1.0 MAJOR STUDIES SUPPORTING THIS SCOPING RISK ANALYSIS

The most important period of past U.S. uranium production spanned from approximately 1948 to the early 1980s (U.S. DOE/EIA 1992). Through 2005 the industry had generated over 420,000 metric tons (MTs) of uranium for nuclear weapons and commercial power plants (U.S. DOE/EIA 2003a, 2003b, 2006). Uranium exploration, mining, and ore processing left a legacy of unreclaimed land workings wherever the uranium concentration in rock was either found or thought to be economically viable. This report investigates some potential health, geographic, and environmental issues of abandoned uranium mines.

The major studies supporting this scoping analysis include EPA's 1983 *Report to Congress on the Potential Health and Environmental Hazards of Uranium Mine Wastes* (U.S. EPA 1983a, b, c) and EPA's risk assessments for underground and surface uranium mines for Clean Air Act requirements (U.S. EPA 1989a). Other analyses considered include a report of two uranium mines on the Superfund National Priorities List (U.S. EPA 2001b) and a U.S. Department of Energy report (U.S. DOE/EIA 2000). These studies are discussed in this chapter.

1.1 1983 EPA Report to Congress

The Uranium Mill Tailings Radiation Control Act of 1978 directed EPA to conduct a study on "the location and potential health, safety and environmental hazards of uranium mine wastes," and to provide "recommendations, if any, for a program to eliminate these hazards." When EPA published its 1983 Report to Congress (U.S. EPA 1983a, b, c) (hereafter referred as the 1983 EPA report or study), there were about 340 active uranium mines in the United States. At the end of 2002, there were no active conventional uranium mining operations in the United States, and only two active operations using the *in situ* leaching process (U.S. DOE/EIA 2003a). However, with an increase in the price of uranium since 2004, additional conventional mines have begun production or will be coming on line in the near future, and some suspended mine operations have recommenced. As part of the 1983 study, EPA also made observations at a number of active and inactive uranium mine sites, collected soil and water samples, and took some external gamma and radon flux measurements at sites in Colorado, New Mexico, Texas, and Wyoming.

1.1.1 Sources and Pathways Modeled

In the 1983 report, EPA used the information discussed above to develop models for large and small mines, including an inactive surface mine hypothetically located in Wyoming and an inactive underground mine hypothetically located in New Mexico (U.S. EPA 1983b). From these model mines, which were classified as an average mine or a large mine, EPA estimated the health effects to populations within 50 miles (80 km) of each mine and on a hypothetical most exposed individual living about 1 mile from the center of a mine. The pathways considered were as follows:

- Breathing air containing windblown dust and radon decay products
- Drinking water containing uranium and its decay products

- Eating food contaminated by either air or water
- Living in homes on land covered by mine wastes (U.S. EPA 1983b)

With the exception of the last pathway, the focus of the report was on estimating risks to people who were off site. The home pathway was not explicitly modeled like the other pathways, but used estimates of indoor radon as a function of radium in the soil. While the 1983 report produced many analyses, some issues were not explicitly addressed, including the following:

- Drinking groundwater and surface water near a mine. This pathway was considered and included for the regional population, but was not included for the most exposed individual due to lack of information on radionuclides in potable water.
- Individuals spending time on mine sites.
- Using mine waste material for buildings.

In its 1983 Report to Congress, EPA identified the sources modeled and those considered, but not modeled, due to a lack of information (Table 1.1). For groundwater, the report noted that uranium mines may pose a problem, but the authors did not have enough information to consider it. The report also noted that spending time at the mine sites and using waste materials in the buildings would be a health hazard, but did not quantitatively address the issues.

Table 1-1. Sources of Contamination at Uranium Mines

In its 1983 Report to Congress, EPA identified the sources modeled (M) and those considered (C), but not modeled, due to a lack of information.

Sources of Contamination	**Underground Mines**		**Surface Mines**	
	Active	**Inactive**	**Active**	**Inactive**
Waste Rock (Overburden) Pile				
Wind-suspended dust	M	M	M	M
Radon-222 emanation	M	M	M	M
Precipitation runoff	C	C	C	C
Sub-Ore Pile				
Wind-suspended dust	M	M	M	M
Radon-222 emanation	M	M	M	M
Precipitation runoff	C	C	C	C
Ore Stockpile				
Wind-suspended dust	M	M	M	M
Radon-222 emanation	M	M	M	M
Precipitation runoff	C	C	C	C
Abandoned Mine Area Surfaces				
Radon-222 emanation	M	M	M	M
Mining Activities				
Dusts	M	NA	M	NA
Combustion products	M	NA	M	NA
Radon-222	M	NA	M	NA
Wastewater				
Surface discharge	M	NA	M	NA
Seepage	C	C	C	C

Note: NA = not applicable.
Source: USEPA 1983b, Table 2.

1.1.2 1983 EPA Study Findings

Using the risk methodology of the time (AIRDOS-EPA, DARTAB, and RADRISK), the study estimated that a large active underground mine posed an increased chance of a fatal lung cancer to an individual of 2×10^{-3}, primarily from breathing radon decay products, and that risks from other types of uranium mines were somewhat lower. Releases to surface water from an average underground mine one mile from an individual's home were estimated to increase his or her lifetime cancer risk by 1×10^{-3}, and that one additional cancer in several hundred years might occur in nearby populations from the normal operational releases from a mine. Although the study did not address the health effects of contaminated shallow aquifers around active or inactive mines, it recommended that they be evaluated.

For inactive mines, the study noted that radionuclide airborne emissions were smaller than for active mines, with the risks coming from radon emanating from unsealed mine vents, portals, and residual waste piles. The estimates of risks from radon emissions from inactive uranium mines were as follows:

- Individuals living for a lifetime 1 mile (1.6 km) from an inactive mine would have an increased chance of lung cancer of about $2\text{–}3 \times 10^{-5}$.
- The amount of radon-222 released each year from all inactive uranium mine sites would (cumulatively) cause about 0.1 lung cancer~~s~~ fatalities in the lifetime of the regional population living within 50 miles (80 km) of these sites.

The study found insignificant concentrations of hazardous air emissions at inactive sites and thus concluded that their health impacts would be insignificant as well. Although the study acknowledged the potential for hazards from buildings that use uranium mine wastes as construction material, it did not formally analyze the hazard. However, it did mention that building on contaminated land could increase indoor radon concentration and, thus, increase the risk of lung cancer in the residents (U.S. EPA 1983b). The study referenced an earlier study (out of print) jointly conducted by EPA and the Atomic Energy Commission in 1972, that identified about 500 buildings in several western states that exhibited anomalous gamma radiation readings that appeared to be associated with uranium mine wastes. This is further discussed in Chapter 4 of this volume. Tables 1.2 and 1.3 present the specific lifetime cancer risk estimates due to radioactive airborne emissions for one year of exposure and over a lifetime of exposure.

Table 1-2. Estimated Lifetime Fatal Cancer Risks from 1 Year of Exposure to Airborne Uranium Mine Emissions

The cancer risk from inactive uranium mine radon emissions are generally low for 1 year of exposure.

Source of Exposure	Risk to Maximum Exposed Individual[a]	Risk to Average Exposed Individual[b]	Collective Risk to Regional Population
Inactive surface mines—total	4.7×10^{-7}	8.9×10^{-10}	1.3×10^{-5}
Particulates and Radon-222	5.5×10^{-8}	6.4×10^{-11}	9.1×10^{-7}
Radon-222 daughters	4.2×10^{-7}	8.3×10^{-10}	1.2×10^{-5}
Inactive underground mines—total	2.8×10^{-7}	1.2×10^{-9}	4.5×10^{-5}
Particulates and Radon-222	1.5×10^{-8}	2.0×10^{-11}	7.4×10^{-7}
Radon-222 daughters	2.7×10^{-7}	1.2×10^{-9}	4.4×10^{-5}

a An individual living within 1 mile (1.6 km) downwind from the mine.

b The average individual in the regional population within a 50-mile (80-km) radius of the model mine.

Source: U.S. EPA 1983b, Table 6.11.

Table 1-3. Estimated Lifetime Fatal Cancer Risks from Lifetime Exposure to Airborne Uranium Mine Emissions

The risk to the average person from uranium mine emissions is low. While the risk to the maximally exposed individual is significantly larger, it is still within the Superfund 10^{-4} – 10^{-6} *risk range.*

Source of Exposure	Maximum Exposed Individual[a]	Average Exposed Individual[b]
Inactive surface mines—total	3.4×10^{-5}	6.3×10^{-8}
Particulates and Radon-222	3.9×10^{-6}	4.5×10^{-9}
Radon-222 daughters	3.0×10^{-5}	5.9×10^{-8}
Inactive underground mines—total	2.0×10^{-5}	8.6×10^{-8}
Particulates and Radon-222	1.1×10^{-6}	1.4×10^{-9}
Radon-222 daughters	1.9×10^{-5}	8.5×10^{-8}

a An individual living 1 mile (1.6 km) downwind from the mine.

b The average individual in the regional population within a 50-mile (80-km) radius of the model mine.

Source: U.S. EPA 1983b, Table 6.12.

1.1.3 Applicability of 1983 Risk Estimates

According to Table 6.17 of the 1983 EPA report (U.S. EPA 1983b), radon decay products account for 88 percent or more of the fatal cancer risk due to emissions of radioactive particles from inactive surface and underground mines. Risk estimates given for radon decay product releases from these two types of mines in Tables 6.11 and 6.12 of the report are consistent with the methodology used by EPA prior to 1988. At that time, 4.6×10^{-4} cancers were projected per working-level month (WLM)[1] of exposure. An analysis of results from the recent BEIR VI report (NAS 1999b, U.S. EPA 2003a) on risks from exposure to radon suggests that the risk factor should be 5.38×10^{-4} per WLM.

Table 1.4 reproduces the working-level estimates of the model inactive surface mines and model inactive underground mines which are provided in Table 6.3 of the 1983 EPA report. The values in Table 1.5 are based on the working-level estimates in Table 1.4. Table 1.5 presents recalculated risks from 1-year, 30-year, and lifetime exposures to radon decay product emissions using the higher, current risk factor. The table does not account for exposures for the portion of time spent outdoors, and for lifetime exposures it assumes an average life span of 75.4 years, which is slightly longer than the 71-year life span used in the 1983 EPA report. The formulas used to derive the results in Table 1.5 are as follows:

R_1 = Lifetime risk for 1-year exposure at 1 WL = 51.56 WLM/WL-y $\times 5.38 \times 10^{-4}$ WLM$^{-1} \times 1$ year;

- The risk for 30-year exposure at 1 WL = $R_1 \times 30$ years= 0.83
- The risk for lifetime exposure at 1 WL = $R_1 \times 75.4$ years = 2.09

Thus, the 1-year exposure risk estimate from radon decay products for the maximally exposed individual at an inactive surface mine using the 1.8×10^{-5} WL estimate from the model mine in Table 1.4 would be:

$$R_1 = 1.8 \times 10^{-5} \text{ WL} * 51.56 \text{ WLM/WL-y} \times 5.38 \times 10^{-4} \text{ WLM}^{-1} \times 1 \text{ year} = 4.99 * 10^{-7} \cong 5.0 \times 10^{-7}$$

Risks using this updated estimate and presented in Table 1.5 are about 17 percent higher than in the 1983 report, reflecting the increased risk per working level. One limitation relating to this conclusion is that no adjustment was made in the calculations for differences in the distribution of activity-weighted particle size for indoor and outdoor radon exposures.

Table 1-4. Annual Exposure from Radon Decay Product Emissions from Model Uranium Mines

Source of Exposure	Average Radon Daughter Concentration (Working Levels)*	
	Maximum Exposed Individual [a]	Average Exposed Individual [b]
Inactive surface mine	1.8×10^{-5}	3.5×10^{-8}
Inactive underground mine	1.1×10^{-5}	5.1×10^{-8}

* A Working Level is defined in footnote 1 of this chapter.
a An individual living 1 mile (1.6 km) downwind from the mine.
b The average individual in the regional population within a 50-mile (80-km) radius of the model mine.
Source: U.S. EPA 1983b, Table 6.3.

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[1] The working level (WL) is defined as any combination of short-lived radon decay products (through polonium 214) per liter of air that will result in the potential emission of 1.3×10^5 MeV of alpha energy. A person exposed to one WL for 170 hours is said to have acquired an exposure of one working-level month (WLM) (Shapiro 1990). This 170-hour value is based on the typical number of hours underground miners worked in 1 month.

Table 1-5. Estimated Individual Lifetime Fatal Cancer Risks for Various Exposures to Radon Decay Products

With the modification for the current risk methodology, the lifetime fatal cancer risk from radon decay products is still within or below the Superfund $10^{-4} – 10^{-6}$ risk range. (See the discussion for additional background of the risk estimates.)

Source of Exposure	**Exposure Duration**	**Lifetime Risk of Fatal Cancer**	
		Maximum Exposed Individual [a]	**Average Exposed Individual** [b]
Inactive surface mine	1 year	5.0×10^{-7}	9.7×10^{-10}
	30 years	1.5×10^{-5}	2.9×10^{-8}
	75.4 years (lifetime)	3.8×10^{-5}	7.3×10^{-8}
Inactive underground mine	1 year	3.1×10^{-7}	1.4×10^{-9}
	30 years	9.2×10^{-5}	4.3×10^{-8}
	75.4 years (lifetime)	2.3×10^{-5}	1.1×10^{-7}

[a] An individual living 1 mile (1.6 km) downwind from the mine.

[b] The average individual in the regional population within a 50-mile (80-km) radius of the model mine.

Source: U.S. EPA 1983b, Table 6.17.

1.2 1989 EPA Study in Support of NESHAPs

In 1989, EPA conducted risk assessments for active underground uranium mines and surface uranium mines (U.S. EPA 1989a), in support of the National Emission Standards for Hazardous Air Pollutants (NESHAPs) for Radionuclides (U.S. EPA 1989b, c). While some of the information in this investigation was based upon U.S. EPA 1983 (a, b, c), the study also included some new field work and analysis. The study found that of all the radionuclides emitted, radon decay products posed the greatest cancer risk. The maximum exposures from underground mines would create lifetime individual fatal cancer risks of greater than 1×10^{-4}, with a maximum of 4×10^{-3}. The maximum individual risk of fatal cancer from radon decay products at surface uranium mines was estimated to be 5×10^{-5}; this risk estimate, too, would be slightly higher, given the current methodology. The 1989 study found that only a limited number of people lived within several hundred feet of the mines and would have been exposed to the maximum levels; most of the nearest residents lived several miles from the mines.

1.3 Uranium Mines on the National Priorities List

Although several uranium mill tailings sites are on the Superfund National Priorities List (NPL), only two uranium mines are on the list: Midnite Mine, near Wellpinit, Washington, and the Fremont National Forest—White King/Lucky Lass Mines, Oregon. Both sites have progressed far enough in the Superfund process to have had a cleanup remedy selected in a Record of Decision (U.S. EPA 2001b, U.S. EPA 2006c). Figures 1.1 and 1.2 are aerial images of Midnite Mine and the White King/Lucky Lass Mine sites, respectively.

Figure 1-1. Aerial Image of Midnite Mine, Washington State

Midnite Mine is on the NPL. The site has uranium and other heavy metal contamination in the disturbed area and two pit lakes.

Source: Photo courtesy of EPA Region 10 Superfund Program.

No one is currently living at the White King/Lucky Lass site, nor is a future resident anticipated, given that the site is on U.S. Forest Service property and is not near population centers. However, the risk assessment did assume a future resident as a scenario. In addition, the receptors evaluated included a site worker (e.g., timber or U.S. Forest Service employees) and a recreational user. The following areas were used as exposure points (U.S. EPA 2001b):

- The protore stockpile at the White King Mine
- The overburden stockpile at the White King and Lucky Lass mines
- Off-pile areas at the White King and Lucky Lass mines

The primary chemicals of concern at the White King/Lucky Lass site were arsenic in soil and shallow groundwater, uranium-234/238 in stockpile groundwaters, radium-226/228 in soil and shallow bedrock wells, and radon in water. Of note, and in spite of several high radon flux rates, inhalation of radon in ambient air was not an issue, since radon concentrations from the stockpiles were equivalent to background concentrations.

Figure 1-2. Aerial Image of White King and Lucky Lass Mines, Oregon

The Lucky King Mine pit lake is approximately 5,000 feet (1,500 meters) northwest (left) of the White King Mine pit lake.

Table 1.6 summarizes the risks at the mine sites for the human receptors. With the approach used in the Record of Decision, the exposure assessment indicated an extremely high risk to future potential residents and child recreational users. The high risks were primarily due to ingestion of arsenic in soils and shallow groundwater and external radiation from radium. In the ecological assessment, no adverse effects were seen from the radionuclides. However, some potential adverse ecological effects were identified due to arsenic, selenium, antimony, lead, and mercury in surface and subsurface soils at the White King Mine. At Lucky Lass, only slightly elevated risks (the noncarcinogen chemical hazard index ranging from 1 to 3) were predicted for the vagrant shrew and terrestrial plants exposed to arsenic and silver in surface soil. In contrast, Midnite Mine has a greater potential for future use, but the cancer risks were predicted to equal 8×10^{-1} for a resident of the affected area and 2×10^{-3} for recreational visitors.

Table 1-6. Potential Cancer Risks from the White King/Lucky Lass and Midnite Mine Sites

The combination of arsenic and radium produces very high cancer risks to potential on-site residents.

Receptor	Total Cancer Risk	Pathway	Notes
White King Mine current adult worker	6×10^{-5}	Ingestion of arsenic in soil and exposure to external radiation from radium-226/228 in the top 6 inches of soil.	Current exposure estimates for soil are based on 0–6 inches; future exposure estimates for soil are based on 0 - 6 feet.
Future recreational user (child) at the White King Mine	4×10^{-4}	Arsenic in soil, exposure to external radiation from radium-226/228 in soil and ingestion of arsenic in Augur Creek and White King groundwater. Ingestion of arsenic in soil and exposure to external radiation from radium-226/228 in the top 6 feet of soil, ingestion of arsenic in shallow bedrock groundwater, inhalation of radon in shallow bedrock groundwater, and exposure to arsenic in White King pond surface water and sediment.	Deep bedrock water contains high levels of naturally occurring arsenic, radon, and minerals that would preclude its use as drinking water.
Potential future resident (adult) at the White King Mine	3×10^{-1}		
Potential future resident (child) at the White King Mine	2×10^{-1} Hazard Index values for noncarcinogenic effects to current and potential future child recreational users were 4 and 11, respectively, and higher for potential future residents from ingestion of arsenic and manganese in shallow bedrock groundwater and ingestion of arsenic in soil.		
Potential future resident at the Lucky Lass Mine	1×10^{-3}		
Potential future resident at the Midnite Mine Area	1		

Note: A Hazard Index value below 1 indicates no adverse health effects are expected as a result of exposure.
Source: U.S. EPA 2001b.

1.4 DOE Report on Costs of U.S. Uranium Mine Environmental Restoration

A report commissioned by the U.S. Department of Energy (DOE) found that a number of uranium mines are undergoing or have completed remediation (U.S. DOE/EIA 2000). According to the report, 21 mines, primarily in Wyoming and Texas, were selected for analysis for one or more of the following reasons: (1) substantial output of uranium concentrates, (2) major impact on the environment, and (3) significant costs required for remediation. While the report does not specify whether these sites are undergoing risk assessments, it does specify whether a particular site has an exposure pathway of surface water, groundwater, or windblown particulates. The information lists groundwater as an exposure pathway for many of the mines, while the surface water and windblown particulate pathways are not as prevalent.