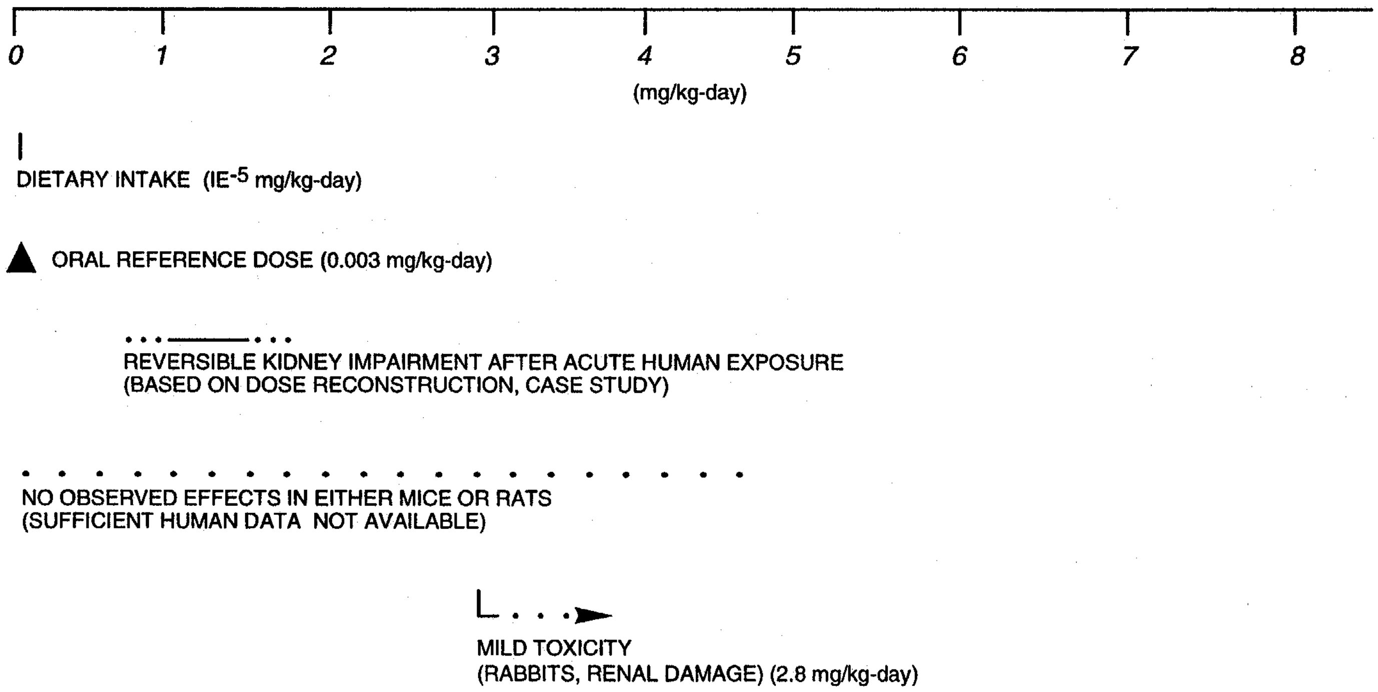


FIGURE 5.12
URANIUM TOXICITY RANGES

MAC: SITE/SRK/ BRA/URN-GEN

Tissue accumulation and clearance

Vanadium is found in all body tissues in concentrations ranging from 0.08 μg per gram wet weight in spleen tissue to 0.14 μg per gram in brain and heart tissue and 0.33 μg per gram in aortic tissue (Yakawa and Suzuki-Yasumoto, 1980). Vanadium concentrations in human blood serum are reported to be 0.016 to 0.939 nanograms per milliliter (ng/mL). Vanadium concentrations in hair range from 20 to 60 ng per gram, with higher values found in manic-depressive patients (57 ng per gram) than in normal control groups (29 ng per gram).

The distribution of vanadium in humans following oral exposure may be extrapolated from animal studies. In acute-duration exposures, vanadium is rapidly distributed, primarily in the bones. After intermediate-duration exposure, vanadium concentrations reaching the tissues are low, with the kidneys, bones, liver, and lungs initially showing the highest levels.

Vanadium is an element and is not metabolized. However, in the body, interconversion occurs between vanadyl and vanadate. Vanadium can reversibly bind to the protein transferrin in the blood and then be taken up into erythrocytes. Compared to vanadate, vanadyl uptake into erythrocytes is slower, possibly due to the time required for the vanadyl form to be oxidized to vanadate. Initially, vanadyl leaves the blood more rapidly than vanadate, possibly because of the slower vanadyl uptake into cells (Harris et al., 1984). Five hours after administration, blood clearance is essentially identical for the two forms. Vanadate is the dominant vanadium species present in ground water at the Slick Rock sites.

Because vanadium is poorly absorbed in the gastrointestinal tract, a large percentage of vanadium in rats is excreted unabsorbed in the feces following oral exposure. In rats, the principal route of excretion of the small absorbed portion of vanadium is through the kidneys. The mean urinary output per 24 hours is reported to be 10 μg.

Environmental sources of vanadium

Elemental vanadium does not occur in nature, but its compounds exist in more than 50 different mineral ores and in association with fossil fuels. Vanadium is released to the atmosphere mainly through the combustion of fossil fuels, particularly residual fuel oils. Vanadium is released to soil and water mainly through natural weathering of geological formations (Byerrum et al., 1974; Van Zinderen Bakker and Jaworski, 1980).

Food constitutes the major source of exposure to vanadium for the general population (Lagerkvist et al., 1986). As a whole, dietary intake is estimated to be 6 to 18 μg per day (Pennington and Jones, 1987), although other estimates from older studies using different (and possibly less sensitive) analytical methods have been as high as 2 mg per day (Schroeder et al., 1963).

Drinking water is not considered an important source of vanadium exposure for the general population. Values for 92 percent of the water samples taken from across the United States were below 10 μg/L. Typical values appear to be around 1 μg/L (Lagerkvist et al., 1986). The estimated daily intake of vanadium by inhalation is 1 μg (Byrne and Kosta, 1978).

Although vanadium is considered an essential element for chickens and rats, there is no certainty about human dietary requirements. For animals, the daily requirement is about 10 to 25 μg/day (Pennington and Jones, 1987).

Toxicity of vanadium

The major adverse health effect to humans from vanadium is seen in workers exposed to large amounts of vanadium pentoxide dusts. The probable oral lethal dose of vanadium pentoxide for humans is between 5 and 50 mg/kg (Gosselin et al., 1976).

Systemic effects of vanadium exposure have been observed in the liver, kidneys, nervous and cardiovascular systems, and blood-forming organs. Metabolic effects include interference with the biosynthesis of cystine and cholesterol, depression and stimulation of phospholipid synthesis, and at higher concentrations, inhibition of serotonin oxidation. Other effects of vanadium on mammalian metabolism include depression of phospholipid synthesis (Snyder and Cornatzer, 1958), reduction of coenzyme Q levels in mitochondria (Aiyar and Sreenivasan, 1961), and stimulation of monoamine oxidase, which oxidizes serotonin (Perry et al., 1955).

Vanadium salts were given to patients in several studies to reduce cholesterol levels (Curran et al., 1959; Somerville and Davies, 1962; Dimond et al., 1963; Schroeder et al., 1963). The doses of vanadium in these studies varied from 7 to 30 mg/day. Transient decreases in serum cholesterol levels were observed in some patients, as were loosened stool and cramps. Green tongue, a hallmark of vanadium exposure, was observed in all patients.

A relationship between the concentration of vanadium in drinking water and the incidence of dental caries in children is reported by Tank and Storvick (1960). Dental caries incidence in children aged 7 to 11 years was reduced three times (compared to controls) by applying ammonium vanadate in glycerol to the teeth (Belehova, 1969). This relationship was not found in other studies (Hadjimarkos, 1966; 1968).

It has been suggested that raised tissue levels of vanadium are important in the etiology of manic-depressive illness. Improvement after treatment with ascorbic acid or reduced vanadium intake was seen both in manic and depressed patients.

Although animal studies report impaired conditioned reflexes following doses of vanadium from 0.05 mg/kg-day (after 6 months of exposure) to 0.5 mg/kg-day (after 21 days of exposure), effects on the nervous system were not observed following repeated oral administration of vanadium in humans. Workers exposed by inhalation to fairly high concentrations of vanadium compounds reported nonspecific symptoms, including headache, weakness, vomiting, nausea, and ringing of the ears (WHO, 1988).

Data on vanadium toxicity are insufficient to evaluate its effect on cholesterol levels, iron metabolism, blood-cell production, and mutagenesis. However, due to poor absorption from the gut, vanadium is not considered very toxic following oral administration (WHO, 1988). Figure 5.13 summarizes the toxicity of vanadium.

5.2 CONTAMINANT INTERACTIONS

Some information is available on potential interactions between contaminants found at UMTRA Project sites. However, only qualitative discussions of potential interactions is possible. In addition to physiological variables between individuals that can affect toxicity, uncertainties in interactions also result from 1) differences in the relative exposure concentrations of the different contaminants compared to the concentrations tested experimentally, and 2) the presence of additional ground water constituents that may occur in sufficient quantities to modify predicted toxicities even though they themselves are not considered constituents of potential concern for human health. Therefore, the interactions described below should be recognized as some of the factors that can influence the predicted toxicity, although the precise nature and magnitude of that influence cannot be determined.

Of primary concern among the contaminants in ground water at the UC site is the potential for nitrate-sulfate interactions. No clear data are available to completely assess this interaction, but the epidemiological evidence suggests that in infants, gastrointestinal upset such as that caused by sulfate could increase their sensitivity to methemoglobinemia produced by nitrates. However, it is also possible that sulfate-induced diarrhea could decrease the nitrate-reducing bacteria in the intestine, causing a decreased nitrate toxicity.

Interactions between nitrate, sulfate, and hemoglobin also occur. However, no studies have been found that address the potential interactions in a combined exposure to high concentrations of both nitrate and sulfate. Nitrate has been used in the treatment of hydrogen sulfide poisoning. The hydrosulfide anion binds to methemoglobin to form sulfmethemoglobin, effectively removing circulating hydrosulfide. Additional data are needed to assess the likelihood of hydrosulfide formation with oral sulfate exposure or the subsequent formation or stability of sulfmethemoglobin.

Sulfate also interacts in a complex manner with molybdenum and copper. Ruminants seem to be the most susceptible species to imbalances between these elements. In ruminants, copper prevents the accumulation of molybdenum in the liver and may antagonize molybdenum absorption. Molybdenum can

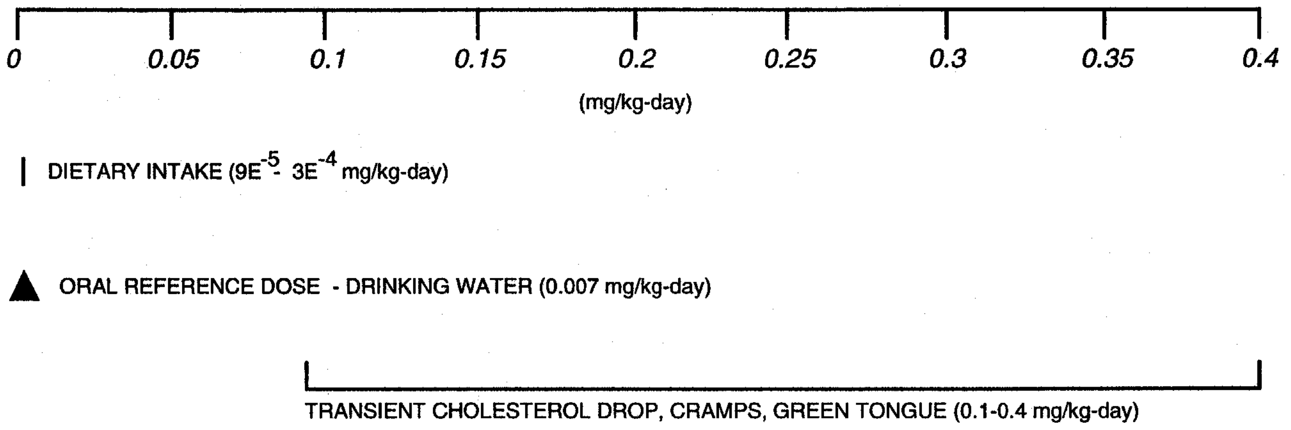


FIGURE 5.13
VANADIUM TOXICITY RANGES

MAC: SITE/SRK/BRA/VAN-GEN

produce a functional copper deficiency, but only in the presence of sulfate. It has also been suggested that sulfur can displace molybdate in the body (Casarett and Doull, 1991). In laboratory animal studies, the molybdenum toxicity is more pronounced when dietary copper intake is low (EPA, 1994a). In ruminants, both copper and sulfates can protect against molybdenum toxicity, and molybdenum and sulfur can block copper toxicity. Molybdenum in the form of sodium molybdate has alleviated cadmium toxicity in rats.

Interactions between several similar metals can alter the predicted absorption, distribution in the body, metabolism, toxicity, or clearance of a metal of interest. For example, cadmium absorption can be considerably increased under conditions of low intake of calcium, iron, or protein (Nordberg et al., 1985). Low body-iron stores can increase cadmium uptake fourfold (Flanagan et al., 1978).

Cadmium, copper, manganese, and zinc can induce synthesis of the metal-binding protein metallothionein (DHHS, 1989a, 1992; Casarett and Doull, 1991). This protein seems to have a paradoxical effect on the systemic toxicity of cadmium. Metallothionein binds cadmium and in this way protects certain organs such as the testes from cadmium toxicity. However, the methallothionein-cadmium complex may enhance nephrotoxicity, because the complex is taken up by the kidney more readily than the free ion. However, in the continued presence of these other metals, there may be competition for metallothionein binding sites.

Strontium toxicity is strongly influenced by calcium intake. Toxicity is enhanced in low calcium conditions and decreased in the presence of high calcium.

Selenium interacts with a wide range of metals, including arsenic, bismuth, cadmium, cobalt, copper, lead, mercury, platinum, silver, tellurium, and thallium (Friberg et al., 1986). Selenium forms insoluble complexes with silver, copper, cadmium, and mercury. Selenium deficiency may develop in the presence of these other metals, as is seen with cobalt and copper. The formation of these complexes can reduce the toxicity of both selenium and the other metals (Casarett and Doull, 1991). Most of these interactions have been observed in laboratory animals or in livestock. The mechanisms are not completely understood. Often the selenium-metal complex binds in a stable complex to a larger protein than the metal alone and redistributes this complex away from target tissues.

Selenium can protect against most acute effects of cadmium in rats, but it does not protect against chronic kidney toxicity. Sulfate can also interact with selenium, but the interaction is inconsistent. Sulfate at high doses can reduce some toxic effects of selenium, but not others (such as liver damage) (DHHS, 1989b).

No information on interactions of uranium with other metals has been found. However, the common target organ suggests interaction with cadmium in the production of kidney toxicity.

5.3 CONTAMINANT RISK FACTORS

The EPA Office of Research and Development has calculated acceptable intake values, or RfDs, for long-term (chronic) exposure to noncarcinogens. These values are estimates of route-specific exposure levels that would not be expected to cause adverse health effects when exposure occurs for a significant portion of the lifetime. The RfDs include safety factors to account for uncertainties associated with limitations of the toxicological database, including extrapolating animal studies to humans and accounting for variability in response from sensitive individuals. These values are updated quarterly and published in the Health Effects Assessment Summary Tables (HEAST) (EPA, 1994b) and are also provided through the EPA's IRIS database (EPA, 1994a). The most recent oral RfDs for the noncarcinogenic contaminants of concern are summarized in Table 5.1. RfDs for iron, chloride, and sulfate have not been determined.

The EPA currently classifies all radionuclides as Group A, or known human carcinogens, based on their property of emitting ionizing radiation and on the evidence provided by epidemiological studies of radiation-induced cancer in humans. At sufficiently high doses, ionizing radiation acts as a complete carcinogen (both as initiator and promoter), capable of increasing the probability of cancer development. However, the actual risk is difficult to estimate, particularly for the low doses and dose rates encountered in the environment. Most reliable data were obtained under conditions of high doses delivered acutely. It is not clear whether cancer risks at lower doses are dose-proportional (i.e., the linear dose-response hypothesis) or whether the risk is greatly reduced at low doses and rates (the threshold hypothesis). A conservative assumption for all carcinogens is that no threshold dose exists below which there is no additional risk of cancer.

Risk factors are published in HEAST and IRIS that correlate carcinogen intake over a lifetime with the increased excess cancer risk from that exposure. The most recent cancer slope factors for the uranium-234 and -238 radioactive decay series are given in Table 5.2.

Table 5.1 Toxicity values: noncarcinogenic effects

Chemical	Chronic oral RfD (mg/kg-day)	Confidence level	Critical effect/organ	RfD basis/RfD source	Uncertainty factor
Cadmium	5E-4	High	Kidney	Water/IRIS	10
Chloride	a	a	Hypertension	a	a
Iron	a	a	Hemochromatosis	a	a
Manganese	5E-3	Medium to low	Central nervous system	Water/IRIS	1
Molybdenum	5E-3	Medium	Increased uric acid, pain, swelling of joints, decreased copper levels in blood	Water/HEAST	2
Nitrate	7[b]	High	Methemoglobinemia, hematologic	Water,IRIS	1
Selenium	5E-3	High	Hair, nails, skin	Diet/IRIS	15
Sodium	a	a	Hypertension	a	a
Strontium	6E-1	Medium	Bone	Water/IRIS	300
Sulfate	a	a	Diarrhea	a	a
Uranium	3E-3	Medium	Kidney, body weight	Water/IRIS	1000
Vanadium	7E-3	a	Liver, nervous system	Water/HEAST	100

[a] Toxicity value not established or information is not available.

[b] Value represented as nitrate; nitrate-nitrogen RfD is 1.6.

Table 5.2 Toxicity values: carcinogenic effects

Parameter	Oral SF $(pCi)^{-1}$	Weight of evidence classification	Type of cancer	SF basis/SF source
Lead-210	5.1E-10	A	Bone	Water/HEAST
Polonium-210	1.5E-10	A	Liver, kidneys, spleen	Water/HEAST
Radium-226	1.2E-10	A	Bone	Water/HEAST
Thorium-230	1.3E-11	A	Bone	Water/HEAST
Uranium-238	1.6E-11	A	Note[a]	Water/HEAST
Uranium-234	1.6E-11	A	Note[a]	Water/HEAST

[a] No human or animal studies show a definite association between oral exposure to uranium and development of cancer.

SF - slope factor.

6.0 HUMAN RISK EVALUATION

To evaluate human health risks to an individual or population, the results of the exposure assessment are combined with the results of the toxicity assessment. As discussed in Section 5.0, potential adverse health effects are a function of how much of the contaminant an individual takes into the body. Indeed, at lower levels many of the contaminants associated with the mill tailings are beneficial to health because they are essential nutrients. At higher levels, these same elements can cause adverse health effects. The potential exposure intakes, if ground water within the plume were used as drinking water, are correlated below with potential health effects from these levels of exposure.

6.1 POTENTIAL NONCARCINOGENIC HEALTH EFFECTS

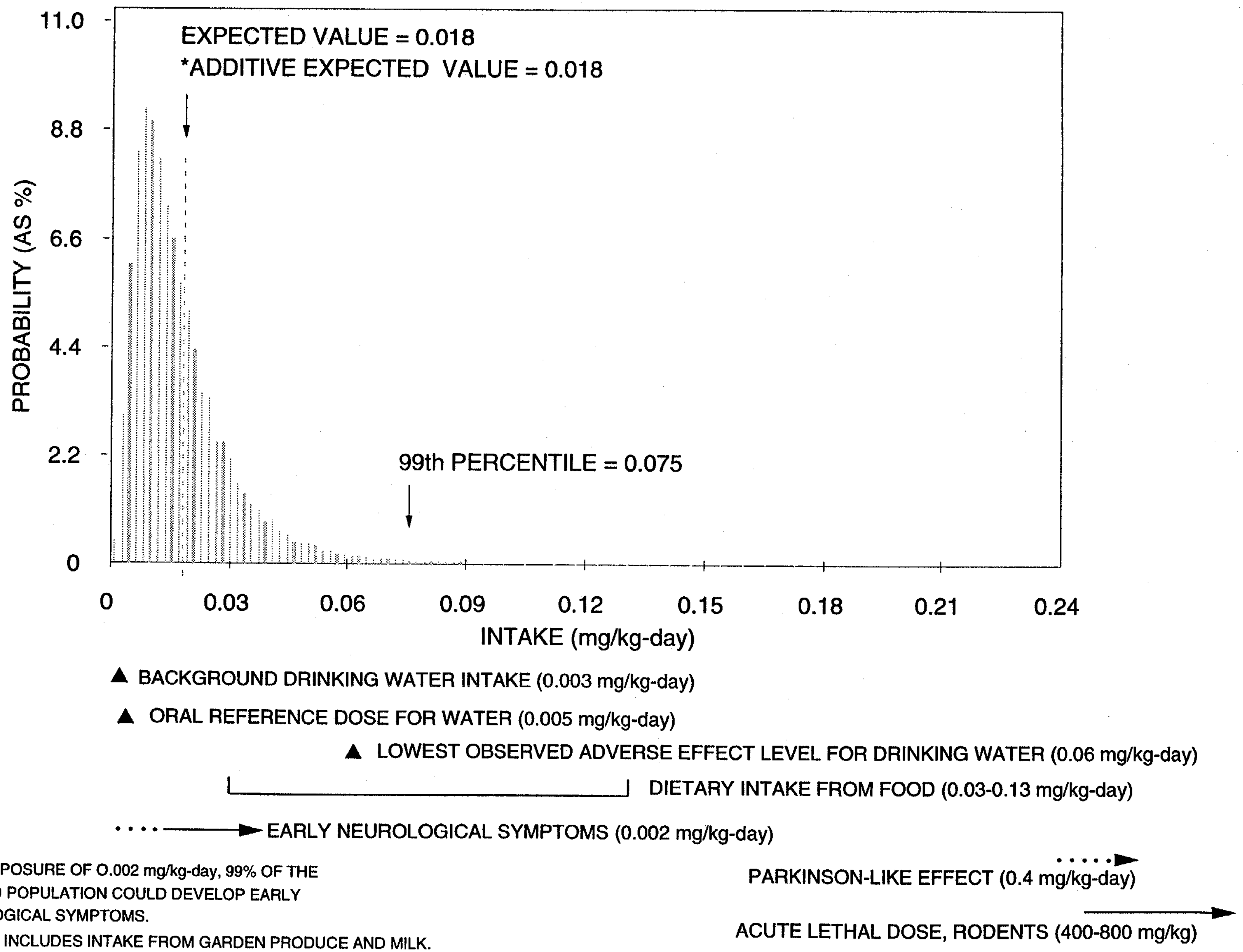
The results from the exposure assessment showing either the highest intake-to-body-weight ratios (or highest doses) or the toxicologically most sensitive group were used to evaluate potential health effects for noncarcinogens. The highest intake-per-body-weight group for the contaminants of potential concern at the Slick Rock sites is children 1 to 10 years old. However, the most toxicologically sensitive group for sulfate and nitrate is infants (birth to 1 year). Therefore, this group was evaluated for sulfate and nitrate in this report.

6.1.1 North Continent site

The primary adverse noncarcinogenic human health effects from ingesting contaminants of potential concern in ground water at the NC site are from exposure to manganese, sulfate, and sodium. Exposure to uranium is not expected to cause adverse noncarcinogenic human health effects at this site. However, the uncertainty associated with adverse health effects from uranium exposure are discussed below.

Manganese

At the manganese intake value of 0.002 mg/kg-day (estimated value where toxic effects have been observed), nearly 100 percent of the population could exhibit adverse early neurological effects including a mask-like face, muscle rigidity and tremors, and mental disturbances (Figure 6.1). The 2-percent contribution of manganese exposure from garden produce and milk ingestion adds a negligible amount to the net additive effect (e.g., expected or average value increased from 0.018 mg/kg-day to 0.0183 mg/kg-day). Thus, the same adverse effects would be anticipated for both of these intakes. Manganese and iron are known to interact by inhibiting the absorption of each other. The effect of this interaction could be a decreased adverse effect of manganese on the central nervous system.



NOTE: AT AN EXPOSURE OF O.002 mg/kg-day, 99% OF THE EXPOSED POPULATION COULD DEVELOP EARLY NEUROLOGICAL SYMPTOMS.

*ADDITIVE VALUE INCLUDES INTAKE FROM GARDEN PRODUCE AND MILK.

FIGURE 6.1
HEALTH EFFECTS OF POTENTIAL MANGANESE EXPOSURE RANGES FOR CHILDREN
SLICK ROCK, COLORADO, NC SITE

Sulfate

Nearly 50 percent of the potential intakes (38 mg/kg-day) fall within the range of exposures that could result in severe persistent diarrhea in infants and lead to ionic imbalances and dehydration (Figure 6.2). In addition, adults could exhibit laxative effects. However, ground water containing high levels of sulfate tends to be unpalatable to most people. There are cases, however, where local populations have adapted to the taste. It is important to note that the exposure distribution for infants is based on tap-water intake rates across a population that includes breast-fed and canned-formula-fed infants. Infants consuming powdered formula reconstituted with well water would be in the upper percentiles of this exposure distribution and would be at high risk of severe diarrhea.

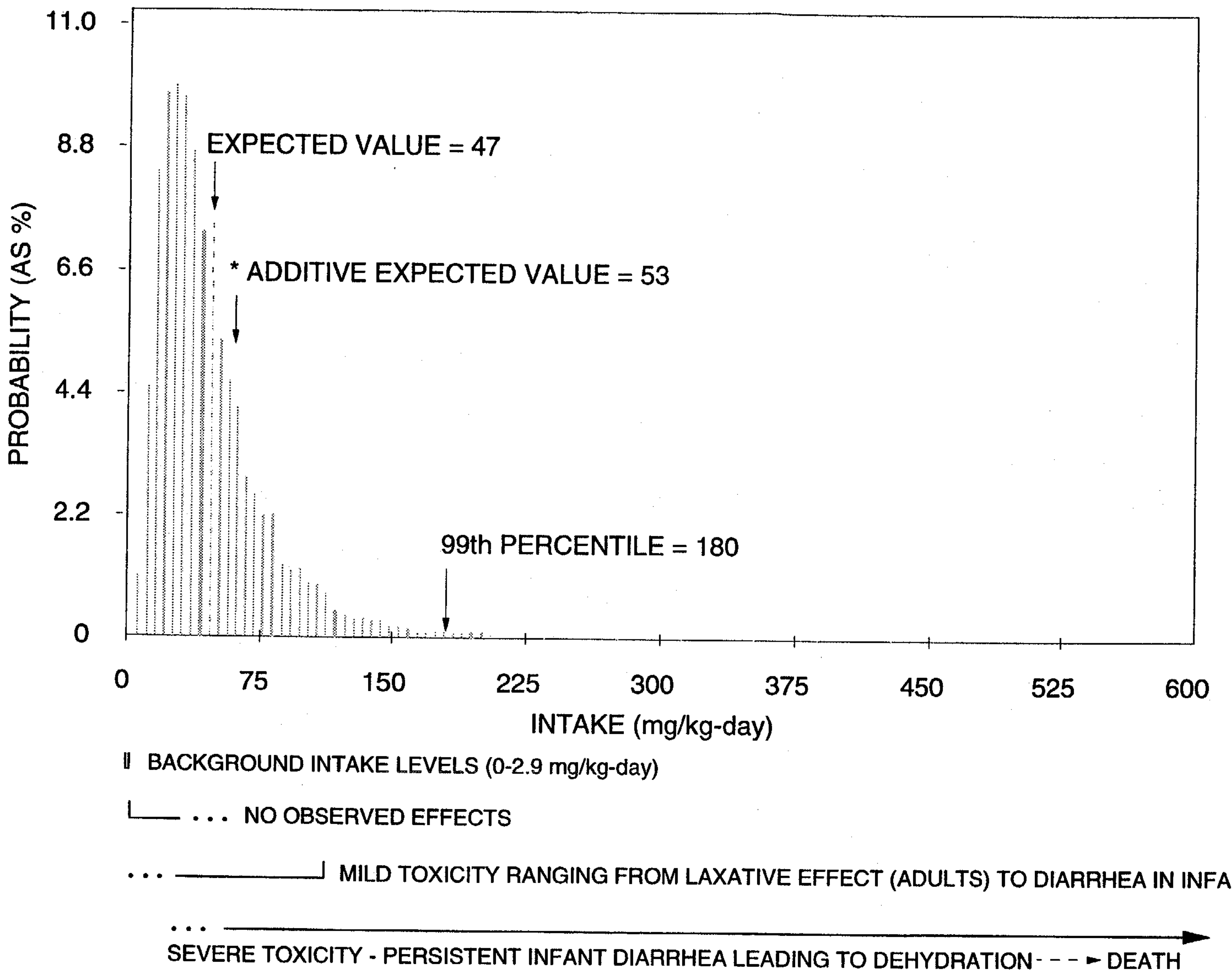
Additionally, the 13-percent increase in the sulfate intake from the ingestion of milk and meat would not appreciably shift the probability distribution. As seen in Figure 6.2, 12 percent of the expected value of 47 mg/kg-day (6 mg/kg-day) would increase the expected value to 53 mg/kg-day. Fifty-three mg/kg-day fall within the range of the same toxic effects exhibited at 47 mg/kg-day, thereby not appreciably adding to the expected adverse toxic effects.

Sodium

Chronic sodium exposure can be associated with the development of hypertension in both children and adults. At an intake of 23 mg/kg-day (estimated lower-end value where hypertension has been observed), 31 percent of the exposed population could exhibit hypertension from ingesting the ground water at the NC site alone. However, as can be seen in Figure 6.3, at the upper end of the NRC-recommended limit of 34 mg/kg-day, approximately 15 percent of the exposed population could also develop hypertension. In addition, at 57 mg/kg-day (the lower-end of the estimated dietary intake levels), 3 percent of the exposed population could develop hypertension. Since the average daily intake of sodium from diet alone can cause hypertensive effects (in the United States), the addition of sodium from a drinking water source containing these amounts of sodium could increase the probability of an individual's developing hypertension.

Additionally, the 35-percent increase in sodium intake from the ingestion of milk and meat would not appreciably shift the probability distribution. Figure 6.3 indicates that 35 percent of the expected value of 20 mg/kg-day would increase by 7 mg/kg-day to 27 mg/kg-day (which falls within the same range of toxic effects exhibited at 20 mg/kg-day), thereby not appreciably adding to the expected adverse toxic effects.

Because ingesting high levels of sulfate produces diarrhea that can lead to dehydration and ingesting high levels of sodium leads to fluid retention, a physiological interaction might be expected with simultaneous ingestion of both, thereby counteracting the adverse effects of each contaminant. However, data



NOTE: AT THE EXPOSURE OF 38 mg/kg-day, 50% OF THE EXPOSED POPULATION COULD DEVELOP DIARRHEA.

*ADDITIVE VALUES INCLUDE INTAKE FROM GROUND WATER INGESTION AND THE MILK AND MEAT EXPOSURE PATHWAYS.

FIGURE 6.2
HEALTH EFFECTS OF POTENTIAL SULFATE EXPOSURE RANGES FOR INFANTS
SLICK ROCK, COLORADO, NC SITE

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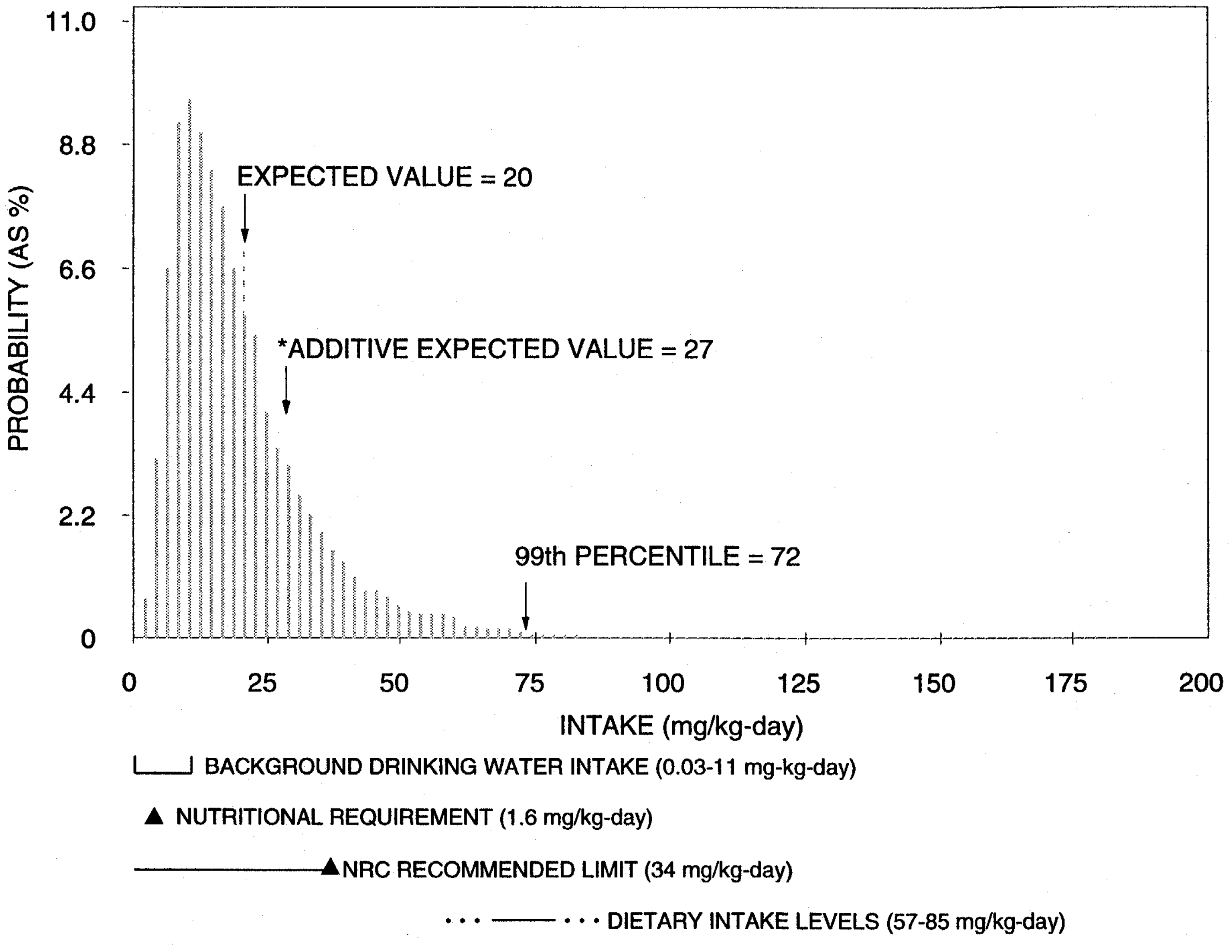


NOTE: AT 23 mg/kg-day, 31% OF THE EXPOSED POPULATION COULD EXHIBIT HYPERTENSION.

*ADDITIVE VALUE INCLUDES INTAKE FROM GROUND WATER INGESTION AND THE MILK AND MEAT EXPOSURE PATHWAYS.

FIGURE 6.3
HEALTH EFFECTS OF POTENTIAL SODIUM EXPOSURE RANGES FOR CHILDREN
SLICK ROCK, COLORADO, NC SITE

are not available to predict the net effect of chronic ingestion of sulfate and sodium simultaneously at high concentrations.

Uranium

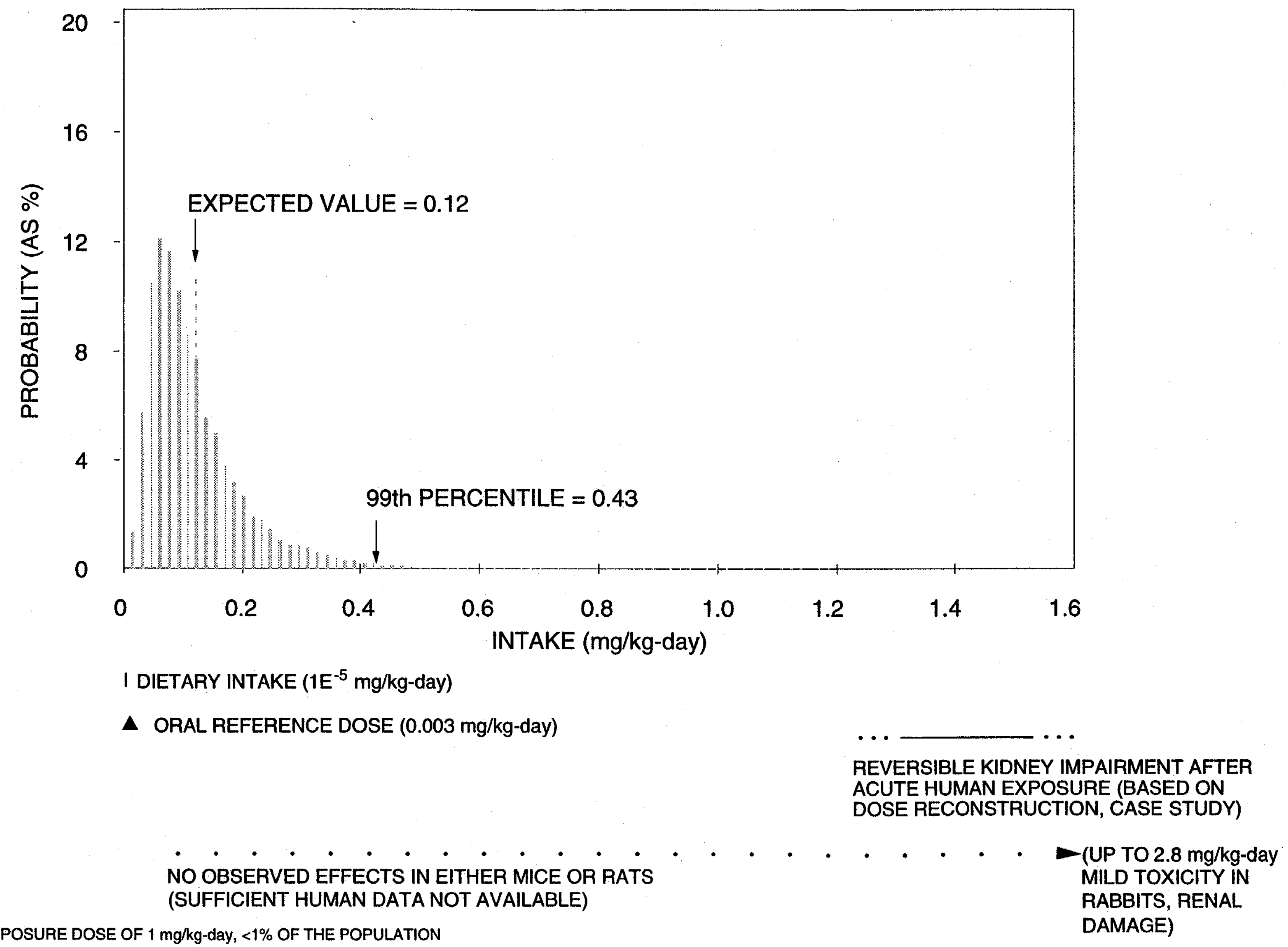
Uranium has not been shown to serve a beneficial purpose in biological systems; therefore, unlike nutrient metals, a uranium threshold of toxicity is difficult to define. The lack of available human data to evaluate the oral toxicity of uranium at these concentrations, and the fact that animal data are not always predictive of human toxicity do not indicate toxic effects will not occur. However, the entire exposure distribution for the noncarcinogenic effects of uranium falls above the oral RfD of 0.003 mg/kg-day but below ranges resulting in adverse effects in animal studies (Figure 6.4). In addition, the contribution of uranium exposure doses from the milk ingestion exposure pathway would be less than 1 percent of the drinking water pathway. This additional source would not alter the interpretation of potential risk from uranium exposure at the NC site.

6.1.2 Union Carbide site

The most significant noncarcinogenic adverse health risks associated with the contaminants of potential concern at the UC site are from nitrate, sulfate, manganese, chloride, sodium, molybdenum, selenium, and iron. Adverse human health effects from vanadium, cadmium, strontium, and uranium, at the concentrations detected at the UC site, are not anticipated.

Nitrate and sulfate

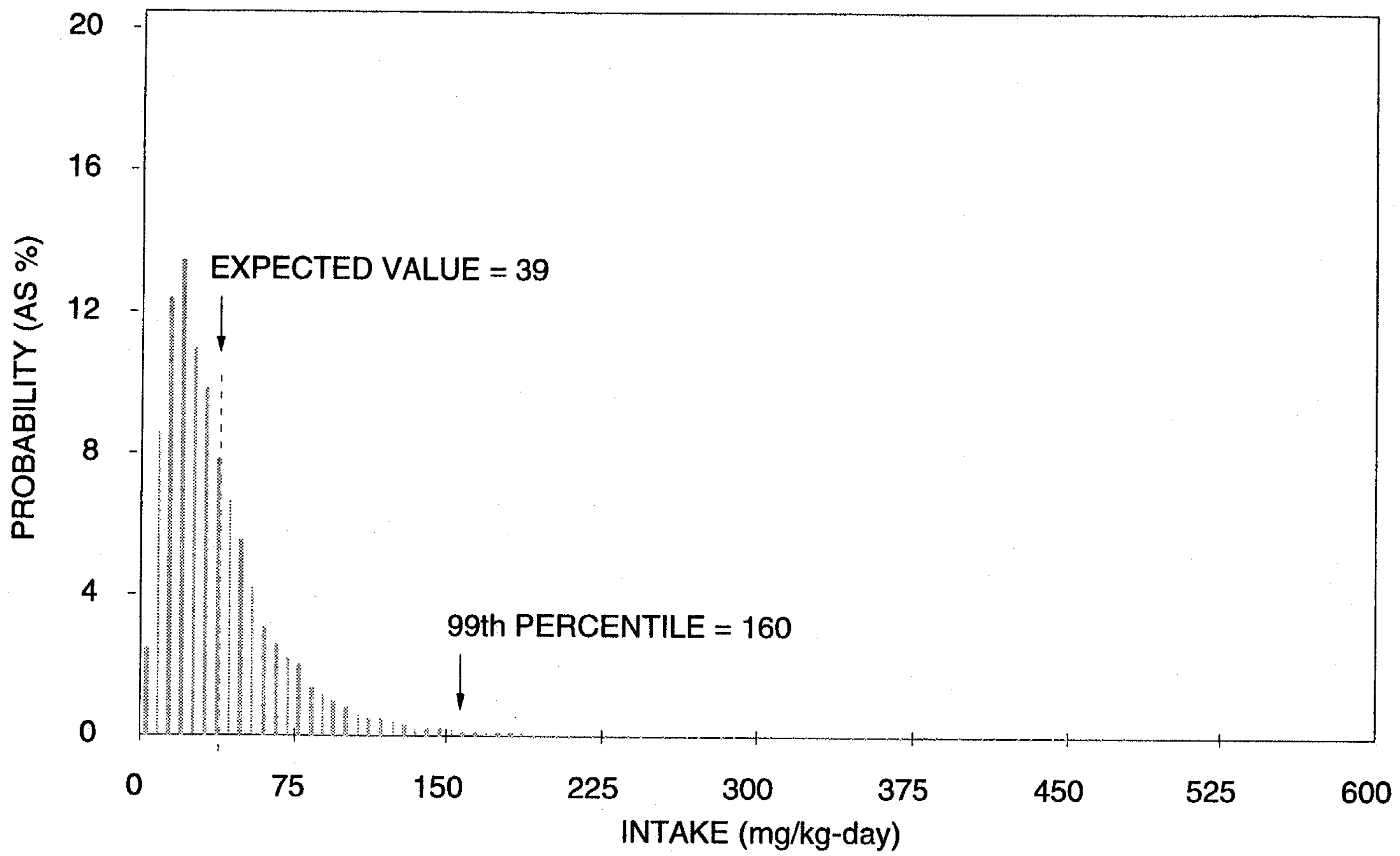
Approximately 40 percent of the potential intake exposure distribution for nitrate is above the level (35 mg/kg-day) for infants where some degree of methemoglobinemia would be expected (Figure 6.5). The nitrate levels associated with lethal cases of methemoglobinemia vary considerably; one of the more significant contributing factors is that infants prone to gastrointestinal distress are more sensitive to nitrate and sulfate. For this reason, it is possible that the gastrointestinal effects associated with sulfate exposures could increase the toxicity of nitrate. However, it is also possible that sulfate-induced diarrhea could decrease the intestinal content of nitrate-reducing bacteria, making nitrate less toxic. Likewise, high sulfate concentrations may cause the water to be unpalatable to infants, thus reducing their exposure. Figure 6.6 shows that most of the exposure distribution for sulfate falls within the range that could cause mild diarrhea in infants. In addition, at the exposure intake of 50 mg/kg-day, approximately 70 percent of the exposures for infants fall within the range of severe toxicity, leading to persistent diarrhea and dehydration. The exposure distribution for infants is based on tap water intake rates across a population that includes breast-fed and canned-formula-fed infants (Section 6.1.1). Infants consuming powdered formula reconstituted with well water would be in the upper percentiles of this exposure distribution and would be at high risk of severe diarrhea and methemoglobinemia. Further, these effects would be expected after very short-term exposures.



NOTE: AT THE EXPOSURE DOSE OF 1 mg/kg-day, <1% OF THE POPULATION WOULD BE EXPECTED TO DEVELOP REVERSIBLE KIDNEY IMPAIRMENT AFTER AN ACUTE EXPOSURE.

FIGURE 6.4

HEALTH EFFECTS OF POTENTIAL URANIUM EXPOSURE RANGES FOR CHILDREN SLICK ROCK, COLORADO, NC SITE



▲ ORAL REFERENCE DOSE (7 mg/kg-day as nitrate)

▲ NO OBSERVED EFFECTS (7 mg/kg-day)

L. . . MILD TOXICITY - WEAKNESS, RAPID PULSE, RAPID BREATHING (7-30 mg/kg-day)

. . . —— . . . SEVERE TOXICITY - METHEMOGLOBINEMIA INCREASE, CYANOSIS, COMA (35 mg/kg-day)

. . . ——→
POTENTIALLY LETHAL METHEMOGLOBINEMIA

NOTE: AT THE EXPOSURE DOSE OF 35 mg/kg-day, METHEMOGLOBINEMIA COULD DEVELOP IN 40% OF THE INFANT POPULATION.

FIGURE 6.5
HEALTH EFFECTS OF POTENTIAL NITRATE EXPOSURE RANGES FOR INFANTS
SLICK ROCK, COLORADO, UC SITE

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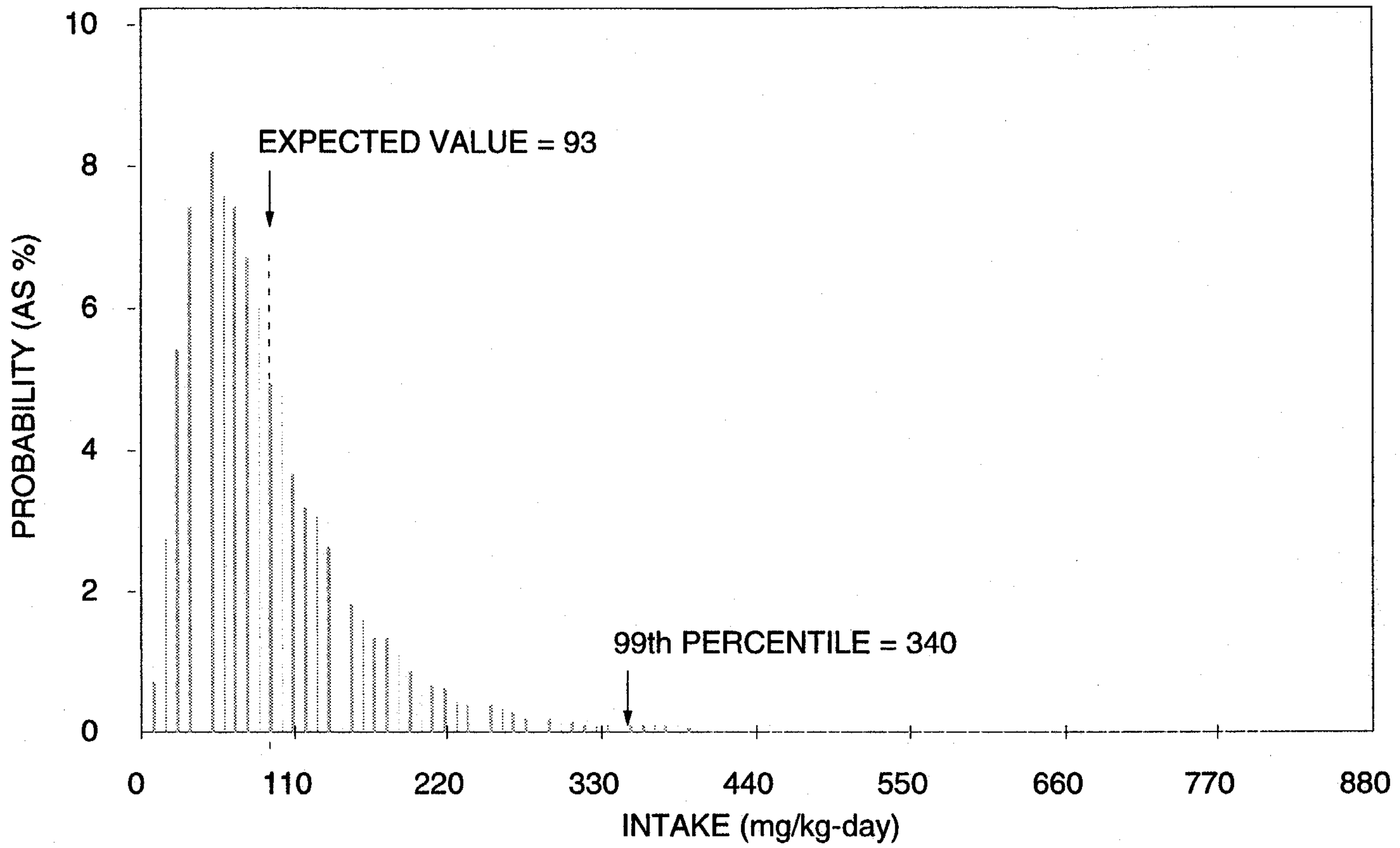


| ESTIMATE OF WESTERN UNITED STATES DRINKING WATER RANGE (0-2.9 mg/kg-day)

. . . ———┘ MILD TOXICITY RANGING FROM LAXATIVE EFECTS (ADULTS) TO DIARRHEA IN INFANTS

. . . . ——————► SEVERE TOXICITY TO PERSISTENT INFANT DIARRHEA LEADING TO DEHYDRATION - - -► DEATH

NOTE: AT THE EXPOSURE DOSE OF 50 mg/kg-day, 70% OF THE INFANT POPULATION COULD DEVELOP DIARRHEA. AT HIGHER CONCENTRATIONS (e.g., 93 mg/kg-day) SEVERE TOXICITY LEADING TO DEHYDRATION AND DEATH COULD OCCUR IN 37% OF THE INFANT POPULATION.

FIGURE 6.6
HEALTH EFFECTS OF POTENTIAL SULFATE EXPOSURE RANGES FOR INFANTS
SLICK ROCK, COLORADO, UC SITE

Sulfate also interacts in a complex manner with molybdenum and copper. For example, ruminants seem to be the most susceptible to imbalances between these elements. In ruminants, copper prevents molybdenum accumulation in the liver and may antagonize molybdenum absorption. Molybdenum can produce a functional copper deficiency, but only in the presence of sulfate. In ruminants, both copper and sulfates can protect against molybdenum toxicity, and molybdenum and sulfur can block copper toxicity. In addition, molybdenum in the form of sodium molybdate alleviates cadmium toxicity in laboratory rats.

Manganese

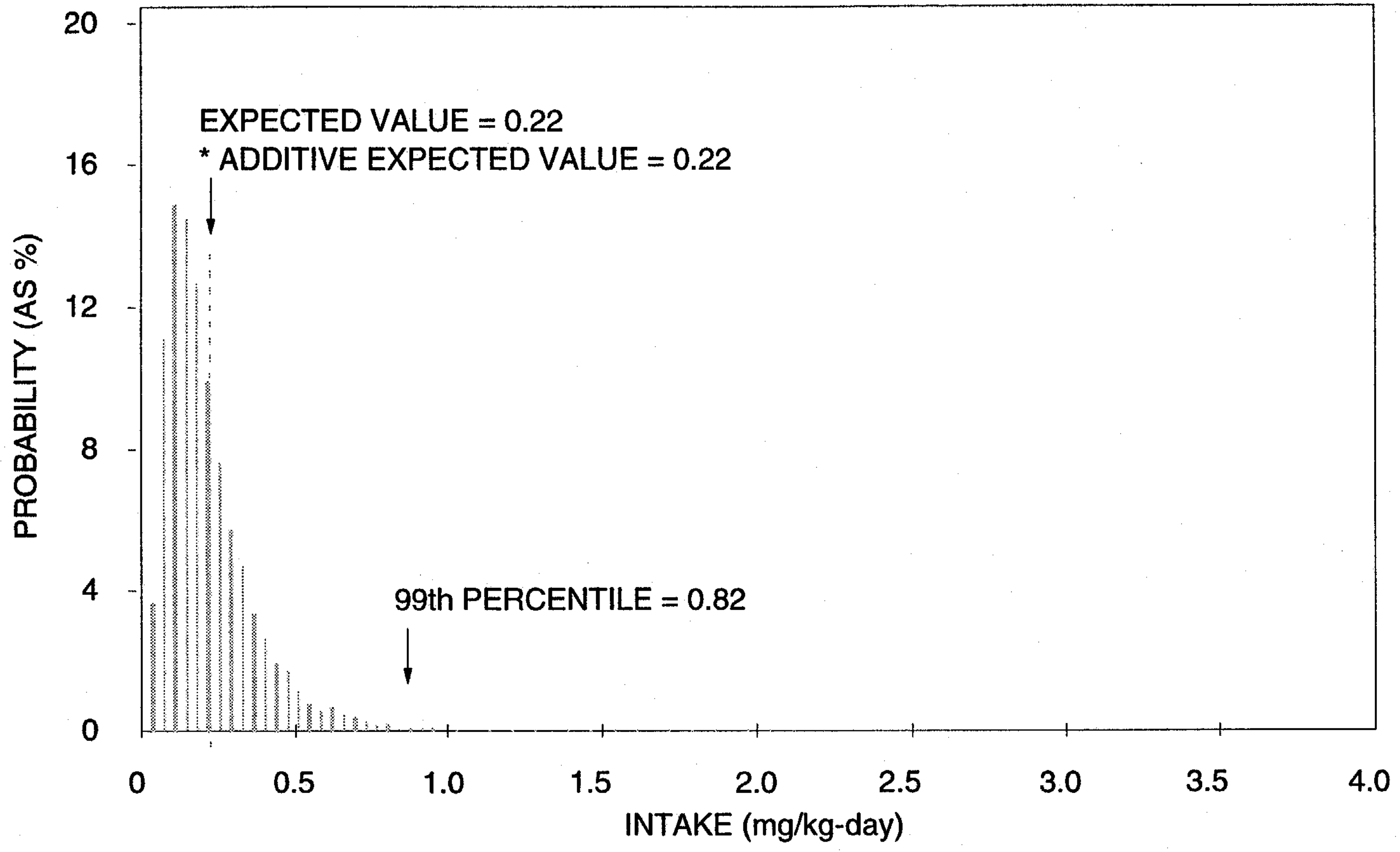
At the intake of 0.002 mg/kg-day of manganese, approximately 100 percent of the population could exhibit early adverse neurological effects including a mask-like face, muscle rigidity and tremors, and mental disturbances (Figure 6.7). At higher doses (above 0.4 mg/kg-day) approximately 10 percent of the exposed population could develop Parkinson-like effects. The contribution of manganese from the ingestion of garden produce to the total manganese intake from ground water ingestion is negligible (expected value went from 0.22 to 0.222 mg/kg-day). Manganese and iron are known to interact by inhibiting the absorption of the opposite metal. This interaction could reduce manganese toxicity to the central nervous system.

Chloride

Chronic ingestion of high concentrations of chloride (as salts) is associated with hypertension in sensitive individuals. At the intake of 36 mg/kg-day (estimated value where hypertensive effects have been observed) approximately 60 percent of the population could develop hypertension (Figure 6.8). If exposures increased by 4 percent (e.g., if the expected value increased from 66 to 69 mg/kg-day) due to the ingestion of garden produce, the same toxic effects would be expected as those produced solely by the ingestion of ground water as drinking water.

Sodium

The potential exposure distribution of sodium indicates that at an intake of 23 mg/kg-day, approximately 50 percent of the exposed population could develop hypertension (Figure 6.9). At 57 mg/kg-day (the lower end of the estimated dietary intake levels), approximately 15 percent of the exposed population could develop hypertension. These values indicate that additional intake of sodium concentrations at these levels (other than from dietary sources) would significantly contribute to increasing the probability of hypertension in the general population.



▲ BACKGROUND DRINKING WATER INTAKE (0.003 mg/kg-day)

⊔ DIETARY INTAKE FROM FOOD (0.03-0.13 mg/kg-day)

▲ ORAL REFERENCE DOSE FOR WATER (0.005 mg/kg-day)

···——··· EARLY NEUROLOGICAL SYMPTOMS (0.002 mg/kg-day)

····· → PARKINSON-LIKE EFFECT

→ ACUTE LETHAL DOSE, RODENTS (400-800 mg/kg)

NOTE: AT THE EXPOSURE OF O.002 mg/kg-day, 100% OF THE EXPOSED POPULATION COULD EXHIBIT ADVERSE NEUROLOGICAL SYMPTOMS AND AT HIGHER DOSES (0.4 mg/kg-day) PARKINSON-LIKE EFFECTS.

*ADDITIVE VALUES INCLUDE INTAKE FROM GROUND WATER INGESTION AND GARDEN PRODUCE.

FIGURE 6.7
HEALTH EFFECTS OF POTENTIAL MANGANESE EXPOSURE RANGES FOR CHILDREN
SLICK ROCK, COLORADO, UC SITE

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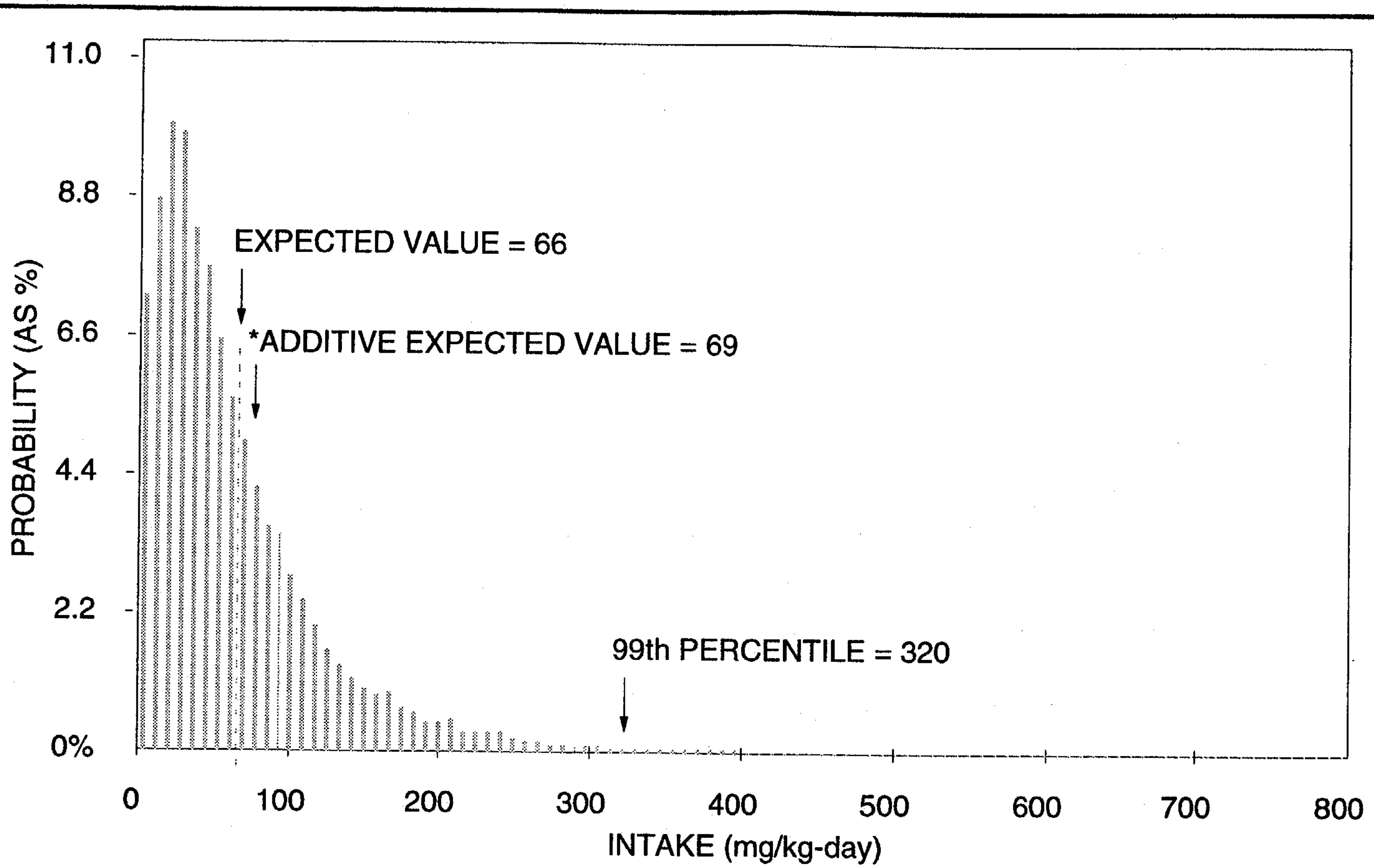

| INTAKE FROM DRINKING WATER (0.6 mg/kg-day)

▲ RECOMMENDED INTAKE LIMIT FROM DRINKING WATER (7 mg/kg-day)

• • • ——→ (ESTIMATED 36-180 mg/kg-day)
HYPERTENSION IN HUMANS

NOTE: AT THE EXPOSURE OF 36 mg/kg-day, 60% OF THE EXPOSED POPULATION COULD DEVELOP HYPERTENSION.

*ADDITIVE VALUES INCLUDE INTAKE FROM GROUND WATER INGESTION AND GARDEN PRODUCE.

FIGURE 6.8
HEALTH EFFECTS OF POTENTIAL CHLORIDE EXPOSURE RANGES FOR CHILDREN
SLICK ROCK, COLORADO, UC SITE

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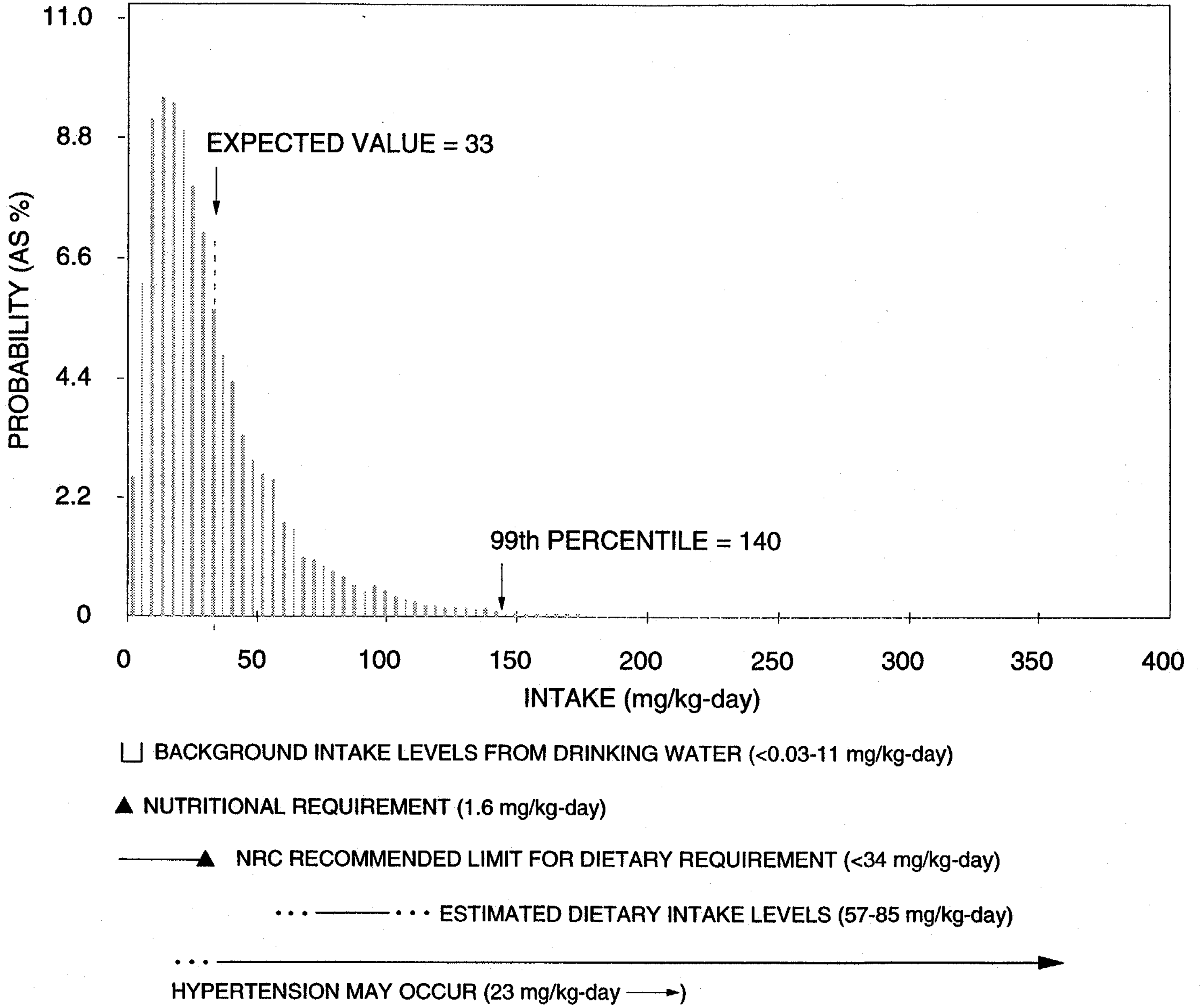


NOTE: AT THE EXPOSURE DOSE OF 23 mg/kg-day, GREATER THAN 50% OF THE POPULATION COULD EXHIBIT HYPERTENSION.

FIGURE 6.9
HEALTH EFFECTS OF POTENTIAL SODIUM EXPOSURE RANGES FOR CHILDREN
SLICK ROCK, COLORADO, UC SITE

Molybdenum

Approximately 40 percent of the potential molybdenum exposure distribution falls above the upper end of the nutritional range and above the RfD (Figure 6.10). At an intake of 0.008 mg/kg-day (estimated value where mild toxicity was observed) approximately 100 percent of the population could exhibit altered copper and sulfur excretion patterns. In addition, at higher molybdenum intakes (i.e., 0.14 mg/kg-day), 5 percent of the population could develop an increase in uric acid production; accumulation in joints could occur and develop into gout. The contribution of molybdenum from garden produce does not appreciably increase the net additive effect (e.g., the expected value went from 0.054 to 0.057 mg/kg-day). The same toxic effects would be expected as those produced due solely by ground water ingestion.

Selenium

The potential exposure distribution for selenium indicates that at an intake of 0.013 mg/kg-day (estimated value where mild toxicity was observed) approximately 70 percent of the population could exhibit mild selenosis (Figure 6.11). Mild selenosis could include hair loss or breakage and thickening and brittle nails.

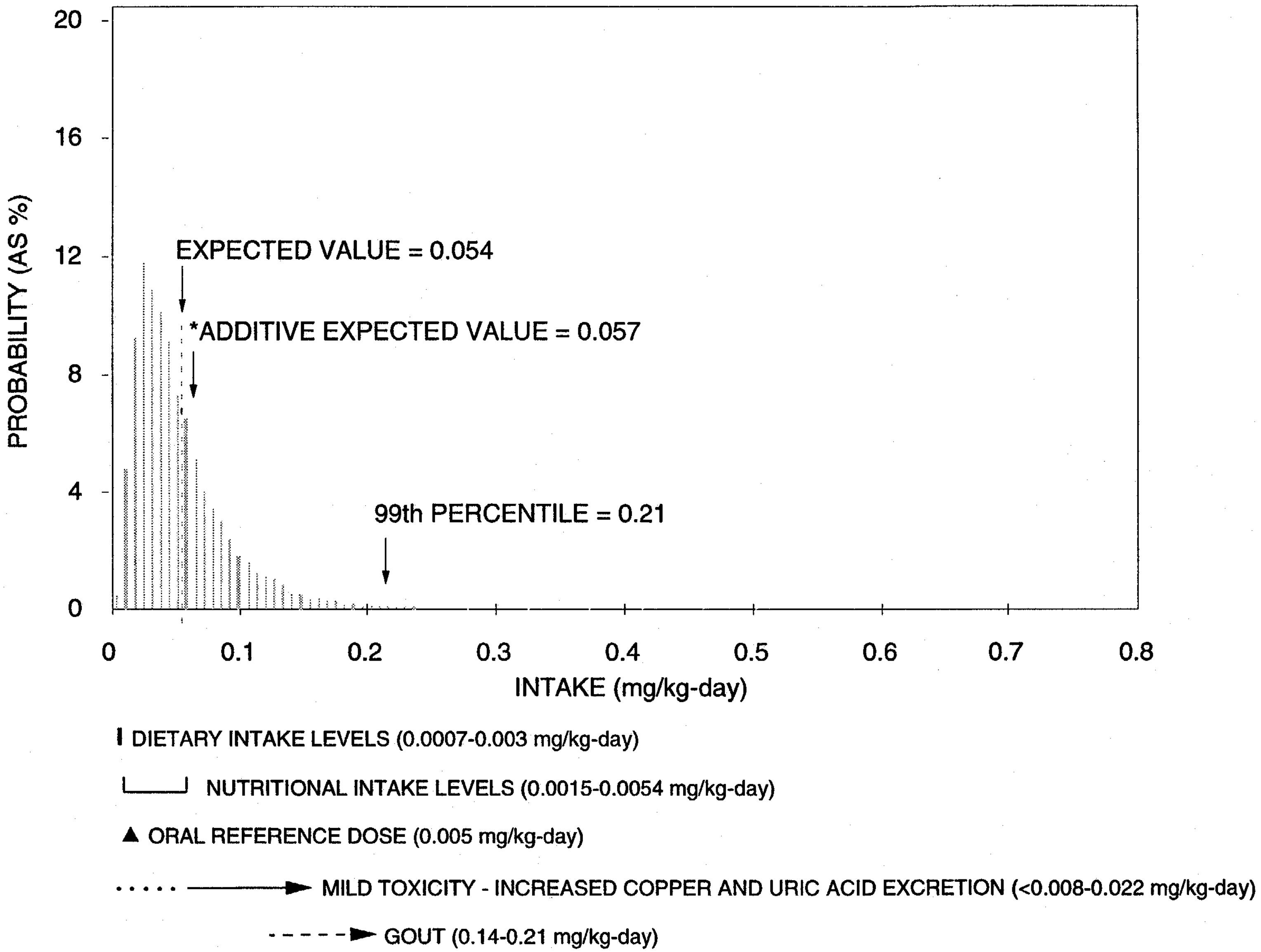
Selenium can also interact with cadmium by forming an insoluble complex, thereby reducing the toxicity of both selenium and cadmium. Often the selenium-cadmium complex binds in a stable complex to a larger protein than the metals alone redistributes this complex away from target tissues. Selenium can protect against most acute effects of cadmium in rats, but it does not protect against chronic kidney toxicity. Selenium also can interact with sulfate but the interaction is inconsistent (i.e., sulfate at high doses can reduce some toxic effects of selenium, but not others such as liver damage).

Iron

Approximately 3 percent of the potential exposure distribution for iron is above the dose that produces chronic iron toxicity. This is exhibited by pigmentation of the skin and potential disruption of liver and endocrine function (Figure 6.12). Long-term exposure to these concentrations of iron could also result in cirrhosis of the liver and/or development of diabetes. The entire range of exposure intakes fall below the level (22 mg/kg) that produces acute severe poisoning in children.

Vanadium

More than 90 percent of the potential vanadium exposure distribution falls above the EPA RfD (0.007 mg/kg-day). However, less than 1 percent of the potential exposures to vanadium fall above any levels (0.1 mg/kg-day) that would be expected to produce toxic effects (i.e., a transient cholesterol drop, cramps, or green tongue) (Figure 6.13).



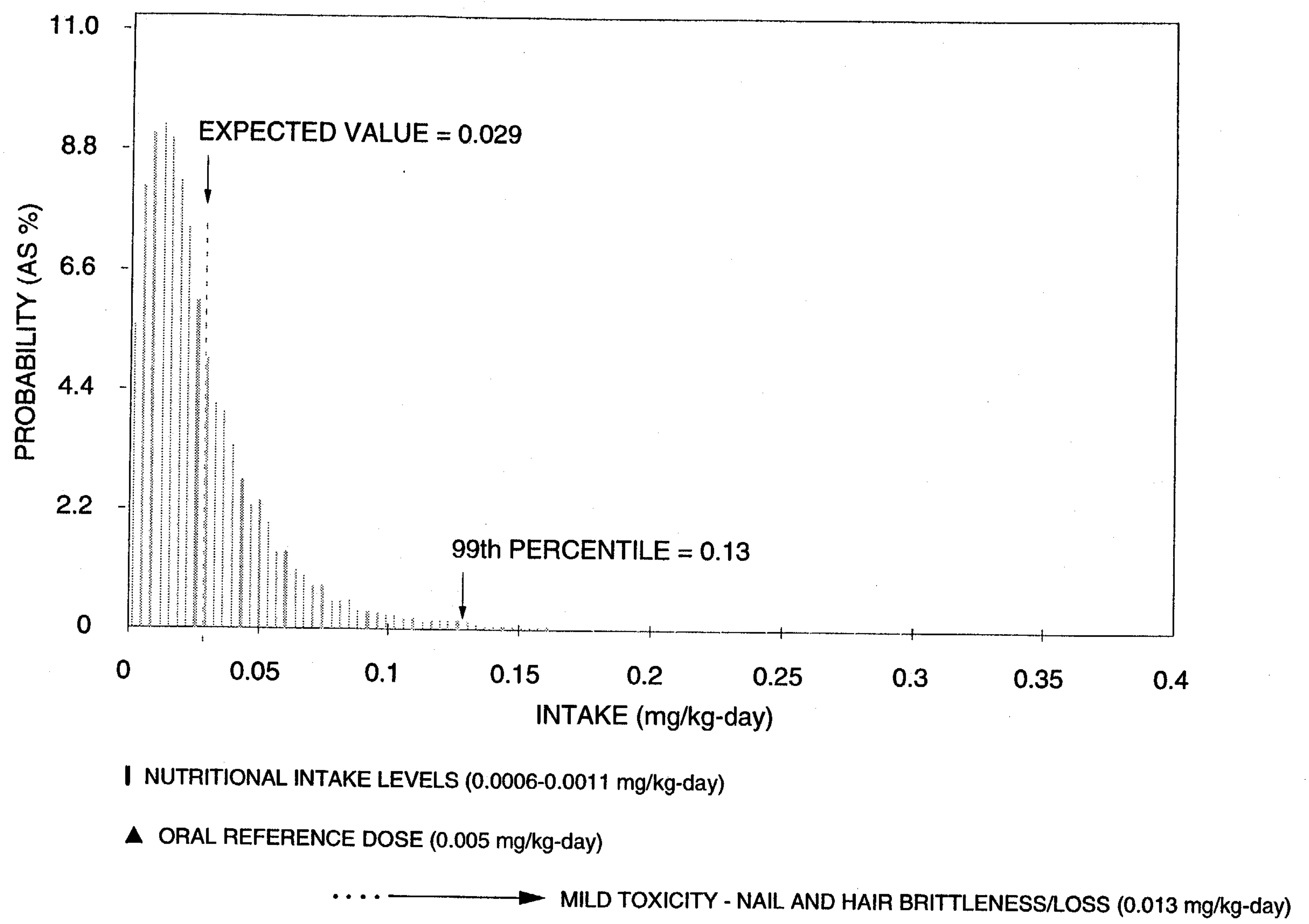
NOTE: AT THE EXPOSURE OF 0.008 mg/kg-day, APPROXIMATELY 100% OF THE EXPOSED POPULATION COULD EXHIBIT A MILD TOXICITY. AT 0.14 mg/kg-day, 5% OF THE POPULATION COULD DEVELOP GOUT.

*ADDITIVE VALUES INCLUDE INTAKE FROM GROUND WATER INGESTION AND GARDEN PRODUCE.

FIGURE 6.10
HEALTH EFFECTS OF POTENTIAL MOLYBDENUM EXPOSURE RANGES FOR CHILDREN
SLICK ROCK, COLORADO, UC SITE

PATH I:\FL3.01\SRKBRA

MOLHLTUC.DRW



NOTE: AT THE EXPOSURE DOSE OF 0.013 mg/kg-day, 70% OF THE POPULATION COULD EXHIBIT MILD TOXICITY SUCH AS NAIL AND HAIR BRITTLENESS AND LOSS.

FIGURE 6.11
HEALTH EFFECTS OF POTENTIAL SELENIUM EXPOSURE RANGES FOR CHILDREN
SLICK ROCK, COLORADO, UC SITE

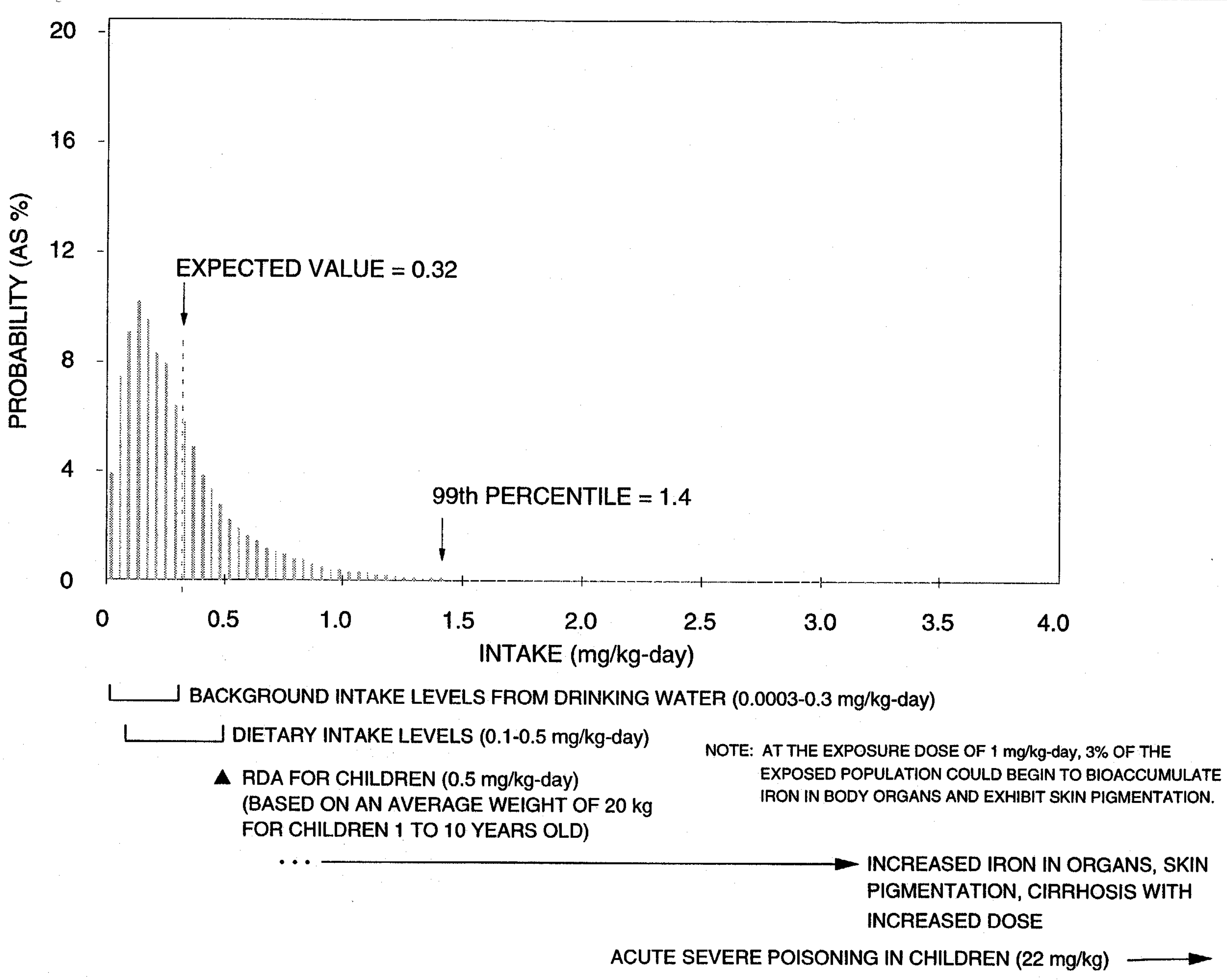
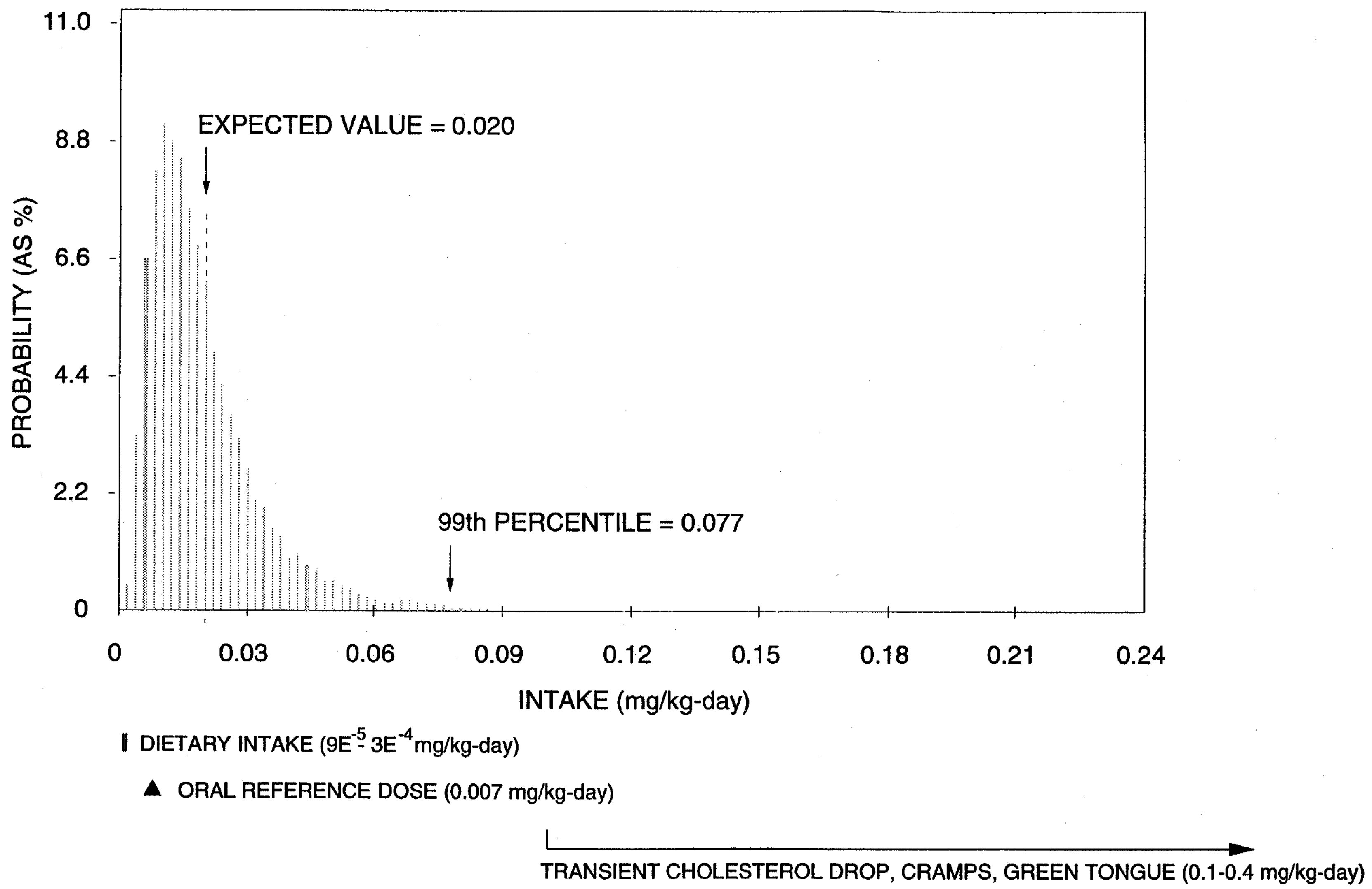


FIGURE 6.12
HEALTH EFFECTS OF POTENTIAL IRON EXPOSURE RANGES FOR CHILDREN
SLICK ROCK, COLORADO, UC SITE

PATH I:\FL3.01\SRKBRA

IROHLTUC.DRW



NOTE: MILD TOXICITY COULD BE SEEN IN LESS THAN 1% OF THE EXPOSED POPULATION AT AN INTAKE OF 0.1 mg/kg-day OR ABOVE.

FIGURE 6.13
HEALTH EFFECTS OF POTENTIAL VANADIUM EXPOSURE RANGES FOR CHILDREN
SLICK ROCK, COLORADO, UC SITE

Cadmium

Thirty-five percent of the potential exposure distribution for cadmium falls above the acceptable intake level used by the EPA (RfD of 0.0005 mg/kg-day). The RfD falls within the lower range of background dietary intake levels (Figure 6.14). No observed effects from cadmium consumption were identified in the exposure distribution that would occur at this site; however, a very small portion (0.01 percent) of the distribution falls above the level where mild toxicity (proteinuria) was observed. If ingesting garden produce increased these exposures by 43 percent, the expected dose would fall into the upper end of the background intake levels and would exceed the RfD. However, mild toxicity would not be expected until an intake of 0.0075 mg/kg-day occurred. Therefore, the contribution to the total cadmium intake from ingesting garden produce would not be expected to significantly increase adverse effects. However, diabetics and the elderly may be more sensitive to cadmium toxicity due to their already impaired kidney function. Therefore, toxic effects may appear in these sensitive individuals at lower intake levels than those presented in Section 5.0.

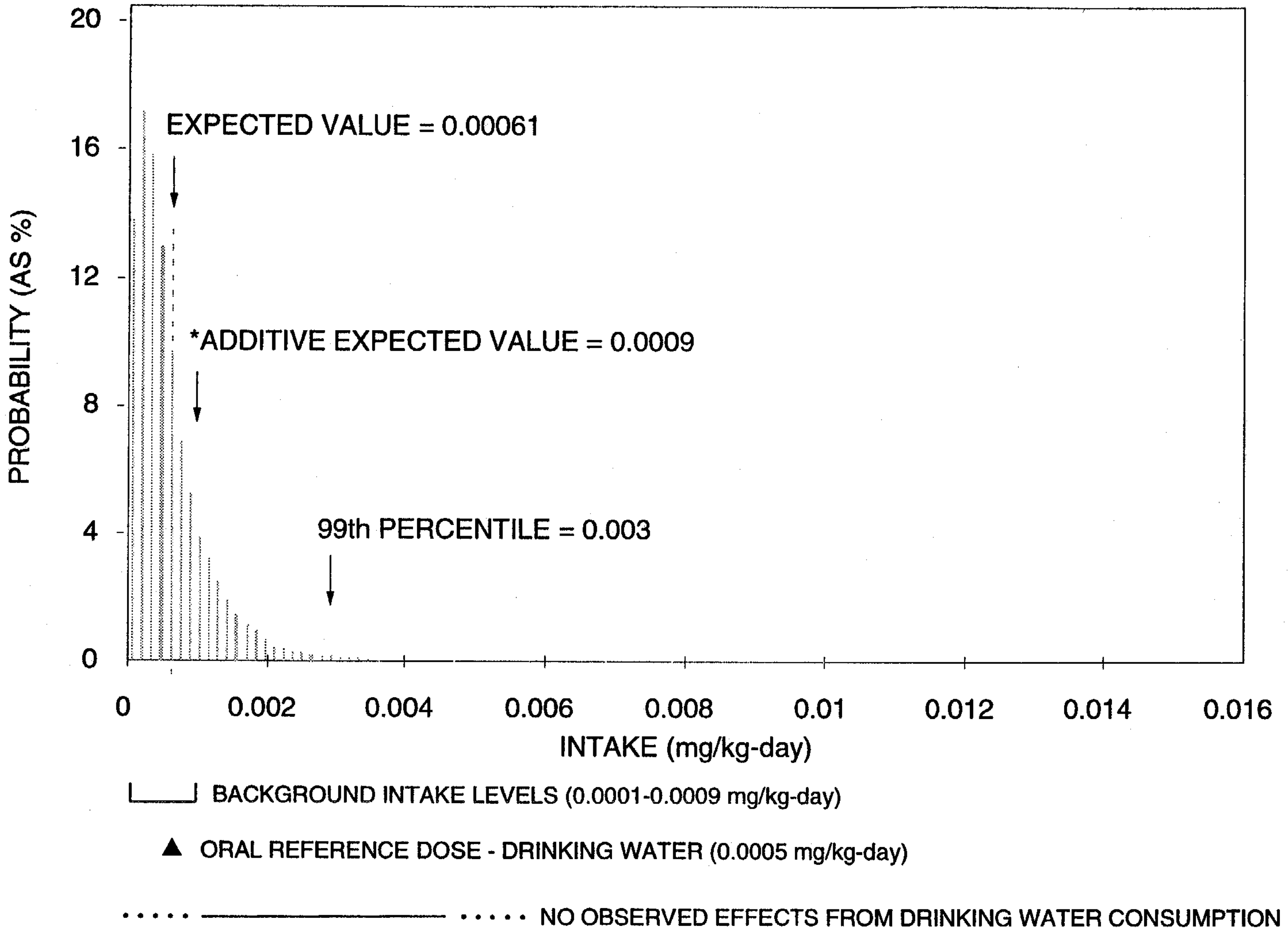
In addition, the absorption of cadmium can be increased fourfold under conditions of low iron. This interaction could increase cadmium toxicity at the UC site. Cadmium can also induce synthesis of the metal-binding protein metallothionein. Metallothionein binds cadmium, protecting certain organs such as the testes from cadmium toxicity. However, the methallothionein-cadmium complex may enhance the already nephrotoxic metal in a synergistic reaction, since the complex is taken up by the kidney more readily than the free ion.

Strontium

Approximately 95 percent of the potential exposure distribution of strontium falls below the acceptable intake level (recommended EPA RfD) of 0.6 mg/kg-day (Figure 6.15). The remaining portion of the exposure distribution falls in the range of the no-observed-effect levels for humans. Although the toxicological database for strontium is limited, these doses have not been associated with adverse health effects in either humans or rats. If ingesting garden produce increased these exposures by 6 percent, the doses would still be well below a level of potential concern.

Uranium

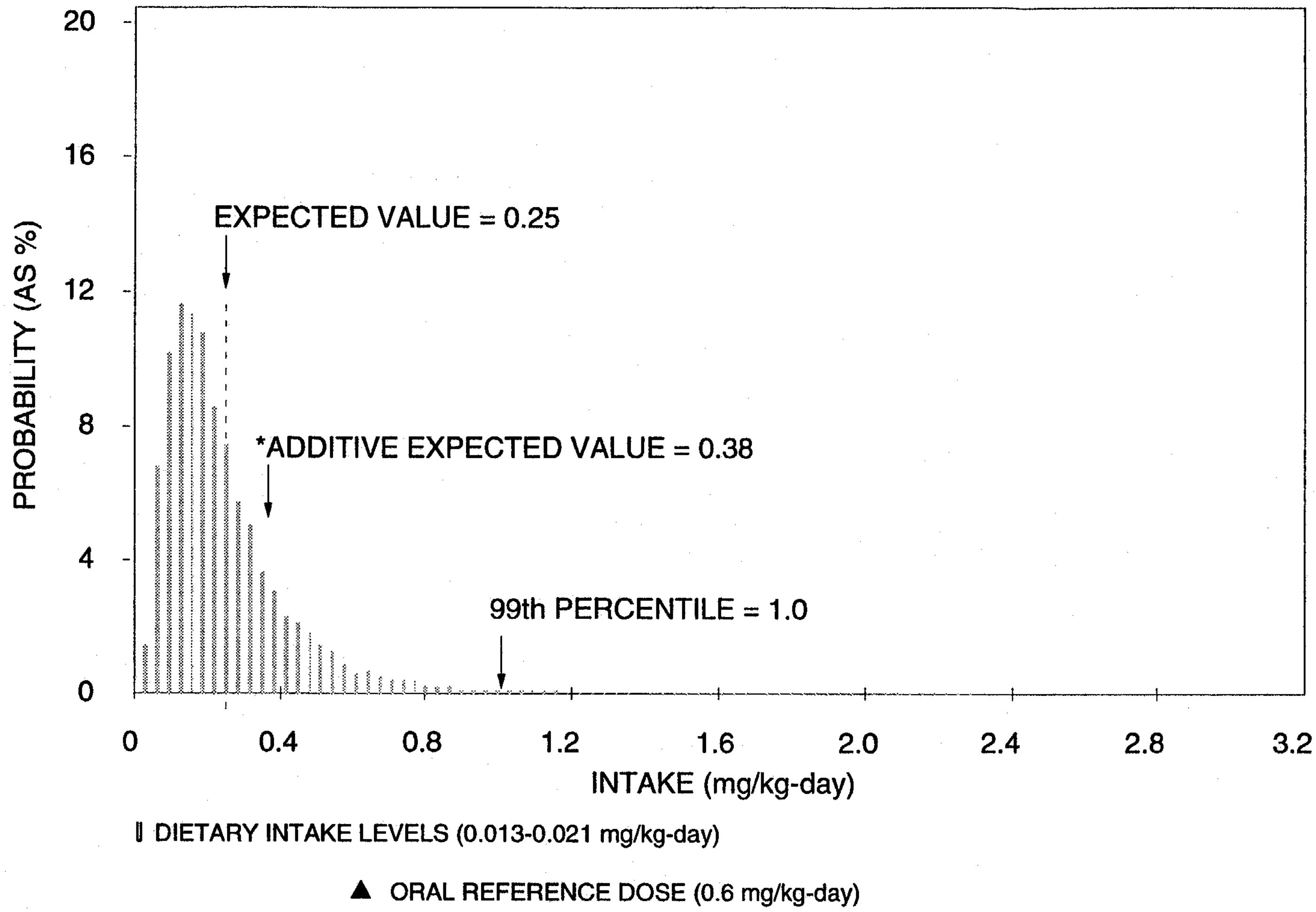
A threshold of toxicity for uranium is difficult to define due to the lack of available human data and the fact that animal data are not always predictive of human toxicity. Approximately 40 percent of the uranium exposure distribution falls above the EPA acceptable intake level (RfD of 0.003 mg/kg-day). However, the entire potential exposure distribution for uranium falls within the no-adverse-effect level and is less than one-fourth the level of any observed adverse health effects in humans or animal studies (Figure 6.16). Therefore,



NOTE: AT THE VALUE OF 0.0075 mg/kg-day, LESS THAN 0.01% OF THE EXPOSED POPULATION COULD EXHIBIT PROTEINURIA.

*ADDITIVE VALUE INCLUDES INTAKE FROM GROUND WATER INGESTION AND GARDEN PRODUCE.

FIGURE 6.14
HEALTH EFFECTS OF POTENTIAL CADMIUM EXPOSURE RANGES FOR CHILDREN
SLICK ROCK, COLORADO, UC SITE

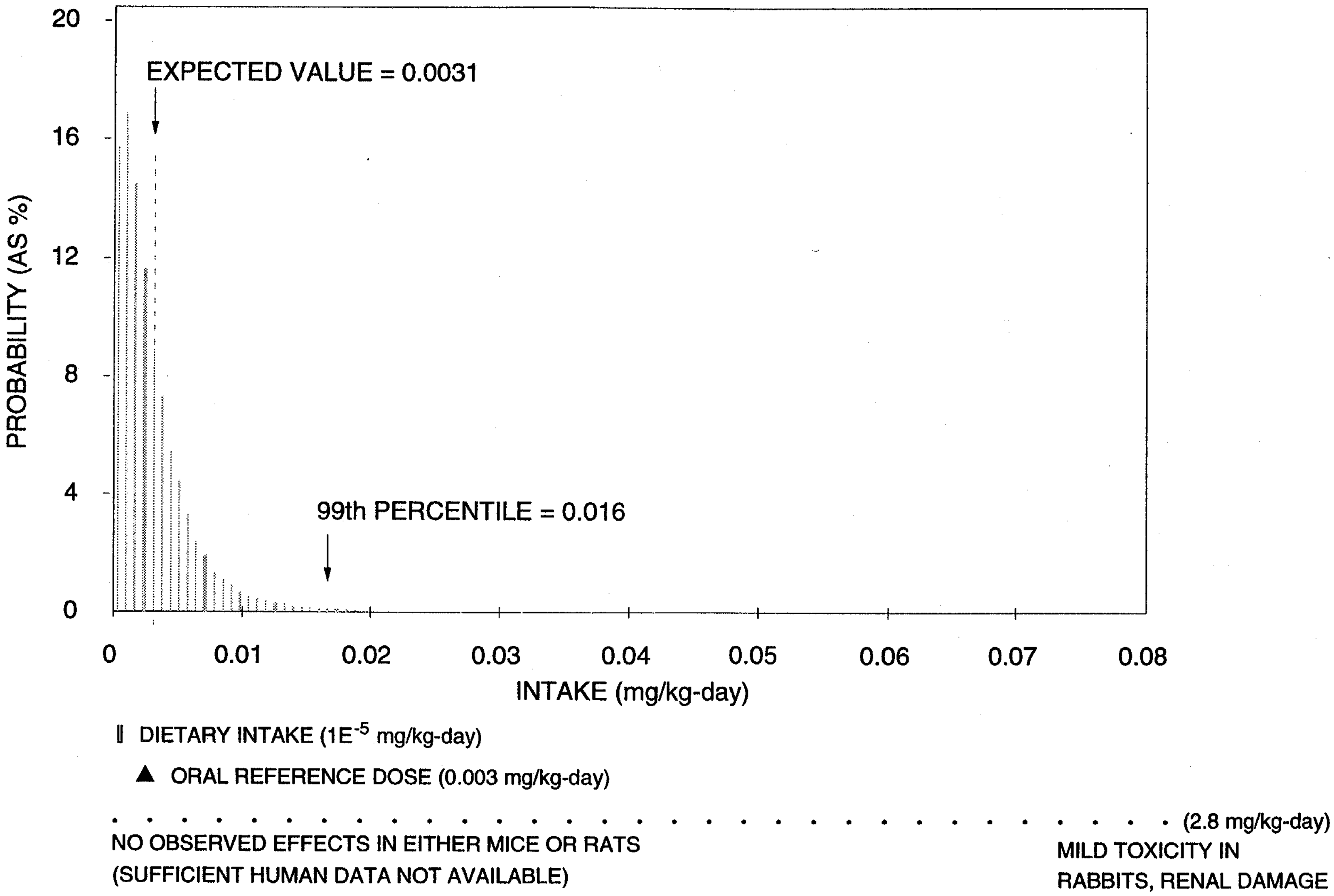


..... →
MILD TOXICITY
(RATS) (380 mg/kg-day)

NOTE: INTAKE FOR 5% OF THE EXPOSED POPULATION WOULD EXCEED THE ORAL REFERENCE DOSE OF 0.6 mg/kg-day. MILD TOXICITY IN RATS HAS NOT BEEN OBSERVED UNTIL EXPOSURE DOSES ARE AS HIGH AS 380 mg/kg-day.

*ADDITIVE VALUES INCLUDE INTAKE FROM GROUND WATER INGESTION AND GARDEN PRODUCE.

FIGURE 6.15
HEALTH EFFECTS OF POTENTIAL STRONTIUM EXPOSURE RANGES FOR CHILDREN
SLICK ROCK, COLORADO, UC SITE



NOTE: AT EXPOSURE DOSES GREATER THAN 0.003 mg/kg-day, APROXIMATELY 40% OF THE POPULATION WOULD EXCEED THE ORAL REFERENCE DOSE. MILD TOXICITY IN RABBITS HAS NOT BEEN SEEN UNTIL CONCENTRATIONS AS HIGH AS 2.8 mg/kg-day WERE ADMINISTERED.

FIGURE 6.16

HEALTH EFFECTS OF POTENTIAL URANIUM EXPOSURE RANGES FOR CHILDREN
SLICK ROCK, COLORADO, UC SITE

adverse noncarcinogenic toxic effects due to uranium would not be expected at the UC site.

Cadmium and uranium exposures should be considered additive, because they affect reabsorption in the proximal tubule of the kidney. This causes protein and other nutritive compounds to be excreted in the urine rather than retained by the body. The levels of cadmium and uranium detected at the UC site are well below their threshold levels for these effects; nonetheless, the presence of both of these metals indicates a potential for additive effects; diabetics and the elderly may be more sensitive to these toxic effects on the kidney.

6.2 POTENTIAL CARCINOGENIC HEALTH EFFECTS

All uranium isotopes are radioactive and, as such, are considered potential carcinogens. Uranium decays to radioactive progeny, including lead-210, radium-226, polonium-210, and thorium-230. All the longer-lived radioactive progeny of the uranium decay series and uranium were evaluated for carcinogenic risk. These estimates are based on the cancer slope factors developed by the EPA; however, natural uranium has not been demonstrated to cause cancer in humans or animals following ingestion. The National Contingency Plan (NCP) acceptable carcinogenic range is expressed as one additional cancer in a population of 10,000 (1E-04) to one additional cancer in a population of 1,000,000 (1E-06). Values that fall within this range are regarded as acceptable risk levels. Values that exceed 1E-04 are regarded as unacceptable risk levels.

6.2.1 North Continent site

Table 6.1 presents maximum excess lifetime cancer risk estimates from ground water ingestion for the carcinogenic radionuclides evaluated at the NC site (carcinogenic risks are presented to one significant figure). The combined risks of all radionuclides equals 7E-03. However, the maximum estimates for lead-210 (5E-03) and uranium (2E-03) exceed the NCP guidance for increased incremental lifetime cancer risk of 1E-04 and are the major contributors to the potential carcinogenic risks at the NC site.

Table 6.1 also presents the excess lifetime cancer risks for contaminants of potential concern that contribute to the exposure doses from other pathways (garden produce and milk and meat ingestion) relative to ground water ingestion (as drinking water). As can be seen from these carcinogenic risk levels, lead-210, polonium-210, radium-226, and uranium do not appreciably increase the incremental carcinogenic risk due to the additivity of these exposure pathways.

6.2.2 Union Carbide site

Table 6.2 presents maximum excess lifetime cancer risk estimates from ground water ingestion of the carcinogenic radionuclides evaluated at the UC site. The

Table 6.1 Carcinogenic risk for ground water (as drinking water) ingestion pathway at the NC site, Slick Rock, Colorado

Radionuclide	Exposure point concentration (pCi/L)	Intake (pCi/year)	Ingestion SF $(\text{pCi})^{-1}$	Lifetime risk	Additive lifetime risk
Lead-210	216	1E+07	5.1E-10	5E-03	5E-03[a]
Polonium-210	0.8	4E+04	1.5E-10	6E-06	6E-06[b]
Radium-226	2.4	1E+05	1.2E-10	1E-05	1E-05[c]
Thorium-230	0.8	4E+04	1.3E-11	5E-07	5E-07[d]
Uranium	2675	1.3E+08	1.6E-11	2E-03	2E-03[e]
Total				7E-03	7E-03

[a] Includes drinking water, garden produce, milk and meat ingestion.
[b] Includes drinking water and meat ingestion.
[c] Includes drinking water and milk ingestion.
[d] Includes drinking water ingestion.
[e] Includes drinking water and milk ingestion.

Notes: 1. Ingestion rate: 2 L.
2. Exposure frequency: 350 days per year.
3. Exposure duration: 70 years.

SF - slope factor.

Table 6.2 Carcinogenic risk for ground water ingestion pathway at the UC site, Slick Rock, Colorado

Radionuclide	Exposure point concentration (pCi/L)	Intake (pCi/year)	Ingestion SF $(pCi)^{-1}$	Lifetime risk	Additive lifetime risk
Lead-210	6.5	3E+05	5.1E-10	2E-04	2E-04[a]
Polonium-210	0.4	2E+04	1.5E-10	3E-06	3E-06[b]
Radium-226	3.3	2E+05	1.2E-10	2E-05	2E-05[b]
Thorium-230	0.8	4E+04	1.3E-11	5E-07	5E-07[b]
Uranium	163	8E+06	1.6E-11	1E-04	1E-04[b]
Total				3E-04	3E-04

[a] Includes drinking water and garden produce ingestion.
[b] Includes drinking water ingestion.

Notes: 1. Ingestion rate: 2 L.
2. Exposure frequency: 350 days per year.
3. Exposure duration: 70 years.

SF - slope factor.

combined risks of all radionuclides equals 3E-04. However, the maximum estimate for lead-210 (2E-04) exceeds the NCP guidance for increased incremental lifetime cancer risk of 1E-04 and is the major contributor to the carcinogenic risk at the UC site.

Table 6.2 also presents the additive lifetime risks for the contaminants of potential concern that contributed to the exposure doses from the garden produce ingestion pathway relative to ground water ingestion (as drinking water). As can be seen from these carcinogenic risk levels, lead-210 does not appreciably contribute incremental carcinogenic risk from the garden produce exposure pathway.

6.3 LIMITATIONS OF RISK EVALUATION

The following potential limitations apply to interpretations of this risk evaluation:

- This risk assessment evaluates only risks related to inorganic ground water contamination. Potential contamination with any of the few organic constituents used in uranium processing is not addressed.
- Subpopulations that might have increased sensitivity are not specifically addressed on the graphs.
- Some individuals may be more sensitive to the toxic effects of certain constituents for reasons that have not been determined.
- Data available to interpret potential adverse health effects are not always sufficient to allow accurate determination of all health effects (i.e., lack of testing in humans or testing of dose ranges other than those expected at this site).
- Although plume movement is evaluated hydrologically and geochemically, the monitoring locations sampled may not be in the most contaminated portion of the plume.
- Only the drinking water exposure pathway has been considered in depth, although other pathways were screened to determine their contribution.

The evaluation presented here considers these limitations and compensates wherever possible by presenting toxicity ranges rather than point estimates to incorporate as much variability as could be reasonably defined. The impact of these potential limitations is discussed more fully in Section 8.2.

7.0 ECOLOGICAL EVALUATION

This section assesses the potential for site-related contaminants to adversely affect the existing biological communities, grazing livestock, and agricultural practices in the area. Currently, the EPA has no guidance for quantifying potential ecological impacts of the release of hazardous contaminants; however, the EPA has developed a qualitative approach for ecological risk evaluations (EPA, 1989b). As part of this qualitative approach, the EPA recommends conducting ecological assessments in a phased approach to ensure the most effective use of resources while all necessary work is conducted (EPA, 1992b). This approach consists of four increasingly complex phases, starting with identifying potentially exposed habitats (phase 1), collecting chemistry data (phase 2), collecting biological samples (phase 3), and conducting toxicity testing (phase 4). If the initial inspection of the habitats and the analysis of media samples indicate little or no potential for ecological risk, the assessment will likely be complete. If the early phases of the assessment indicate the contaminants may be adversely affecting ecological receptors, a higher level of analysis may be warranted.

The ecological risk assessment does not evaluate the two Slick Rock sites separately; the ecological environment of the two sites is evaluated as one unit. The ecological risk assessment at the Slick Rock sites consists of the first two phases, because habitats may have been impacted (phase 1) and water chemistry data collected for many years are available (phase 2). Thus, this qualitative approach provides a screening level assessment of the risks associated with potential exposure to contaminated media at the site.

It is often difficult to determine if contaminants have affected the biological component of an ecosystem and to predict whether observed effects will damage the ecosystem. However, sampling environmental media such as surface water can help assess potential ecological risk. For such an ecological risk to occur, a source of contamination must exist and there must be a pathway for this contamination to reach the biological communities. The following sections identify the areas of contamination and the potential pathways by which this contamination may be entering the aquatic and terrestrial biological communities at the Slick Rock sites; the potential ecological receptors at the site; the contaminants of potential concern; and the hazards the contaminants of potential concern may pose to ecological resources, livestock, and agricultural crops.

7.1 EXPOSURE CHARACTERIZATION

The currently impacted media at the sites are the tailings piles and associated contaminated soil and ground water. The surface water and sediment in the Dolores River could also be affected by contaminated ground water discharged from the sites. Under the UMTRA Surface Project, the tailings piles and associated contaminated soil should be removed from the sites by the fall of 1996. Therefore, following the removal of the tailings, some direct exposure pathways (e.g., incidental ingestion of soil, dermal contact with soil, and inhalation of air containing particulates) will not continue to present an ecological concern and, therefore, will not be evaluated in this baseline risk assessment. Other direct exposure pathways (e.g., ingestion of surface water and sediment) and indirect exposure pathways (e.g., consumption of previously exposed organisms such as fish) are currently possible at the sites.

The net accumulation by organisms of a constituent directly from the surrounding environment is known as bioconcentration. Net accumulation by organisms as a result of all routes of exposure, including diet, is known as bioaccumulation. Generally, bioconcentration measures uptake of chemicals from water by aquatic organisms. BCFs for soil ingestion and dermal contact are too variable and dependent on site conditions to identify generic soil BCFs.

7.1.1 Ground water

A potential current pathway is plant uptake of contaminants in ground water. Due to the shallow depth to ground water (approximately 10 to 20 ft [3 to 6 m] or less below land surface) (DOE, 1994a), some deeper-rooted plants can reach contaminated ground water. To evaluate plant uptake at the NC and UC sites, plant roots were assumed to reach soil saturated with ground water containing the UCL concentrations for the contaminants of potential concern from the most contaminated wells at each site. Plant BCFs from the literature were used in the evaluation.

A conservative estimate of exposure assumed an alluvial domestic well could be used to create a livestock watering source (i.e., a pond which could also be stocked with fish) or the water source could be used to irrigate agricultural crops.

7.1.2 Surface water and sediment

The main surface water body in the area of the Slick Rock processing sites is the Dolores River. Since March 1984, McPhee Dam has regulated flow of the Dolores River in the vicinity of the former processing site. In addition to McPhee Dam and McPhee Reservoir, 55 river mi (88 km) east (upstream) of the former processing site, numerous irrigation diversions control flow on the Dolores River. The Dolores River drains into the Colorado River 10 mi (16 km) west of the Colorado-Utah state line (DOE, 1994a).

Surface water bodies are potential exposure points for resident aquatic life, terrestrial wildlife, and domestic animals to contact surface water and/or sediment. These exposure pathways were evaluated for the ecological risk assessment.

7.2 ECOLOGICAL RECEPTORS

The following information on ecological receptors is based primarily on field surveys and provides historical perspective. Limited aquatic organisms and terrestrial plant and animal communities were observed at the surface water and sediment sampling locations during a September 1993 qualitative field survey.

7.2.1 Terrestrial plant communities

The NC and UC sites are in the Great Basin sagebrush habitat of the Colorado Plateau. The two tailings piles are in the Dolores River valley. Dense riparian vegetation along the river is flanked by steep juniper and desert shrub-covered slopes (DOE, 1994a).

Vegetation

Six plant community types were observed in the area of the NC and UC sites: disturbed grassland, desert shrub, and four riparian plant communities.

Disturbed grassland is found on the tailings piles and in disturbed areas within the site boundaries. Grasses such as crested wheatgrass, Indian ricegrass, and red brome are common. Scattered shrubs such as fourwing saltbush, rabbitbrush, and broom snakeweed also occur in these areas. The shrub density is greatest on the NC site tailings pile.

The desert-shrub plant community type is characterized by scattered sagebrush, rabbitbrush, and broom snakeweed. Patches of grass and herbs are the predominant ground cover.

The riparian plant communities are along the Dolores River. The dense willow-saltcedar shrub community grows in bands next to the river. Farther back from the river, the upper riparian grasslands are dominated by grass and scattered shrubs such as big sagebrush, greasewood, New Mexico privet, squawbush, saltcedar, and Russian olive. The upper riparian shrub community contains more shrubs than the upper riparian grassland and its dense ground cover consists mostly of grass. The remaining riparian plant community is dominated by fairly large cottonwoods. The ground cover is dense. Shrubs such as squawbush, big sagebrush, and box elder are scattered throughout. These riparian plant communities are described in greater detail in Attachment 2 of the site-specific environmental assessment (DOE, 1994a).

7.2.2 Terrestrial fauna community

Wildlife at these sites is a mixture of species that occur in riparian and desert-shrub habitats. The sagebrush lizard and whiptail are common reptiles observed on the site. A total of 66 species of birds have been observed; the yellow-breasted chat, yellow warbler, and blue grosbeak are common species in the riparian zone. Birds of prey observed in this area were the kestrel and the red-tailed hawk. Approximately 32 species of mammals may occur at or near the tailings site. Species recorded from tracks along the river were the raccoon, skunk, river otter, bear, muskrat, and bobcat. Beaver signs (cuttings) have been observed along the river and mule deer occur in the area. The desert bighorn sheep also occurs along the steep slopes of the Dolores River Valley and along the river itself in the area of the NC and UC sites.

Threatened and endangered species

Consultation with the Fish and Wildlife Service and the Colorado Division of Wildlife determined 11 threatened and endangered species could be at or near the sites. The Slick Rock environmental assessment analyzes the impacts of the proposed surface remedial action on threatened and endangered species at the Slick Rock sites (DOE, 1994a).

The endangered humpback chub, bonytail chub, and razorback sucker were found in the Dolores River. The Colorado squawfish occurs near the mouth of the river 120 mi (190 km) downriver from the sites. The bald eagle occurs sporadically and in small numbers in the tailings site area from December through mid-April, and over the last few years has been observed roosting in cottonwoods along the river near the UC site. Two nest sites of the peregrine falcon are active along the Dolores River, approximately 8 mi (13 km) from the tailings sites. The absence of prairie dog towns at the tailings sites presupposes the black-footed ferret does not occur in these areas.

The remaining four species are federal candidate species. Neither the white-faced ibis and black tern nor their nesting habitats were observed at or near the sites. The southwestern willow flycatcher was not recorded near the sites, but due to the presence of potential nesting habitats, this species may use the site in the future. The river otter was reintroduced to the Dolores River in 1988 and uses the river at and near the sites.

7.2.3 Aquatic organisms

Irrigation withdrawals from McPhee Reservoir upstream of the site have altered the flow characteristics of the Dolores River, reducing high spring flows and augmenting summer, fall, and winter flows. The Technical Assistance Contractor has not conducted quantitative surveys of aquatic organisms in the Dolores River near the sites. However, a qualitative survey of the aquatic organisms in the Dolores River was conducted in the vicinity of historic surface water sampling locations SRK-01-0696 and SRK-01-0694. The following organisms were observed using a fine-mesh dip-net at each of the locations: mayfly nymphs, caddisfly larvae, midge larvae, larval beetles, crayfish, and fathead minnows. Other aquatic life known to occur in the area are the bluehead sucker, flannelmouth sucker, common carp, roundtail chub, speckled dace, red shiner, and sand shiner. Game fish species include the green sunfish, channel catfish, and black bullhead (Valdez et al., 1992).

7.3 ECOLOGICAL CONTAMINANTS OF POTENTIAL CONCERN

7.3.1 Ground water

The complete list of constituents analyzed in ground water for the NC and UC sites (Tables 3.2 and 3.4) was initially considered in selecting contaminants of potential concern for ecological receptors. This entire list was used because background ground water quality data were not available. Some constituents not detected in the ground water were excluded from the list: arsenic, beryllium, cadmium, cobalt, cyanide, lead, mercury, silver, and thallium at the NC site and arsenic, beryllium, cobalt, cyanide, lead, mercury, silver, thallium, and tin at the UC site. Some constituents were eliminated because they were detected only once, at levels near the detection limit (which could indicate analytical variability): chromium, copper, nickel, selenium, tin, vanadium, and zinc at the NC site and copper at the UC site. Other constituents were eliminated from consideration as contaminants of potential concern because they are toxic only at elevated concentrations that were not detected at either site: calcium, magnesium, phosphate, potassium, silica, and sodium.

Following this screening process, the following constituents were selected as ecological contaminants of potential concern for ground water for the NC site: aluminum, ammonium, antimony, boron, bromide, chloride, fluoride, iron, manganese, molybdenum, nitrate, strontium, sulfate, sulfide, uranium, lead-210, polonium-210, radium-226, and thorium-230. At the UC site, aluminum, ammonium, barium, boron, bromide, cadmium, chloride, chromium, fluoride, iron, manganese, molybdenum, nickel, nitrate, selenium, strontium, sulfate, sulfide, uranium, vanadium, zinc, lead-210, polonium-210, radium-226, and thorium-230 were selected.

7.3.2 Surface water and sediment

Filtered and unfiltered analyses were performed for surface water sampling events from 1987 to 1994 (Table 3.10). However, the most recent surface water data were used for this ecological risk assessment because these data more accurately represent current ecological conditions at the Slick Rock sites. The data evaluated included unfiltered (total) surface water data collected in 1993 and 1994. The surface water quality standards of the state of Colorado for inorganics are expressed as filtered (dissolved) concentrations. However, for some of the inorganics detected, site-specific total concentration standards were calculated based on site-specific hardness concentrations (i.e, calcium and magnesium concentrations). This was done because fish ingest total concentrations, not just dissolved concentrations. Site-specific total concentration standards were calculated for the contaminants of potential concern for surface water. Surface water sampling locations are presented on Figure 2.3. Sampling location SRK-01-0696 was identified as the background location for a limited list of constituents that included cadmium, calcium, copper, magnesium, molybdenum, nitrate, selenium, uranium, vanadium, and zinc (Table 7.1).

In selecting the contaminants of potential concern for surface water, unfiltered samples collected from the Dolores River initially were evaluated for the complete list of contaminants. If a contaminant was never detected in surface water (molybdenum and selenium), or if the concentration was equal to or less than the background concentration (copper and nitrate), it was excluded as a contaminant of potential concern. Calcium and magnesium were eliminated

Table 7.1 Constituents detected in the Dolores River near the Slick Rock, Colorado, sites

Contaminant of potential concern	NC site				UC site			
	Background SRK-01-0696		Downstream SRK-01-0692		Downstream SRK-01-0693		Downstream SRK-01-0694	
	(9/93)	(2/94)	(9/93)	(2/94)	(9/93)	(2/94)	(9/93)	(2/94)
Cadmium	<0.001	<0.001	—	<0.001	—	0.002	<0.001	<0.001
Calcium	33	43	—	87	—	45	34	45
Copper	0.01	—	—	—	—	—	0.01	—
Magnesium	6.0	10	—	28	—	13	6.3	13
Molybdenum	<0.01	<0.01	—	<0.01	—	<0.01	<0.01	<0.01
Nitrate	13	<1	—	<1	—	<1	8.0	<1
Selenium	<0.005	<0.005	—	<0.005	—	<0.005	<0.005	<0.005
Uranium	0.001	<0.001	—	0.003	—	0.001	0.001	0.001
Vanadium	<0.01	<0.01	—	0.01	—	<0.01	<0.01	<0.01
Zinc	0.044	<0.05	—	<0.05	—	<0.05	0.077	<0.05

Notes:
1. All concentrations are single sample concentrations reported in milligrams per liter from unfiltered samples.
2. Numbers in parentheses are sampling dates.
3. Dash indicates samples were not analyzed for this constituent.

because they are the major cationic constituents of natural surface water and are relatively nontoxic. The final list of contaminants of potential concern for surface water included cadmium, uranium, and zinc because they exceeded background concentrations.

Surficial sediment samples (0 to 4 inches [0 to 10 cm]) were collected in September 1993 and February 1994 from the same locations at which surface water samples were collected (Figure 2.3). The background location for sediment was identified as SRK-01-0696. Prior to this sampling event, no sediment samples had been collected in the vicinity of the sites. The sediment samples were analyzed for cadmium, copper, molybdenum, selenium, uranium, vanadium, and zinc. The concentrations of all seven constituents exceeded background levels. Therefore, all these constituents were retained as contaminants of potential concern. Sediment data are presented by location in Table 7.2.

7.4 POTENTIAL IMPACTS TO WILDLIFE AND PLANTS

The exposure pathways that could potentially impact wildlife and plants are discussed below.

7.4.1 Ground water

Terrestrial vegetation

Terrestrial vegetation can be directly exposed to contaminants in ground water through uptake by the roots. Contaminants may bioaccumulate in various plant parts and exert a wide range of influences, depending on the specific contaminant. Plant uptake rates vary greatly among species and are affected by factors such as soil characteristics (pH, moisture, redox potential, organic matter), plant sensitivity, input-output balance, and cumulative effects. Foraging wildlife can be indirectly exposed to contaminants in ground water by ingesting plants that have bioaccumulated certain contaminants. Terrestrial wildlife can be directly and indirectly exposed to contaminants in surface water bodies by ingesting the surface water, sediments, and aquatic organisms. However, reliable information on generic BCFs for terrestrial wildlife is currently not available in the scientific literature.

Concentrations of the contaminants of potential concern in plant tissue were estimated using soil-to-plant BCFs. Soil concentrations in the saturated zone were estimated by multiplying the ground water concentration by the soil-water distribution coefficient, Kd. For simplicity, ground water and associated soils are assumed to be in equilibrium. Tables 7.3 and 7.4 present the methodology and parameters used to estimate root uptake and plant tissue concentrations at harvestable maturity for the contaminants of potential concern for the NC and UC sites, respectively. This methodology is described in detail elsewhere in the literature (Baes et al., 1984) and therefore will not be presented here.

Table 7.2 Contaminants analyzed in Dolores River sediment, Slick Rock, Colorado, sites

Contaminant of potential concern	NC site			UC site			NOAA value[a] (mg/kg)	USGS regional range[b] (mg/kg)
	Background SRK-01-0696		Downstream SRK-01-0692	Downstream SRK-01-0693	Downstream SRK-01-0694			
	(9/93)	(2/94)	(2/94)	(2/94)	(9/93)	(2/94)		
Cadmium	0.5	1.3	1.2	1.1	1.7	0.77	5	—
Copper	3.0	—	—	—	15	—	70	2 - 300
Molybdenum	2.0	4.8	6.3	5.2	3.0	<2.6	—	<3 - 7
Selenium	<0.5	1.2	3.1	3.2	3.0	<1.5	—	<0.1 - 4.3
Uranium	1.4	2.0	2.2	1.9	1.9	1.4	—	0.68 - 7.9
Vanadium	18	33	46	43	32	24	—	7 - 500
Zinc	38	53	75	86	73	40	120	10 - 2100

[a] Effective range-low concentrations for selected chemicals in sediment (dry weight) (NOAA, 1990).

[b] Ranges of elements in soil and other surficial materials sampled in the western United States (Shacklette and Boerngen, 1984).

Notes: 1. All results reported in milligrams per kilogram dry weight.
2. Numbers in parentheses are sampling dates.
3. Dash indicates samples were not analyzed for this constituent or criteria were not available.

Table 7.3 Comparison of estimated plant concentrations to phytotoxic concentrations, Slick Rock, Colorado, NC site

Contaminant of potential concern	95% UCL[a] ground water concentration	Kd	Estimated soil concentration (mg/kg DW)	Soil to plant concentration factors		Estimated concentration in vegetative growth (mg/kg DW)[b]	Estimated concentration in fruits/tubers (mg/kg DW)[c]	Approximate toxic concentration in mature leaf tissue (mg/kg DW)[d]
				Bv	Br			
Inorganic (mg/L)								
Aluminum	0.27	NA	NC	0.004	0.00065	NC	NC	NA
Antimony	0.013	6	8E-02	0.2	0.03	2E-02	2E-03	150
Boron	0.4	1.3	5E-01	4	2	2E+00	1E+00	50-200
Iron	2.7	15	4E+01	0.004	0.001	2E-01	4E-02	NA
Manganese	0.61	25.3	2E+01	0.25	0.05	4E+00	8E-01	200[e]-1000
Molybdenum	0.095	120	1E+01	0.25	0.06	3E+00	7E-01	10-50
Nitrate[f]	1.2	NA	NC	30	30	NC	NC	NA
Strontium	2.5	100	3E+02	2.5	0.25	6E+02	6E+01	NA
Sulfate[g]	1500	NA	NC	0.5	0.5	NC	NC	NA
Uranium	3.7	50	2E+02	0.0085	0.004	2E+00	7E-01	NA
Radionuclide (pCi/L)								
Lead-210	220	597	3E-09	0.045	0.009	1E-10	3E-11	NA
Polonium-210	0.68	15	2E-13	0.0025	0.0004	4E-16	6E-17	NA
Radium-226	1.4	100	1E-09	0.015	0.0015	2E-11	2E-12	NA
Thorium-230	0.64	500	3E-08	0.00085	0.000085	3E-11	3E-12	NA

[a] Maximum ground water concentrations used if unable to calculate 95% UCL due to limited number of samples.

[b] Estimated soil concentration multiplied by Bv.

[c] Nonvegetative portions; calculated as estimated soil concentration multiplied by Br.

[d] Concentrations are not presented for very sensitive or for highly tolerant plant species (Kabata-Pendias and Pendias, 1992).

[e] The value of 200 mg/kg is a recommended criterion of the Illinois Institute of Environmental Quality (Saric, 1986).

[f] Bv and Br factors available for elemental nitrogen only. Bv and Br factors for nitrate are expected to be higher than for nitrogen.

[g] Bv and Br factors available for elemental sulfur only; thus, these factors were reduced by a factor of 3 for sulfate.

Bv - vegetative portions of food crops and feed plants (Baes et al., 1984).
Br - nonvegetative portions (e.g., fruits, tubers) of food crops and feed plants (Baes et al., 1984).
DW - dry weight.
NA - not available.
NC - value cannot be calculated because Kd is unavailable.
Note: No Kd, Bv, or Br values available for ammonium, bromide, chloride, fluoride, and sulfide.

Table 7.4 Comparison of estimated plant concentrations to phytotoxic concentrations, Slick Rock, Colorado, UC site

Contaminant of potential concern	95% UCL[a] ground water concentration	Kd[b]	Estimated soil concentration (mg/kg DW)	Soil to plant concentration factors		Estimated concentration in vegetative growth (mg/kg DW)[c]	Estimated concentration in fruits/tubers (mg/kg DW)[d]	Approximate toxic concentration in mature leaf tissue (mg/kg DW)[e]
				Bv	Br			
Aluminum	0.28	f	g	0.004	0.00065	g	g	f
Barium	0.073	2800	204.4	0.15	0.015	3E+01	3E+01	f
Boron	0.5	1.3	0.65	4	2	3E+00	1E+00	50-200
Cadmium	0.02	423	8.5	0.55	0.15	5E+00	1E+00	5-30
Chromium	0.03	565	28	0.0075	0.0045	2E-01	1E-01	5-30
Iron	12	15	180	0.004	0.001	7E-01	2E-01	f
Manganese	6.9	25	173	0.25	0.05	4E+01	9E+00	200[h]-1000
Molybdenum	2	120	240	0.25	0.06	6E+01	1E+01	10-50
Nickel	0.077	59	4.543	0.06	0.06	3E-01	3E-01	10-100
Nitrate[i]	1400	f	0	30	30	g	g	f
Selenium	1.1	15	17	0.025	0.025	4E-01	4E-01	5-30
Strontium	8.6	100	860	2.5	0.25	2E+03	2E+02	f
Sulfate[j]	2900	f	0	0.5	0.5	g	g	f
Uranium	0.12	50	6	0.0085	0.004	5E-02	2E-02	f
Vanadium	0.65	100	65	0.0055	0.003	4E-01	2E-01	5-10
Zinc	0.036	939	56	1.5	0.9	8E+01	5E+01	100-400

Table 7.4 Comparison of estimated plant concentrations to phytotoxic concentrations, Slick Rock, Colorado, UC site (Concluded)

Contaminant of potential concern	95% UCL[a] ground water concentration	Kd[b]	Estimated soil concentration (mg/kg DW)	Soil to plant concentration factors		Estimated concentration in vegetative growth (mg/kg DW)[c]	Estimated concentration in fruits/tubers (mg/kg DW)[d]	Approximate toxic concentration in mature leaf tissue (mg/kg DW)[e]
				Bv	Br			
Radionuclide								
Lead-210	6.5	597	8.5E-11	0.045	0.009	4E-12	8E-13	f
Polonium-210	0.4	15	8.9E-14	0.0025	0.0004	2E-16	4E-17	f
Radium-226	1.8	100	2.0E-09	0.015	0.0015	3E-11	3E-12	f
Thorium-230	0.8	500	4.0-08	0.00085	0.000085	3E-11	3E-12	f

[a] Maximum detected ground water concentrations used if unable to calculate 95% UCL due to limited number of samples.
[b] Kds from PNL (1989) for pH 5-9 and loamy soils.
[c] Estimated soil concentration multiplied by Bv.
[d] Nonvegetative portions; calculated as estimated soil concentration multiplied by Br.
[e] Concentrations are not presented for very sensitive or for highly tolerant plant species (Kabata-Pendias and Pendias, 1992).
[f] Unavailable.
[g] Value cannot be calculated because Kd is unavailable.
[h] The value of 200 mg/kg is a recommended criterion of the Illinois Institute of Environmental Quality (Saric, 1986).
[i] Bv and Br factors available for elemental nitrogen only. It is expected that the Bv and Br factors for nitrate would be higher than for nitrogen.
[j] Bv and Br factors available for elemental sulfur only; thus, these factors were reduced by a factor or 3 for sulfate.

Bv - vegetative portions of food crops and feed plants (Baes et al., 1984).
Br - nonvegetative portions (e.g., fruits, tubers) of food crops and feed plants (Baes et al., 1984).
DW - dry weight.

Note: 1. Inorganic concentrations are reported in milligrams per liter. Radionuclide concentrations are reported in picocuries per liter.

The estimated tissue concentrations for the contaminants of potential concern in the vegetative portions (stems and leaves) and in the nonvegetative portions (fruits and tubers) of plants at harvestable maturity were compared to approximate concentrations (in mature leaf tissue) that have been reported to be toxic to plants (phytotoxic). As illustrated in Tables 7.3 and 7.4, few available data relate tissue concentrations to phytotoxicity. The reported phytotoxic concentrations are not representative of very sensitive or highly tolerant plant species. At the NC site, the estimated tissue concentrations for the contaminants of potential concern in plants that may reach soil saturated with contaminated ground water do not exceed the available phytotoxicity data. However, at the UC site the concentrations of cadmium and zinc are within the phytotoxic range and the concentration of molybdenum exceeds the range. No comparison data were available for aluminum, barium, iron, nitrate, strontium, sulfate, uranium, lead-210, polonium-210, radium-226, and thorium-230. Thus, it is not possible with available information to evaluate whether the estimated tissue concentrations could result in adverse effects to plants.

Terrestrial organisms

Bioaccumulation of contaminants of potential concern in terrestrial organisms from ingested plants or animals (for example, birds eating fish) is a potential exposure pathway at the site. Birds and other vertebrates consuming these plants and animals can bioaccumulate some of the contaminants of potential concern from this diet if the amount ingested exceeds the amount eliminated. Bioaccumulation often is a function of the areal extent of contamination versus the areal extent of the animal's feeding range. In small contaminated areas, the amount of food in the diet usually exceeds the impacted food and bioaccumulation is not a concern. Therefore, exposure via the diet for all food chain species is possible in certain areas (for example, wetland areas), but the potential for bioaccumulation is not always a concern.

Biomagnification is a more severe situation in which the concentration of a contaminant increases in higher levels of the food chain because the contaminant concentrations are accumulated through each successive trophic level. Of particular concern for biomagnification effects are the top predators, especially the carnivorous birds and mammals. Only a limited number of constituents have the potential to magnify in the food chain. Most constituents are metabolized in organisms and eliminated at each level of the food chain and do not increase up the food chain. Based on available information, the potential for the detected contaminants of potential concern to represent a concern via food chain transfer is probably low.

In Tables 7.5 and 7.6, UCLs for ground water concentrations for the contaminants of potential concern at each site are compared to available water quality values. The comparisons were used to evaluate the potential impact of a hypothetical pond (recharged by contaminated ground water) and to evaluate the effects to wildlife drinking water from the pond and fish stocked in the pond. There are no federal or state criteria or standards established for the protection

Table 7.5 Comparison of contaminants of potential concern in ground water with available water quality values, NC site, Slick Rock, Colorado

Contaminant of potential concern	95th UCL concentration	Aquatic life water quality value[a] (mg/L)	Water concentration protective of livestock[b] (mg/L)	Concentration in irrigation water protective of plants[b] (mg/L)
Aluminum	0.27	0.087	5	5.0
Ammonium	0.27	NA	NA	NA
Antimony	0.013	NA	NA	NA
Boron	0.4	1.0[c]	5	0.75
Bromide	0.5	NA	NA	NA
Chloride	350	230[d]	NA	NA
Fluoride	0.32	NA	NA	1.0
Iron	2.7	1	NA	5.0
Manganese	0.61	1	NA	0.2
Molybdenum	0.09	50 (0.79[e])	10[d]	0.01
Nitrate	1.2	NA	100	NA
Strontium	2.5	NA	NA	NA
Sulfate	1500	NA	1000[f]	NA
Sulfide	0.26	NA	NA	NA
Uranium	3.7	7.9[g]	NA	NA
Radionuclide (pCi/L)				
Lead-210	220	NA	NA	NA
Polonium-210	0.68	NA	NA	NA
Radium-226	1.4	5	NA	NA
Thorium-230	0.64	60	NA	NA

[a] From CDH (1991), unless specified otherwise. Standards are protective of aquatic life via chronic exposure.
[b] From EPA (1972), unless specified otherwise. Irrigation water values shown are for water used continuously on all soils.
[c] No state or federal water quality value available. Value presented is the current boron criterion recommended by the FWS for the protection of aquatic life (Eisler, 1990).
[d] No state water quality value available. Value presented is the Federal Water Quality Criterion (FWQC) for the protection of freshwater aquatic life via chronic exposure (EPA, 1992c).
[e] No state or federal water quality value available. Value presented is the current molybdenum criterion recommended by the FWS for the protection of aquatic organisms, except for newly fertilized eggs of rainbow trout, which are sensitive to molybdenum concentrations above 0.79 mg/L (Eisler, 1989).
[f] From National Research Council (1971).
[g] Water hardness-related state standard (CDH, 1991). Criterion presented was calculated using the mean hardness (455 mg/L) determined from concentrations of calcium and magnesium in the plume wells (filtered data).

Concentrations reported in milligrams per liter, unless otherwise noted.
NA - not available.

Table 7.6 Comparison of contaminants of potential concern in ground water with available water quality values, UC site, Slick Rock, Colorado

Contaminant of potential concern	95th UCL concentration	Aquatic life water quality value[a] (mg/L)	Water concentration protective of livestock[b] (mg/L)	Water concentration in irrigation water protective of plants[b] (mg/L)
Aluminum	0.28	0.087	5	5.0
Ammonium	182	NA	NA	NA
Barium	0.073	NA	NA	NA
Boron	0.5	1.0[c]	5	0.75
Bromide	5.7	NA	NA	NA
Cadmium	0.025	0.0037[d]	0.05	0.01
Chloride	2400	230[e]	NA	NA
Chromium	0.03	0.716[d]	1	0.10
Fluoride	0.46	NA	NA	1.0
Iron	12	1	NA	5.0
Manganese	6.9	1	NA	0.2
Molybdenum	1.8	50 (0.79[f])	10[c]	0.01
Nickel	0.077	0.302[d]	NA	0.2
Nitrate	1400	NA	100	NA
Selenium	1.1	0.017	0.05	0.02
Strontium	8.6	NA	NA	NA
Sulfate	2900	NA	1000[g]	NA
Sulfide	0.43	NA	NA	NA
Uranium	0.11	7.9[d]	NA	NA
Vanadium	0.65	NA	0.1	0.1
Zinc	0.036	0.383[d]	25	2.0
Radionuclide (pCi/L)				
Lead-210	6.5	NA	NA	NA
Polonium-210	0.4	NA	NA	NA
Radium-226	1.8	5	NA	NA
Thorium-230	0.8	60	NA	NA

[a] From CDH (1991), unless specified otherwise. Standards are protective of aquatic life via chronic exposure.

[b] From EPA (1972), unless specified otherwise. Irrigation water values shown are for water used continuously on all soils.

[c] No state or federal water quality value available. Value presented is the current boron criterion recommended by the FWS for the protection of aquatic life (Eisler, 1990).

[d] Water hardness-related state standard (CDH, 1991). Criterion presented was calculated using the mean hardness (455 mg/L) determined from concentrations of calcium and magnesium in the plume wells (filtered data).

[e] No state water quality value available. Value presented is the Federal Water Quality Criterion (FWQC) for the protection of freshwater aquatic life via chronic exposure (EPA, 1992c).

Table 7.6 Comparison of contaminants of potential concern in ground water with available water quality values, UC site, Slick Rock, Colorado (Concluded)

[f] No state or federal water quality value available. Value presented is the current molybdenum criterion recommended by the FWS for the protection of aquatic organisms, with one exception. The exception is for newly fertilized eggs of rainbow trout, which are sensitive to molybdenum concentrations above 0.79 mg/L (Eisler, 1989).

[g] From National Research Council (1971).

Note: Concentrations reported in milligrams per liter, unless otherwise noted.

NA - not available.

of terrestrial wildlife via water exposure. Therefore, it is difficult to evaluate the potential hazards to terrestrial receptors without additional information. However, water quality standards for the protection of freshwater aquatic life for the state of Colorado are available (CDH, 1991).

Ground water concentrations for aluminum, chloride, and iron at the NC site and for aluminum, cadmium, chloride, iron, manganese, molybdenum, and selenium at the UC site exceeded the aquatic life water quality values, indicating this water would be unacceptable for aquatic organisms. Ground water concentrations for manganese, molybdenum, uranium, radium-226, and thorium-230 at the NC site and for chromium, nickel, uranium, zinc, radium-226, and thorium-230 at the UC site were below the comparison values. No comparison water quality values are available for ammonium, antimony, barium, boron, bromide, fluoride, nitrate, strontium, sulfate, sulfide, tin, vanadium, lead-210, and polonium-210.

Irrigation

Another future hypothetical use of the ground water in the area would be irrigating agricultural crops. Tables 7.5 and 7.6 compare the approximate concentrations in water used for irrigation that should be protective of plants with the ground water concentrations from the NC and UC sites, respectively (EPA, 1972). The EPA developed these approximate irrigation water concentrations to protect agricultural crops from toxicity associated with buildup of a particular contaminant in the soil. Twelve contaminants of potential concern (aluminum, boron, cadmium, chromium, fluoride, iron, manganese, molybdenum, nickel, selenium, vanadium, and zinc) have comparison values.

At the NC site, the UCL concentrations in ground water for manganese and molybdenum exceeded the comparison values for protection of plants, while the concentrations of aluminum, boron, fluoride, and iron were below the comparison values.

At the UC site, the ground water concentrations for cadmium, iron, manganese, molybdenum, selenium, and vanadium exceeded the comparison values for protection of plants, while the concentrations of aluminum, boron, chromium, fluoride, nickel, and zinc were below the comparison values.

Comparison values are not available for the remainder of the contaminants of potential concern (ammonium, barium, bromide, chloride, nitrate, strontium, sulfate, sulfide, uranium, lead-210, polonium-210, radium-226, and thorium-230). Thus, it is not possible to evaluate the potential for these compounds to adversely affect plants when applied in irrigation water.

Available data indicate use of the alluvial ground water near the NC site as a continuous source of irrigation water may adversely affect crops, primarily because of the elevated concentrations of manganese and molybdenum. Use of the alluvial ground water near the UC site as a continuous source of irrigation water may adversely affect crops due to elevated concentrations of cadmium, iron, manganese, molybdenum, selenium, and vanadium.

7.4.2 Surface water and sediment

Risk to aquatic life - surface water

Aquatic life in the Dolores River may be exposed to contaminants associated with the site. The zones of contaminated ground water are believed to discharge to the river. It is also possible that contaminants may discharge into the river through surface water runoff until the tailings are removed.

The maximum surface water concentration for the contaminants of potential concern (cadmium, uranium, and zinc) were compared to available water quality standards for aquatic life. Cadmium, uranium, and zinc exceeded background concentrations (cadmium by 100 percent, uranium by 200 percent, and zinc by 75 percent). However, none of the contaminants of potential concern exceeded water quality standards. Surface water quality indicates contaminant discharge from the Slick Rock sites is not discernably affecting the ecological environment in this area. However, since the surface water database for this reach of the Dolores River is limited, trends cannot be identified and conclusive resolution cannot be made about the surface water quality in this area.

Risk to aquatic life - sediment

There are no established state or federal sediment quality criteria (SQC) for the protection of aquatic life for the contaminants at this site (EPA, 1988). The EPA is evaluating a methodology based on the three-phase sorption model for free-metal ion activity and is assessing its applicability for determining the bioavailable fraction within sediments (EPA, 1988). Currently, several predictive models and methods are being investigated for metals, but no single approach has been accepted to adequately develop sediment-based metals criteria (Shea, 1988; Chapman, 1989; EPA, 1988; NOAA, 1990; Di Toro et al., 1991; Burton, 1991). Therefore, only a qualitative hazard assessment of the metals detected in sediments will be presented in this risk assessment.

National Oceanic and Atmospheric Administration (NOAA) effects-based sediment quality values are available for evaluating the potential of contaminants in sediment to cause adverse biological effects to aquatic organisms. Of the contaminants of potential concern for the sediment (cadmium, copper, molybdenum, selenium, uranium, vanadium, and zinc), there are NOAA values for cadmium, copper, and zinc. However, the detected concentrations of these three metals fall below their respective NOAA values and therefore are not likely to cause adverse biological effects. Because NOAA values are not available for the remaining contaminants, their potential for representing a hazard to aquatic life is difficult to evaluate. However, all the contaminants of potential concern were compared to values for naturally occurring concentrations of elements found in surficial soil samples in the western United States (USGS, 1984). The concentrations for each of the contaminants of potential concern fall within reported USGS ranges (Table 7.2).

7.5 POTENTIAL IMPACTS TO LIVESTOCK

Contaminated alluvial ground water is believed to discharge to the Dolores River near the former processing sites. Livestock could drink water from the Dolores River. Ingestion of vegetation by livestock that may have bioconcentrated contaminants from alluvial ground water is another potential pathway. However, without additional data (for example, actual plant tissue concentrations or exposure and toxicity information for livestock), this exposure pathway is difficult to evaluate.

To evaluate the potential impact to livestock that might drink out of the Dolores River near the site, the detected concentrations in surface water were compared to approximate drinking water concentrations considered to be protective of livestock (Table 7.7). Guidelines are available for two of the three contaminants of potential concern (cadmium and zinc). Comparing these guidelines to the surface water concentrations suggests that, at the detected levels of these chemicals, livestock could use the Dolores River as a sole source of drinking water. Except for one sampling location (SRK-01-0692) downgradient from the NC site, uranium concentrations were the same as background (0.001 mg/L), suggesting minimal impact from uranium mill tailings.

Because of its proximity, the likely source of drinking water for livestock is the Dolores River. However, as a hypothetical scenario, ground water could be used in the future to provide water for a livestock watering pond. To evaluate the potential impact to livestock, the UCL ground water concentrations for the contaminants of potential concern were compared to drinking water concentrations considered to be protective of livestock (EPA, 1972) (Tables 7.5 and 7.6).

At the NC site, the UCL of sulfate exceeded the water concentration considered protective of livestock. However, the concentrations of aluminum, boron, molybdenum, and nitrate were below comparison guidelines.

At the UC site, the UCL concentrations in ground water of nitrate, selenium, sulfate, and vanadium exceeded the water concentrations considered protective of livestock. If the ground water at the UC site were used as the sole source of drinking water for livestock, the sulfate levels (2900 mg/L) could cause diarrhea in exposed animals (Church, 1984). Although the levels in literature are somewhat conflicting, adverse effects (including weight loss, sulfhemoglobinemia, coordination loss, convulsions, and death) were reported in cattle chronically exposed to sulfate in drinking water at concentrations as low as 2200 mg/L (McKee and Wolf, 1963; EPA, 1972; NAS, 1974). In addition, the nitrate levels (UCL = 1400 mg/L) detected at the UC site could cause methemoglobinemia in livestock. The TDS concentrations range from 310 and 9560 mg/L in the UC site vicinity. The National Academy of Science guideline

Table 7.7 Comparison of contaminants of potential concern in the Dolores River with available water quality values, Slick Rock, Colorado, sites

Contaminant of potential concern	NC site				UC site				Aquatic life water quality value[a] (mg/L)	Water concentration protective of livestock[b] (mg/L)
	Background SRK-01-0696		Downstream SRK-01-0692		Downstream SRK-01-0693		Downstream SRK-01-0694			
	(9/93)	(2/94)	(9/93)	(2/94)	(9/93)	(2/94)	(9/93)	(2/94)		
Cadmium	<0.001	<0.001	NA	<0.001	NA	0.002	NA	<0.001	0.0031	0.05
Uranium	0.001	<0.001	NA	0.003	NA	0.001	0.001	0.001	6.1	NA
Zinc	0.044	<0.005	NA	<0.05	NA	<0.05	0.077	<0.05	0.312	25

[a] From CDH (1991). These values are standards protective of aquatic life via chronic exposure. Criterion presented was calculated using the mean hardness (357 mg/L) determined from concentrations of calcium and magnesium in the Colorado River (unfiltered data).

[b] From EPA (1972).

NA - not available.

Notes: 1. All concentrations are single sample concentrations reported in milligrams per liter from unfiltered samples.
2. Numbers in parentheses are sampling dates.

for TDS in drinking water for livestock is 7000 mg/L. Levels above 7000 mg/L are not acceptable because of potential toxic effects in young cattle or cattle that are pregnant or lactating. Considering the additive effects of sulfate, nitrate, and TDS, it is unlikely that livestock could chronically ingest the ground water without adverse effects. The concentrations of aluminum, boron, cadmium, chromium, molybdenum, and zinc were below comparison guidelines.

Although toxicological information on selenium intake by livestock addresses higher concentrations than those found at the Slick Rock sites, toxic effects reported in the literature include alkali disease syndrome. Water quality standards have been set for the remaining contaminants of potential concern.

7.6 LIMITATIONS OF THE ECOLOGICAL RISK ASSESSMENT

The qualitative evaluation of potential ecological risks presented here is a screening level assessment of the risks associated with potential exposure of plants and animals to contaminated ground water, surface water, and sediment at the Slick Rock sites. Sources of uncertainty in any ecological assessment arise from the monitoring data, exposure assessments, toxicological information, and the inherent complexities of the ecosystem. In addition, methods of predicting nonchemical stresses (for example, drought), biotic interactions, behavior patterns, biological variability (differences in physical conditions, nutrient availability), and resiliency and recovery capacities are often unavailable. In general, limitations for the Slick Rock ecological risk assessment include the following:

- Only a small amount of ecological data were collected for this screening.
- Little is known about site-specific intake rates for wildlife or amounts of contaminants taken up by plants. General literature values were used in many cases.
- Only limited ecotoxicological reference data are available.
- Considerable uncertainty is associated with the toxicity of mixing contaminants.

7.7 SUMMARY

Surface water data from the Dolores River near the sites indicate that cadmium, uranium, and zinc exceed background concentrations, but do not exceed state standards for surface water. The data suggest that although ground water or overland flow of surface water is discharging into the Dolores River, the quality of the surface water is not being discernably affected. However, a definitive conclusion cannot be made at this time because of the limited data available.

The sediment concentrations for cadmium, copper, and zinc fell below their respective NOAA values, indicating adverse effects to aquatic organisms are not likely. In addition, cadmium, copper, molybdenum, selenium, uranium, vanadium, and zinc all fell within western United States regional surficial soil ranges. Again, the data suggest that although the ground water or overland flow of surface water is discharging into the Dolores River, the quality of the sediment is not adversely affected. However, because this conclusion is based on limited data, a definitive conclusion cannot be made at this time.

Evaluation of the Dolores River surface water indicates that surface water would be suitable as a long-term watering source for livestock. However, ground water used as a sole drinking water source (e.g., a pond) would not be suitable as a long-term source of drinking water for livestock due to the adverse effects associated with elevated levels of sulfate at the NC site, and with the elevated levels of nitrate and sulfate at the UC site.

Available data and criteria indicate no ecological threat to plants at harvestable maturity that may have roots in contact with soil saturated with the most contaminated ground water in the alluvial aquifer at the NC site. However, at the UC site, the concentrations of cadmium, molybdenum, and zinc fall within or exceed the range that is toxic to mature leaf tissue. Water from the most contaminated wells in this aquifer would not be suitable as a source of water for fish. This is primarily due to the elevated concentrations of aluminum, chloride, and iron at the NC site and of the aluminum, cadmium, chloride, iron, manganese, molybdenum, and selenium at the UC site. These chemicals exceeded the aquatic life water quality values, indicating this water would be unacceptable for aquatic organisms.

Tissue analysis from biota (for example, fish and plants) has not been conducted (based on available surface water, sediment, and ground water data). However, the potential for the contaminants of potential concern detected in media at the site to represent a food chain hazard to terrestrial and aquatic wildlife (via bioaccumulation and biomagnification) is considered low.

8.0 INTERPRETATION AND RECOMMENDATIONS

8.1 RISK SUMMARY

The UMTRCA (42 USC §7901 *et seq.*) requires the UMTRA Project to protect human health and the environment from radiological and chemical hazards associated with the former uranium mill sites. This baseline risk assessment was conducted on the Slick Rock former processing NC and UC sites to evaluate the presence of these hazards in ground water. Additionally, surface water and sediment were qualitatively evaluated for this assessment.

Two active private wells are near the Slick Rock sites; one is upgradient and one is crossgradient and across the Dolores River from the sites. Therefore, current exposures to ground water have not been identified and only future potential exposure to ground water was evaluated for this baseline risk assessment.

The most contaminated wells from the alluvial aquifer at the Slick Rock former processing sites were evaluated. This is a conservative approach because the alluvial unit is the most contaminated of the aquifers, contaminant concentrations in the alluvial unit are expected to decrease over time due to removal of the source of contamination (i.e., tailings), and contaminant concentrations will decrease over time due to the already occurring effects of dilution and dispersion in ground water.

8.1.1 Human health risks from ground water, NC site

Some future potential health risks could be associated with ground water ingestion at the NC site. Adverse noncarcinogenic health effects could result from the chronic ingestion of manganese, sulfate, and sodium.

Fifty percent of the infant population exposed to sulfate could exhibit severe persistent diarrhea leading to dehydration; adults could exhibit laxative effects from these same intakes. Chronic exposure to sodium at the intake of 23 mg/kg-day (estimated lower-end value where hypertension has been observed) could contribute to the development of hypertension in approximately 30 percent of the exposed population. In addition, exposure to manganese could cause nearly 100 percent of the exposed population to develop early adverse neurological effects (e.g., mental disturbances and tremors). The exposure pathways identified at the NC site (i.e., ingestion of milk, meat, and garden produce) that could contribute additional doses to the drinking water ingestion pathway were determined not to appreciably increase the potential for adverse human health effects from sodium, sulfate, or manganese. Noncarcinogenic effects from uranium would not be anticipated at this site.

Total excess lifetime cancer risk (7E-03) associated with drinking water exposure to radionuclides at the NC site exceeded the NCP acceptable risk level of 1E-04. The major contributors of potential carcinogenic risk were lead-210 and uranium. The additive lifetime cancer risks for the contaminants of potential concern that contributed additional doses from other routes of exposure (i.e., the ingestion of garden produce, and milk and meat products) did not appreciably increase the incremental carcinogenic risk due to lead-210, polonium-210, and uranium.

8.1.2 Human health risks from ground water, UC site

Some potential future health risks could be associated with exposure from drinking ground water at the UC site. Adverse noncarcinogenic health effects could result from the chronic ingestion of nitrate, sulfate, manganese, chloride, sodium, molybdenum, selenium, and iron.

Forty percent of the infant population exposed to nitrates (estimated lethal level is 35 mg/kg-day) at the UC site could develop methemoglobinemia. In 70 percent of the infant population, sulfate exposure at 50 mg/kg-day could result in severe persistent diarrhea leading to dehydration; adults could exhibit laxative effects at these same concentrations. Neurological effects could potentially develop in 100 percent of the exposed population due to chronic ingestion of manganese at the UC site. In addition, 10 percent of the population exposed to manganese could develop Parkinson-like effects.

At an exposure to chloride of 36 mg/kg-day, approximately 60 percent of the population could develop hypertension. Additionally, chronic exposure to sodium at an intake of 23 mg/kg-day could contribute to the development of hypertensive effects in 50 percent of the population. Molybdenum exposure at an intake of 0.008 mg/kg-day could alter copper and sulfur excretion patterns in nearly 100 percent of the exposed population. Mild selenosis, with symptoms that include hair loss or breakage and thickening and brittle nails, could develop in 10 percent of the population (at an intake of 0.013 mg/kg-day). Noncarcinogenic effects from vanadium, cadmium, strontium, and uranium would not be anticipated at this site.

The exposure pathways that could contribute additional doses to the drinking water ingestion pathway (i.e., ingestion of milk, meat, and garden produce) were determined not to appreciably increase the potential for adverse human health effects at the UC site for cadmium, manganese, molybdenum, sodium, or strontium.

Total excess lifetime cancer risks associated with drinking water exposure of radionuclides (3E-04) exceed the NCP acceptable risk level of 1E-04. The major contributor of the potential carcinogenic risk was lead-210. Furthermore, the additive lifetime cancer risks for contaminants of potential concern that contributed to the total dose (such as lead-210) did not appreciably increase the incremental carcinogenic risk with the inclusion of other routes of exposure (i.e., the ingestion of garden produce, milk, and meat products).

8.1.3 Ecological summary, NC and UC sites

Surface water and sediment data suggest that although ground water or overland flow of surface water discharges into the Dolores River, the quality of the surface water is not impacted and adverse affects are not occurring to aquatic organisms and terrestrial wildlife. However, these conclusions are based on limited data and definitive conclusions cannot be made at this time.

Evaluation of the Dolores River surface water indicates that surface water would be suitable as a long-term watering source for livestock. However, ground water used as a sole drinking water source (e.g., a hypothetical ground water-fed pond) would not be suitable as a long-term source of drinking water for livestock due to the adverse effects associated with elevated sulfate levels at the NC site and with the elevated levels of nitrate, sulfate, and TDS at the UC site.

Available data and criteria indicate no ecological threat to plants at harvestable maturity that may have roots in contact with soil saturated with the most contaminated ground water in the alluvial aquifer at the NC site. However, at the UC site the concentrations of cadmium, molybdenum, and zinc fall within or exceed the range that is toxic to mature leaf tissue. Water from the most contaminated wells in the alluvial aquifer (i.e., a ground water-fed pond) would not be suitable as a source of water for fish. This is primarily due to the elevated concentrations of aluminum, chloride, and iron at the NC site, and of the aluminum, cadmium, chloride, iron, manganese, molybdenum, and selenium at the UC site. These chemicals exceed the aquatic life water quality values, indicating this water is unacceptable for aquatic organisms.

Based on available surface water, sediment, and ground water data, the potential for the contaminants of potential concern at the site to represent a food chain hazard to terrestrial and aquatic wildlife (via bioaccumulation and biomagnification) is considered low. However, no tissue analysis from biota (for example, invertebrates and plants) was conducted.

8.2 LIMITATIONS OF THIS RISK ASSESSMENT

The following limitations to this evaluation of health risks should be noted:

- This document evaluates risks associated with exposures to inorganic contaminants in ground water at the NC and UC sites. As discussed in Section 3.0, potential organic contaminants (related to uranium processing) were not considered for this baseline risk assessment.

- The ground water results presented in this document are based on filtered (0.45-μm) water samples. The effect of filtration differs for different elements. Filtered samples can have somewhat lower or equal concentrations than unfiltered samples for some constituents. Constituents in suspension may be lost with filtration but still produce toxic effects if ingested and broken down in the acidic environment of the stomach.

- The toxicity of any constituent varies from person to person. For example, normal variability in biochemical factors between individuals, differences in medical history, previous exposure to toxicants, and dietary and exercise habits can all affect susceptibility to chemical toxicity. Presenting exposure ranges that can produce toxic effects emphasizes that variability and enhances understanding of toxicity probabilities. However, it is not possible to account for all sources of variability and still present useful and meaningful analyses. Specific subpopulations of individuals known to be more sensitive to toxic effects of given constituents are noted.

- To assess toxicity, standardized reference values developed by agencies such as the EPA are used to determine plant uptake, tissue concentrations in livestock, and toxic effects in humans. These reference values themselves have limitations, including the following:

    - Toxicity, uptake, and bioconcentration data are not available for all constituents evaluated at the former Slick Rock processing sites.

    - Some exposure doses to some laboratory animals differ from those expected at the site. The relationship between dose and response is not always linear and humans do not always exhibit the same responses as animals.

    - Data used to determine toxicity are generally based on exposure to only the constituent of concern. In reality, exposures generally occur simultaneously to several chemicals. The interactive effects of multiple constituents and the impact of these interactions on expected toxicity generally cannot be accurately assessed from existing data.

- Although considerable effort has been directed at determining the nature and extent of contamination, variability in physical systems could still result in well placements that have not determined the fullest extent of contaminant migration and impact. Furthermore, most site characterization activities conducted at the former processing sites to date were related to designing a surface remedial action plan to relocate the site-related RRM. Additional site characterization may be necessary for ground water compliance and the hydrogeologic conceptual site model definition and refinement.

- Variability can be introduced through sampling and analytical processes. However, the ground water data at the Slick Rock sites were collected over many years and were subjected to rigorous quality assurance procedures. The use of multiple samples ensures data reliability and validity.

- The ground water ingestion pathway is considered the major determinant of exposure in this assessment. Although other pathways were screened and determined not to contribute significantly to the total exposure, the additivity of exposure from these pathways should be noted. Measurable contributions from other pathways that could increase expected exposure significantly enough to alter predicted toxicities are noted in Section 6.0.

Ranges of toxic effects, summaries of available data on health effects and interactions, and outlines of potential limitations, provide reasonable interpretation of potential health risks associated with ground water contamination at the NC and UC sites. This assessment presents contamination, risk, as accurately as possible, and areas of uncertainty based on available data.

8.3 GROUND WATER CRITERIA

In 1983, the EPA established health and environmental protection standards for the UMTRA Project; in 1987 the EPA proposed revised ground water standards in the UMTRCA. The UMTRA Project is required to adhere to the 1987 proposed ground water standards until final standards are published. The UMTRCA ground water standards consist of ground water protection standards to evaluate disposal cell performance and ground water cleanup standards for existing contamination at processing sites. Tables 8.1 and 8.2 summarize these standards for contaminants that have proposed maximum concentration limits (MCL). Because an MCL is not established for every contaminant, the proposed standard requires meeting background levels for those contaminants that do not have an MCL. However, background water quality has not been established for the Slick Rock sites.

While the UMTRCA standards apply only to the UMTRA Project, the EPA has also published drinking water health advisory levels for both long- and short-term exposures. These advisories are also shown in Tables 8.1 and 8.2.

8.4 RISK MITIGATION MEASURES - INSTITUTIONAL CONTROLS

Institutional controls are defined in the proposed EPA ground water standards as mechanisms that can be effectively used to protect human health and the ecological environment by controlling access to contaminated ground water. Although the proposed standards refer to institutional controls for long periods of time (e.g., up to 100 years during natural flushing), they also can be applied to short-term restriction of access to contaminated ground water. Because not all 24 UMTRA Project sites can be evaluated simultaneously, short-term institutional controls may be needed before remedial action decisions are made and implemented for individual sites.

8.4.1 <u>Well permits</u>

All Colorado UMTRA Project sites are on the Colorado Western Slope and are outside the designated ground water basins. Wells constructed in Colorado outside the designated basins require a written application to the state engineer

Table 8.1 Maximum concentration limits of constituents, NC site, near Slick Rock, Colorado

Constituent	UMTRCA MCL (mg/L)	Health advisories 10-kg child, 10-day (mg/L)	Health advisories 70-kg adult, lifetime (mg/L)
Chemical (inorganic)			
Antimony	a	0.015[b]	0.003[b]
Arsenic	0.05	a	a
Barium	1.0[a]	a	2
Boron	a	0.9	0.6
Cadmium	0.01	0.04	0.005
Chromium	0.05[b]	1.0	0.1
Cobalt	a	a	a
Copper	a	a	a
Fluoride	a	a	a
Iron	a	a	a
Lead	0.05	a	0.015
Manganese	a	a	a
Mercury	0.002	a	a
Molybdenum	0.1[b]	0.08[b]	0.04[b]
Nickel	a	1.0	0.1
Nitrate	44[c]	44[d]	a
Selenium	0.01[b]	a	a
Silver	0.05	0.2	0.1
Strontium	a	25	17
Sulfate	a	a	a
Thallium	a	0.007	0.0004
Vanadium	a	0.08	0.02[a]
Zinc	a	6.0	2
Radionuclide			
Lead-210	a	a	a
Polonium-210	a	a	a
Radium-226/-228	5 pCi/L	a	a
Thorium-230	a	a	a
Uranium (U-234/-238)	30 pCi/L[b] (0.044 mg/L)	0.03	0.1

[a] Standard or guidance not available.
[b] Exceeded in plume wells.
[c] Equal 10 mg/L nitrate as nitrogen.
[d] Proposed values under review; expected revision 1995.

Table 8.2 Maximum concentration limits of constituents, UC site, near Slick Rock, Colorado

Constituent	UMTRCA MCL (mg/L)	Health advisories 10-kg child, 10-day (mg/L)	Health advisories 70-kg adult, lifetime (mg/L)
Chemical (inorganic)			
Antimony	a	0.015	0.003[b]
Arsenic	0.05	a	a
Barium	1.0	a	2
Boron	a	0.9	0.6
Cadmium	0.01[b]	0.04[b]	0.005[b]
Chromium	0.05[b]	1.0	0.1
Cobalt	a	a	a
Copper	a	a	a
Fluoride	a	a	a
Iron	a	a	a
Lead	0.05	a	0.015
Manganese	a	a	a
Mercury	0.002	a	a
Molybdenum	0.1[b]	0.08[b]	0.04[b]
Nickel	a	1.0	0.1
Nitrate	44[b,c]	44[b,d]	a
Selenium	0.01[b]	a	a
Silver	0.05	0.2	0.1
Strontium	a	25	17
Sulfate	a	a	a
Thallium	a	0.007	0.0004
Vanadium	a	0.08[b]	0.02[b]
Zinc	a	6.0	2
Radionuclide			
Lead-210	a	a	a
Polonium-210	a	a	a
Radium-226/-228	5 pCi/L	a	a
Thorium-230	a	a	a
Uranium (U-234/-238)	30 pCi/L[b] (0.044 mg/L)	0.03	0.1

[a] Standard or guidance not available.
[b] Exceeded in plume wells.
[c] Equal 10 mg/L nitrate as nitrogen.
[d] Proposed values under review; expected revision 1995.

Note: Chemical concentrations are reported in milligrams per liter. Radionuclide concentrations are reported in picocuries per liter.

for a permit to construct a new well. Designated basins are isolated hydrogeologic areas where ground water use is stringently evaluated, based on the demands for water rights. The state engineer is required to act on applications for new well permits within 45 days after receipt. If a well would affect existing water rights or if an applicant wants to establish a legal right, adjudication would likely be required before the permit is granted.

8.4.2 Ground water quality

The Colorado Department of Public Health and Environment (CDPHE) is the state agency responsible for setting water quality standards. Within the CDPHE, the State Water Quality Control Commission is responsible for adopting the water quality standards and classifications for state waters in Colorado.

The state of Colorado proposed ground water quality standards require ground water to be free of substances in concentrations shown to be "carcinogenic, mutagenic, teratogenic or toxic to human beings and/or a danger to public health, safety, or welfare" (CDH, 1990).

The state engineer is authorized to enforce the state water quality standards. However, the state engineer cannot deny a permit for drilling a new well based on water quality because private domestic well water quality is not regulated by the state. The state engineer can issue a warning to well users if the well is placed in an aquifer known to be contaminated. A well that will serve 25 or more people must meet state water quality standards and use can be restricted by the CDPHE, Water Quality Control Division, Drinking Water Section.

8.4.3 Land restrictions

The community of Slick Rock is not incorporated. Therefore, land use restrictions are implemented by San Miguel County. The area in the vicinity of the processing site is zoned for agriculture/forestry uses. Zoning restrictions require a minimum of 35 ac (14 ha) per residence for new development. The San Miguel County planning department maintains a permitting process for new land development. The county also requires a permit for land use within 100 ft (30 m) of the Dolores River.

8.5 FUTURE SITE ACTIVITIES AND RECOMMENDATIONS

The proposed ground water standards (MCLs) are sufficient to protect human health at the Slick Rock sites for those applicable contaminants. However, a risk assessment may identify site-specific factors that suggest these standards are too restrictive (e.g., ground water is not used as a drinking water source). When standards are too restrictive, and there is no potential for exposure, a less restrictive alternate concentration limit (ACL) may be sought. In other cases, the standards may not be sufficiently protective (e.g., if many contaminant concentrations are near the MCL and have additive or synergistic adverse health effects and the water is used as a drinking water source).

At the Slick Rock sites, because there is no permanent physical barrier to prevent access to contaminated ground water at the former processing sites, ACLs are probably not justified for those constituents with MCLs. For constituents that do not have MCLs, background concentrations would be used in future ground water compliance strategies. However, background samples that would be defined as appropriate (i.e., in an area not influenced by site activities) for use in a baseline risk assessment were not available for these sites. Establishing background concentrations is recommended so ACLs could be established for contaminants such as vanadium, cadmium, and strontium; these contaminants were shown to be at concentrations below appreciable adverse health effect levels. In addition, background water quality should be established to ensure this baseline risk assessment did not inadvertently overestimate risks from the contaminants of potential concern in contaminated ground water at the NC and UC sites.

The site characterization activities conducted to date at the former Slick Rock processing sites were intended to provide sufficient preliminary site characterization information to design and implement a proposed surface remediation plan for relocating the RRM to the Burro Canyon disposal site. The results of the hydrogeologic testing are estimated values and do not conclusively characterize hydrogeologic conditions at the Slick Rock sites. Additional and more detailed site characterization activities will be needed during the ground water compliance phase of the UMTRA Project to more fully characterize the former processing sites. These site characterization activities may include additional aquifer performance testing, installing and sampling additional monitor wells, and installing surface water level recorders and staff gauges in the Dolores River. Additionally, data should be collected to better characterize the interactions between surface water, sediment, and ground water movement (horizontal and vertical) between the hydrostratigraphic units (Dolores River, alluvium, Entrada Formation, and Navajo Sandstone) in the vicinity of the sites.

The evaluation of surface water analytical data in the vicinity of the Slick Rock sites indicates the former milling activities have not adversely impacted the water quality of the Dolores River. However, the types of analyses and the sample collection times were not consistent, indicating additional surface water sampling may be needed to characterize any potential adverse human health effects and to further characterize the ecological environment.

Evaluation of the sediment analytical data indicate cadmium, molybdenum, selenium, vanadium, and uranium exceeded background concentrations. However, this evaluation is based on a limited analytical data set. Therefore, additional sediment sampling may be needed to characterize the sediment and to evaluate potential adverse human health effects, if any, and to further evaluate the ecological environment. Fish tissue and invertebrate analyses are recommended only after surface water and sediments are fully characterized and only if these media are impacted by site-related contamination.

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