4.0 RISK FROM URANIUM MINING WASTE IN BUILDING MATERIALS

In general, building materials contain low levels of radioactivity. For example, the range of natural uranium concentrations may average as low as about 0.5 ppm (0.34 pCi/g or 13 Bq/kg) total uranium activity in sandstone building materials to as high as 5 ppm (3.4 pCi/g or 130 Bq/kg) in granitic building materials. Concrete and brick buildings are estimated to contribute an average of about 10 mrem (0.1 mSv) annual effective dose equivalent (NCRP 1987) to the average person's background exposure to radiation. However, exceptions can occur to this generalization, especially in buildings constructed with materials containing uranium TENORM mine wastes. In the Grand Junction, Colorado area, thousands of homes and properties were constructed using uranium mill tailings (U.S. EPA 1983a, b, c) in the past as a source of construction sand, gravel, and clays. However, a number of homes have also been built with materials that have been attributed to "uranium ore" that are not considered to be mill tailings. In a 1972 EPA and Atomic Energy Commission (AEC) survey intended to locate building materials contaminated with mill tailings, 537 buildings were identified where uranium ore may have been the source of gamma-ray exposure anomalies (U.S. EPA 1983b):

> *We do not know to what extent the wastes from uranium mines have been removed from mining sites and used in local and nearby communities. However, while surveying in 1972 for locations with higher-than-normal gamma radiation in the Western States to locate uranium mill tailings used in local communities, EPA and AEC identified more than 500 locations where "uranium ore" was believed to be the source of the elevated gamma radiation. The specific type of ore (mill-grade, sub-ore, low-grade waste rock) was not determined as this was beyond the scope of the survey. At some locations, however, surveyors attempted to characterize the ore by using such terms as "ore spillage," "ore specimens," "low-grade crushed ore," or "mine waste dump material." Some locations were identified as sites of former ore-buying stations* [U.S. EPA 1973].

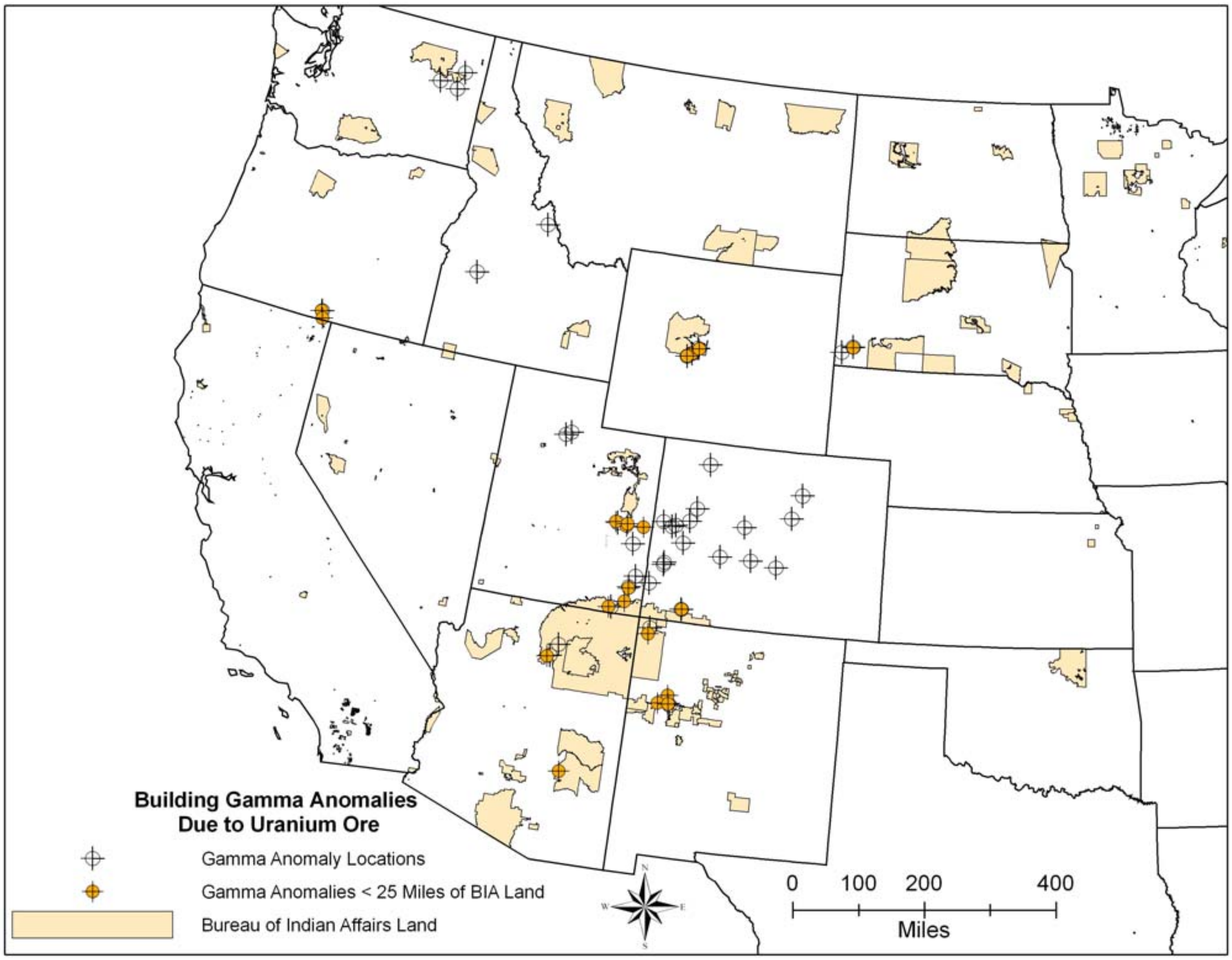
Since it is unlikely that valuable mill-grade ore would have been widely available for off-site use, we suspect that uranium mine waste (perhaps protore) may be the source of the elevated gamma radiation levels at many of the locations where large quantities of ore material are present.

About three-fourths of the 537 buildings were in Colorado and Utah, with the rest distributed among several other states. Figure 4.1 identifies the localities from the 1972 survey that had at least one building thought to have used "uranium ore" construction materials. Many of these same localities also had additional anomalies attributed to either a radioactive source or natural radioactivity. The original report that discusses the survey is unavailable, so it is not possible at this time to determine the basis used for the attribution of the cause. Of the 53 localities with at least one anomaly attributed to uranium ore, 20 are on or within approximately 25 miles (40 km) of Bureau of Indian Affairs (BIA) Reservations. Without knowing the design of the study, it is not possible to determine the statistical significance of the survey. Nevertheless, the survey does indicate the potential problem of contaminated buildings in uranium mining areas, especially on and around Tribal lands. EPA has provided support to Tribal authorities since that time to identify buildings on Tribal lands constructed with uranium mine wastes.

Contaminated buildings are among the mine waste issues that have been publicized regarding the Navajo Nation. Although not specifically addressed herein, anecdotal information is amenable to the methods and models for dose and risk estimates contained in this report. For mattresses placed directly on a contaminated slab (reported in the *Los Angeles Times* on November 19, 2006), a geometrical variation would be applied to the analysis that follows. (As an example involving other exposure pathways, for children who "dug caves in piles of mill tailings and played in the spent mines," variations in the recreational scenario of Chapter 3 would be applied.)

A specific case of the potential problem on Tribal lands is illustrated by hogans with elevated radioactivity found in the Monument Valley area of Utah. In April 2001, EPA razed and removed a building that had been used as a hogan (sacred home) by a Navajo family. As shown in the photograph in Figure 4.2, the hogan was a small, one-room round structure with a concrete slab for a floor and stucco walls, although the building originally had a dirt floor. Figure 4.3 is a picture of another house taken from the vantage point of uranium mine workings.

Figure 4-1. Locations of Building Gamma Anomalies Due to Uranium Ore from 1973 EPA-AEC Study



Source: U.S. EPA.

Short-term gamma-ray exposure rates and radon concentrations were measured prior to the demolition of the hogan (Sowder et al. 2001). Radiation exposures were between 370 µR/h and 600 µR/h. This is equivalent to doses in air of 325–525 µrad/h (~3–5 µGy/h). (Typical indoor background dose rates are in the range of 1.2–16 µrad/h [12–160 nGy/h]). Several stones in the hogan exhibited levels of 1,000 µR/hour on contact. Short-term indoor radon measurements using multiple methods averaged 50–90 pCi/L (1,850–3,300 Bq/m^3) under pseudo-closed conditions. Outdoor exposure rates as high as 75 µR /hour at 3.3 feet (1 m) from the structure were observed. Stones used in the exterior construction produced exposure rates of 500–1,000 µR/hour. Inspection of the floor after demolition revealed that uranium ore had been used as aggregate for the concrete. Apparently, the source of the sand and stones in the building material was a nearby uranium mine or outcrop adjacent to the mine (possibly the Skylight Mine). Other possibilities for the material include mine-waste material debris piles alongside roads, such as the one in Figure 4.4, which is on Navajo Nation land. Readily available construction materials, including clay, sand, gravel, cobbles, and boulders in above-ground piles, make them attractive for houses, stoves, chimneys, and barbecues, and for stucco, cement for log houses, driveways, walkways, and fill dirt.

Figure 4-2. Monument Valley Navajo Hogan

Monument Valley Navajo family hogan razed due to high gamma readings. Note the talus in back, much of which originated from Skylight Mine on top of the mesa directly above.

Photograph by Andrew Sowder (U.S. EPA)

Figure 4-3. Navajo Home in Proximity to Uranium Mine

This picture is another example of the proximity of some homes to uranium mines. A New Mexico mine, now reclaimed, lies in the foreground of the picture, while the house in the background was originally constructed with mine waste but has since be reconstructed to remove the contaminated material.

Photograph by Loren Setlow (U.S. EPA)

Figure 4-4. Uranium Mine Debris Pile

Debris pile of uranium mine wastes just off a road on Navajo Nation land.

Photograph by Andrew Sowder, (U.S. EPA)

4.1 Building Materials Analysis

Given that some homes incorporate uranium mine waste building material, the question arises as to the radium and uranium concentrations in these materials that would result in exposure levels of concern. To identify potential gamma and radon exposures over a range of uranium and radium concentrations from contaminated concrete used as building materials for the floor and each wall, we used the RESRAD-BUILD 3.21 computer code (Yu et al. 2001).

The building we used for our modeling was based on the concrete Monument Valley Navajo hogan. The building modeled had one room with a floor area of 16.4 × 16.4 feet or 269 ft^2 (5 × 5 m or 25 m^2). Each wall is assumed to be 8.2 feet (2.5 m) high, 16.4 feet (5 m) long, with an area of 134 ft^2 (12.5 m^2) (Figure 4.5). Occupancy is assumed to be 70 percent for 365 days a year (NAS 1999). Since the calculations were scoping in nature, we used the RESRAD-BUILD default parameters. We assumed that the floors and walls were made of concrete, the radium and uranium concentrations were equal, and the receptor was at a height of 3.28 feet (1 m). However, RESRAD-BUILD calculates the contribution of the floor and the wall, so that the contribution from each part can be separated. The calculations assume no contribution from the soil beneath the concrete floor. The concrete was assumed to be 6 inches (15 cm) thick, with a density of 2.4 g/cm^3. Results are presented in doses, which are calculated by RESRAD-BUILD.

4.1.1 Results of Building Materials Analysis

From the modeling conducted using RESRAD-BUILD, we calculated doses from external exposures to U-238 and Ra-226 in full secular equilibrium with their short-lived progenies.[1] These doses are listed in Tables 4.1 and 4.2 and are presented graphically in Figures 4.6 and 4.7.

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[1] This is somewhat different from the way uranium was characterized in the analyses presented in Chapter 3. In the latter case, all uranium isotopes were assumed to be present in proportion to their natural abundance, and all long-lived progenies except Ra-226 and its decay chain were included, whereas the analysis in this chapter addresses only U-238, the dominant isotope, and its short-lived progeny.

Figure 4-5. Navajo Hogan Building Model

This 3-D schematic of the Navajo hogan indicates the sources of exposure modeled, with the floor as source 1, and the walls as sources 2 - 5. The origin of the geometry is at the lower left-hand corner, where z represents the vertical extent of the room and x and y represent the lateral extent of the walls.

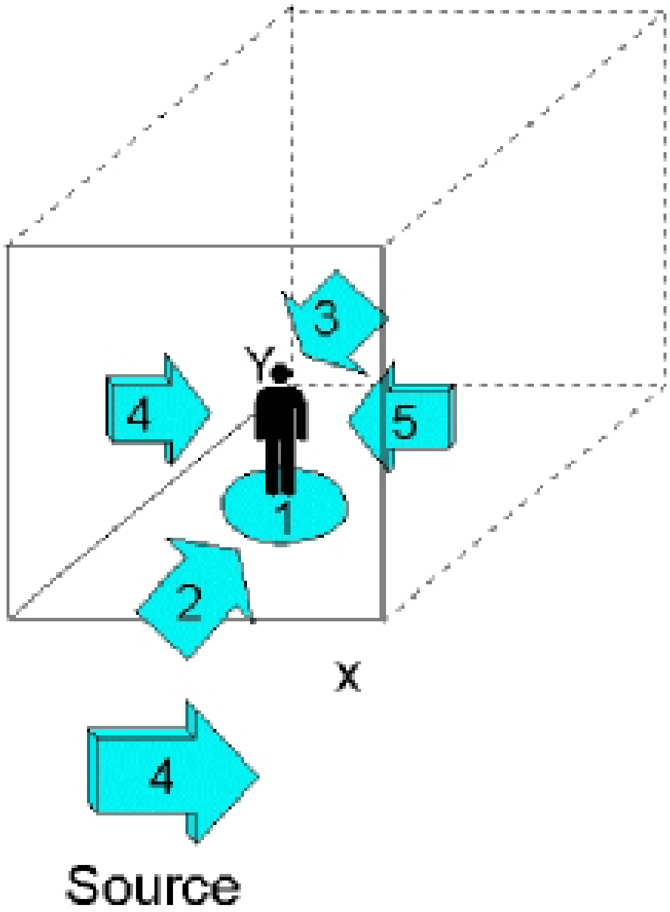


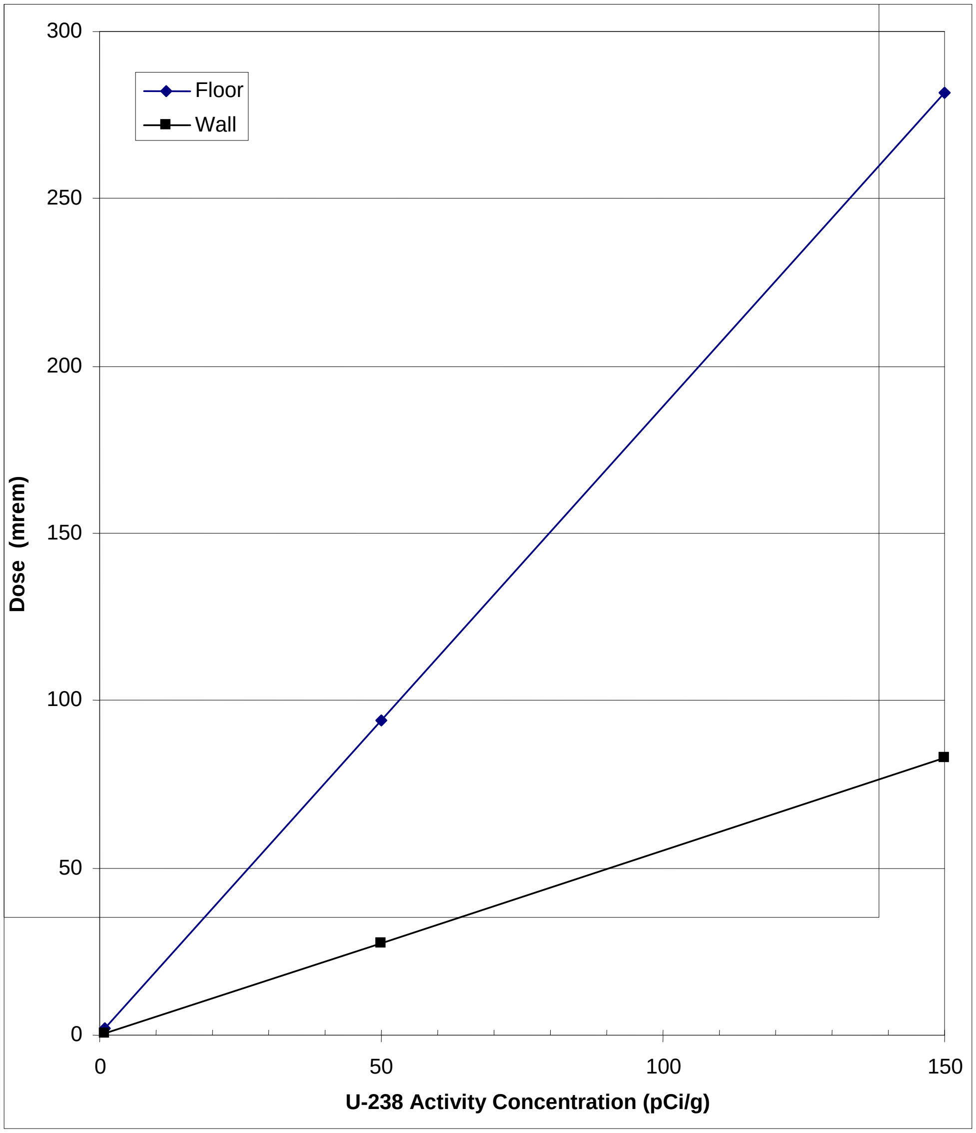
Table 4-1. Doses from 30 Years of External Exposure to U-238 in a Navajo Hogan

The dose from the floor is about equal to all of the walls combined.

Activity Concentration (pCi/g) (Bq/kg)	Dose from Floor (mrem) (mSv)	Dose from One Wall (mrem) (mSv)
1 (37)	1.88 (.02)	0.554 (.006)
50 (1850)	93.9 (.9)	27.7 (.3)
150 (5550)	282 (2.8)	83.1 (.8)

Figure 4-6. Doses from 30 Years of External Exposure to U-238 in a Navajo Hogan

The floor in the Navajo hogan contributed the most gamma exposure.



Doses are listed from external exposure to the floor and to a single wall to allow for an estimate of the dose if just a concrete slab is contaminated. The calculated dose from a single wall is between one-fourth and one-third the calculated dose from the floor. The total dose from the entire structure may be estimated by multiplying the dose from one wall by a factor of four and adding the result to the dose from the floor.

In order that the uranium in building materials could pose a significant risk from external exposure, the uranium concentrations in the building materials must be quite high relative to background concentrations. For example, for a dose of 300 mrem (3 mSv) from the uranium in the floor over a 30-year period, the U-238 activity would need to be about 180 pCi/g

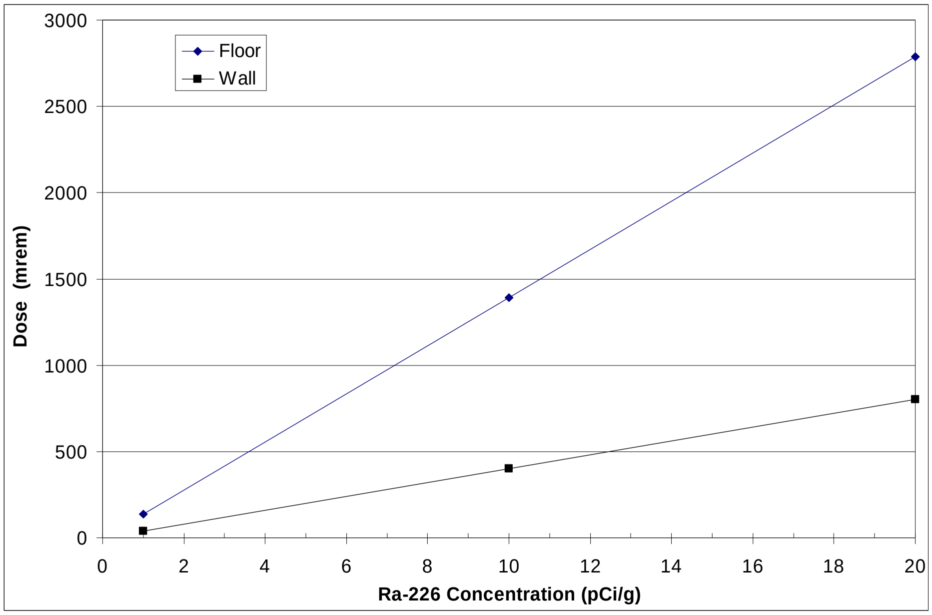
(6,660 Bq/kg or about 540 ppm). However, this level could be found in uranium overburden, and especially in protore.

Table 4-2. Doses from 30 years of External Exposure to Ra-226 in a Navajo Hogan

The dose from the floor is about equal to all of the walls combined.

Activity Concentration (pCi/g) (Bq/Kg)	Dose from Floor (mrem)(mSv)	Dose from One Wall (mrem)(mSv)
1 (37)	139 (1.4)	40 (.4)
10 (370)	1394 (14)	401 (4)
20 (740)	2787 (28)	801 (8)

Figure 4-7. Doses from 30 years of External Exposure to Ra-226 in a Navajo Hogan



Although U-238 would contribute to the overall radiation exposure, the Ra-226 in the mining waste materials is the more hazardous of the two radionuclides. A concentration of 1 pCi/g (37 Bq/kg) of Ra-226 in the floor is estimated to result in a dose of about 140 mrem (1.4 mSv) during 30 years of external exposure. According to the 1985 EPA report to Congress, most of the uranium mines sampled had Ra-226 concentrations of 20 pCi/g (740 Bq/kg) or more in the waste. If waste with this radium activity were incorporated into a concrete floor slab, it would result in a 30-year dose of about 2.8 rem (28 mSv). Figure 4.7 illustrates the relationship between Ra-226 concentrations and doses from external exposure calculated with RESRAD-BUILD.

The dose rate from the floor and four walls is approximately 50 µrem/h per pCi/g of Ra-226 (1.4×10^{-4} mSv/hr per Bq/kg). If the exposure rates measured in the Monument Valley Navajo hogan above were primarily from radium in the floor and walls, and the measurements were made in the center of the hogan, we estimate that the materials in the hogan contained up to about 10 pCi/g of Ra-226 (370 Bq/kg).

In addition to direct radiation exposure, radon generation from radioactive decay could also contribute to risk posed by living in buildings constructed with uranium mine waste, depending on frequency of air exchange and other factors. As mentioned above in the Sowder et al. (2001) study of the hogan in Monument Valley, Utah, short-term indoor radon measurements using multiple methods averaged 50–90 pCi/L (1,850–3,300 Bq/m3) under pseudo-closed conditions. This greatly exceeds EPA's radon action level of 4 pCi/L (U.S. EPA 2004). However, studies of other houses constructed with uranium mine waste on Navajo Lands found many had much lower concentrations of radon, which may have been the result of construction methods and chimneys which allowed inside air to quickly exit the buildings (L. Setlow, U.S.EPA, personal communication, 2007)

4.2 Risk of Exposure of On-site Residents to Uranium Mining Waste

As described in Volume 1, the overburden and protore are typically left as piles, and consist of poorly sorted materials ranging from clay-sized fractions to boulders. Thus, it is not likely that the material would have a building located on it unless it has been flattened by erosion, was accessible from a higher elevation, or had been disposed off a hillside to create a terrace. In populated areas, however, it could be possible for the material to be spread out and a home subsequently built upon the leveled material. This scenario is included here as an upper bound on the potential risks from uranium mines, but it is not a focus of this scoping analysis because there are already guidelines for the amount of radium that is acceptable for Superfund remediation actions (U.S. EPA 1997a) and in the standards at 40 CFR 192 promulgated by EPA under the Uranium Mill Tailings Radiation Control Act (UMTRCA).[2]

The results of a study in Florida (U.S. EPA 1979) developed a relationship between Ra-226 in soil and indoor working levels (WL). The 1983 EPA report to Congress (U.S. EPA 1983b) references this document and assumed a similar relationship for a home built on uranium mine waste material. These data indicate that a concentration of 1 pCi/g (37 Bq/Kg) of Ra-226 in soil produces an indoor concentration of 1 pCi/L (0.03 Bq/L) of Rn-222, which is equal to 0.004 WL, assuming an equilibrium factor of 0.4 (UNSCEAR 2000). Thus, a concentration of 5 pCi/g (185 Bq/kg) of Ra-226 in the soil would produce an indoor radon concentration that is above the current recommended action level of 4 pCi/L (148 Bq/m^3).

The lifetime risk from the indoor radon decay products using current risk estimates is included in Table 4.3, along with the original estimate from 1983. Since the 1983 report was published, numerous studies have concluded that indoor radon concentrations are influenced by a

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[2] EPA regulations at 40 CFR 192 include limitations for radium and radon at UMTRCA sites: The disposal areas must be designed to limit releases of radon-222 from uranium byproduct materials to the atmosphere so as not to exceed an average release rate of 20 pCi/m^2/s. This requirement, however, applies only to a portion of a disposal site that contains a concentration of radium-226 that, as a result of uranium byproduct material, exceeds the background level by more than 5 pCi/g (185 Bq/Kg) averaged over the first 15 cm below the surface, or more than 15 pCi/g (555 Bq/Kg), averaged over 15 cm thick layers more than 15 cm below the surface.

combination of factors, including foundation slab integrity and permeability, indoor and soil pressure differentials, and the soil radium concentration. Thus, it is difficult to predict the indoor radon concentration based on soil parameters. However, modeling can provide a general indication of the radium/radon relationship.

Table 4-3. Estimated Lifetime Risk of Fatal Lung Cancer from Living on Contaminated Land

This table assumes an average individual is inside the home 75 percent of the time for the 1983 estimate, and 70 percent occupancy for the 2006 estimate. Because the estimate of risk per working level has increased from that used in 1983, and it is greater than the decrease in occupancy, the estimated cancer risk is higher in 2006.

Rasium-226 in Soil (pCi/g) (Bq/Kg)	**Indoor Working Levels (WL)**	**Lifetime Risk of Fatal Lung Cancer**	
		1983	**2006***
5 (185)	0.02	0.025	0.029
10 (370)	0.04	0.050	0.059
20 (740)	0.08	0.100	0.117
30 (1110)	0.12	0.150	0.176

* The 2006 risk estimate is calculated using the equation presented in Chapter 1 of this volume, under the Applicability of 1983 Risk Estimates section.

Source: U.S. EPA 1983b.

Additional modeling was conducted using the RESRAD computer code, which embodies a one-dimensional multi-pathway model for residual radioactivity at sites (Yu et al. 2001). This code was chosen because of its applicability, widespread use, testing and review, and ease of use. Most of the RESRAD default values were chosen for this scoping analysis. For the Colorado Plateau on-site resident scenario, we initially assumed that consumption of groundwater was not an exposure pathway. We assumed a ventilation rate of 0.5/h, that the foundation was at the surface with no basement, and that 70 percent of the time was spent indoors and 30 percent outdoors. With these assumptions, the model predicted indoor radon and external exposure to direct penetrating radiation to be the major source of radiation exposure, with the indoor radon exposure higher than the external exposure. Most of the risk from living on contaminated materials is from the decay of indoor radon. When the ventilation rate is reduced to 0.25/h, the working levels increase (~0.031 WL for 5 pCi/g (185 Bq/Kg) radium). When we repeated the analysis with the drinking-water pathway included, using a value of ~82 feet (25 meters) for depth to the aquifer and conservative parameters, such as an evaporation coefficient of 0.5, and K_ds of 10 mL/g for uranium and radium, the indoor radon and external exposure pathways are still dominant. Pending any consideration of the food chain, which is of most potential importance for subsistence ranching and hunting, the risks from uranium are dwarfed by the risks posed by radium and radon.

Uranium mine wastes have the potential to create very high risks to an on-site resident, as indicated by this analysis and the analysis of the White King/Lucky Lass mine site. Ra-226 is the primary contributor to risk from the external exposure and indoor radon inhalation pathways. While the indoor radon concentrations and corresponding working levels resulting from a given concentration of Ra-226 depend on multiple factors, it is possible to estimate approximate relationships among these quantities.