Health Consultation

DURANGO DISCOVERY MUSEUM

Evaluation of a Former Plant Property for Future Use as a Children's Museum

Public Health Implications of Potential Outdoor Exposures to Radionuclides and Gamma Radiations from Uranium Tailings

LA PLATA COUNTY, COLORADO

Prepared by the
Colorado Department of Public Health and Environment

MARCH 9, 2010

Prepared under a Cooperative Agreement with the
U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Agency for Toxic Substances and Disease Registry
Division of Health Assessment and Consultation
Atlanta, Georgia 30333

Health Consultation: A Note of Explanation

A health consultation is a verbal or written response from ATSDR or ATSDR's Cooperative Agreement Partners to a specific request for information about health risks related to a specific site, a chemical release, or the presence of hazardous material. In order to prevent or mitigate exposures, a consultation may lead to specific actions, such as restricting use of or replacing water supplies; intensifying environmental sampling; restricting site access; or removing the contaminated material.

In addition, consultations may recommend additional public health actions, such as conducting health surveillance activities to evaluate exposure or trends in adverse health outcomes; conducting biological indicators of exposure studies to assess exposure; and providing health education for health care providers and community members. This concludes the health consultation process for this site, unless additional information is obtained by ATSDR or ATSDR's Cooperative Agreement Partner which, in the Agency's opinion, indicates a need to revise or append the conclusions previously issued.

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Foreword

The Colorado Department of Public Health and Environment's (CDPHE) Environmental Epidemiology Section has prepared this health consultation in cooperation with the Agency for Toxic Substances and Disease Registry (ATSDR). ATSDR is part of the US Department of Health and Human Services and is the principal federal public health agency responsible for the health issues related to hazardous waste. This health consultation was prepared in accordance with the methodologies and guidelines developed by ATSDR.

The purpose of this health consultation is to identify and prevent harmful health effects resulting from exposure to hazardous substances in the environment. Health consultations focus on health issues associated with specific exposures so that the state or local department of public health can respond quickly to requests from concerned citizens or agencies regarding health information on hazardous substances. The Colorado Cooperative Program for Environmental Health Assessments (CCPEHA) of the Environmental Epidemiology Section (EES) evaluates sampling data collected by our partners, determines whether exposures have occurred or could occur in the future, reports any potential harmful effects, and then recommends actions to protect public health. The findings in this report are relevant to conditions at the site during the time this health consultation was conducted and should not necessarily be relied upon if site conditions or land use changes in the future.

For additional information or questions regarding the contents of this health consultation or the Colorado Cooperative Program for Environmental Health Assessments, please contact the author of this document:

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Summary and Statement of Issues

INTRODUCTION

The Hazardous Materials and Waste Management Division of the Colorado Department of Public Health and Environment (CDPHE) requested assistance from the Colorado Cooperative Program for Environmental Health Assessments (CCPEHA) to evaluate the potential public health hazards at the Durango Discovery Museum site with respect to radiation emanating from the concrete retaining wall along US Highway 550 and from radioactive mine tailings that may be percolating out through drain holes along this retaining wall.

The Durango Power House is listed on the State and National Registers of Historic Places and is one of Colorado Preservation, Inc.'s Most Endangered Places. The Power House was constructed in late-1800s and was abandoned in the mid-1970s. The 6.1-acre parcel of property, which sits on the banks of the Animas River, was neglected until it was eventually acquired by the City of Durango; it is now known as the River City Hall and the Power Plant Property.

The Children's Museum of Durango, founded in 1994, has outgrown its 1,100 square foot attic facility. Needing space to serve older visitors and accommodate yearly growth, the Museum prepared a comprehensive business plan, which proposed converting the Power House and its site to an interactive science museum. In 2002, the Durango City Council passed a resolution supporting the rebirth of the Power House as the Durango Discovery Museum. The Museum is scheduled to open sometime in 2010.

Contaminated soils surrounding the power plant building and historic stack have been remediated; however, uranium mill tailings still exist on the site behind the concrete retaining wall along US Highway 550. Thus, the uranium tailings are emanating gamma radiations through the retaining wall. The drain holes in the concrete retaining wall have been packed with clean pea-gravel and drain caps with a drainage net installed in the drain hole to prevent further transport of the tailings materials. Nonetheless, the accidental removal of covers is always possible; as such, short-term exposures to radionuclides in the tailings may exist.

The historic Durango Power Plant property will be developed as a children's museum (Durango Discovery Museum) with outdoor recreational opportunities for children.

The main focus of this health consultation is on the evaluation of future shorter-term (1-year) outdoor exposures of museum child visitors and workers to the uranium tailings that may be percolating through drain holes along this retaining wall as a result of accidental removal of drain caps. Additionally, this health consultation considers the longer-term potential exposures of workers and shorter-term exposures of children to gamma radiation emanating from uranium mill tailings behind the concrete retaining wall along US Highway 550.

ATSDR and CCPEHA's top priority is to ensure the Durango Discovery Museum community has the best information possible to safeguard its health.

OVERVIEW

The conclusions reached by CCPEHA and ATSDR in the health consultation regarding exposure to gamma radiations and radionuclides at the Durango Discovery Museum site are made with two types of assumptions:

ASSUMPTION 1: the proposed barriers and covers are implemented as recommended in this health consultation.

ASSUMPTION 2: the proposed barriers and covers are not implemented as recommended in this health consultation. This assumption provides conservative, or worst-case, estimates of health risk. The findings of this evaluation would help guide risk management decision-making regarding the need for: (a) additional measures to reduce or prevent exposures; and (b) routine maintenance of already implemented measures for reducing exposures.

CONCLUSION BASED ON ASSUMPTION 1

CCPEHA and ATSDR have reached one important conclusion based on the first assumption that the proposed barriers and covers are implemented as recommended in this health consultation.

CONCLUSION 1

Assuming that the proposed barriers and covers are implemented as recommended in this health consultation, short- or long-term exposures to radionuclides in the tailings materials and gamma radiation at the Durango Discovery

Museum are not likely to harm the health of child visitors or on-site workers.

BASIS FOR DECISION

The reason for this conclusion is that the implementation and routine maintenance (i.e., annual inspections) of recommended control measures, will either eliminate exposures or reduce exposures to background levels.

NEXT STEPS

CDPHE managers should ensure through routine inspection of seep hole covers that exposures to radionuclides in soil are eliminated. In addition, CDPHE managers should consider taking gamma radiation readings in order to ensure that exposure to gamma radiations is reduced to background levels.

CONCLUSIONS BASED ON ASSUMPTION 2

CCPEHA and ATSDR have reached two important conclusions based on the second assumption that the proposed barriers and covers are <u>not</u> implemented as recommended at this site.

CONCLUSION 1

Assuming that the proposed barriers and covers are <u>not</u> implemented as recommended in this health consultation, short-term exposure (20 days or less in a year), to radionuclides in the tailings materials and gamma radiation at the Durango Discovery Museum is not likely to harm the health of child visitors. It is important to note here that exposures (for 20 days in a year) of neighborhood children to the tailings materials are unlikely to occur. Therefore, this conclusion is based on conservative exposure assumptions resulting in overestimation of risk.

BASIS FOR DECISION

The reason for this conclusion is that the available data indicate that the estimated amount of radionuclides and gamma radiations that could get into children's body while playing near the retaining wall is associated with a low increased risk of developing cancer and noncancer health effects.

NEXT STEPS

CDPHE managers must ensure that exposures to radionuclides and gamma radiation are prevented or reduced through implementation and routine maintenance of appropriate control measures.

CONCLUSION 2 **Assuming that the proposed barriers and covers are not implemented as recommended in this health consultation, exposure to radionuclides in the tailings materials for a longer period than three years (e.g., 4 years) could potentially harm the health of child visitors and on-site workers (for short and long exposure periods). It is important to note here that extended exposure to the tailings materials is unlikely to occur. Therefore, this conclusion is based on conservative exposure assumptions resulting in overestimation of risk.**

BASIS FOR DECISION The reason for this conclusion is that the available data indicate that the estimated amount of radionuclides and gamma radiations that could get into children's or worker's body while playing or working near the retaining wall is associated with a high increased risk of developing cancer.

NEXT STEPS CDPHE managers must ensure that exposure to radionuclides and gamma radiations is reduced or prevented through implementation and routine maintenance of appropriate control measures .

FOR MORE INFORMATION If you have concerns about your health, you should contact your health care provider. Please call Shannon Rossiter, MPH at 303-692-2617 for more information on the Durango Discovery Museum health consultation.

Background

Site Description and History

The Durango power plant site is located in the northwest quarter of Section 29 and the northeast quarter of Section 30, T.35N., R.9W., of the Durango West Quadrangle, LaPlata County, Colorado. The site is located in downtown Durango, along the east bank of the Animas River (Figure 1).

The Power Plant in Durango was constructed in between 1889 and 1893, and operated as a consistent power source for the surrounding areas until its closure in 1972 (Cultural Resource Planning, 2004). In 1983, the City of Durango purchased the 6.1-acre parcel of property from La Plata Electric and Colorado Ute Electric Association Inc. This parcel of property is now known as River City Hall and the Power Plant Property. In 1983, the historic Power Plant structure was also listed on the National Register of Historic Places for its architectural significance as a rare example of Mission style architecture in an industrial application. Despite its historical value, the plant suffered 25 years of deterioration as it sat abandoned and without a use. By 2000, momentum to tear the plant down was growing. In 2001, however, the Power Plant was listed on Colorado Preservation, Inc.'s Most Endangered Places list. In 2002, the City of Durango and the Children's Museum of Durango reached agreement on a plan to renovate the plant and build the Durango Discovery Museum.

The Durango Discovery Museum is envisioned as an important community-gathering place, serving regional residents and visitors to the area. The initial plan includes the rehabilitated historic Power House as the main exhibit hall, an outdoor public plaza adjacent to the Animas River, a carousel, outdoor recreation space, parking, and access improvements (Durango Discovery Museum, 2004). The Durango Discovery Museum is presently planning on opening sometime in 2010.

Historically, the powerhouse site contained several environmental concerns. While the power plant's operations contributed to the condition, the adjacent highway and a former gas station also contributed to the pollution on the site. The soil on the site contained visible remnants of the coal and slag from the plant's historic operations. In the initial Brownfield investigation, CDPHE found concentrations of various polynuclear aromatic hydrocarbons (PAHs) in shallow soils exceeding State cleanup standards (CDPHE, 2003). These compounds were probably present due to incomplete combustion in the Power House and possibly from wood treatment. These environmental concerns have been addressed through Brownfields remediation activities.

Sources of Contamination

Documentation shows that the uranium mill tailings were deposited immediately adjacent to this site, and under US Highway 550. The wall that divides the site and the highway is also built on top of uranium mine tailings. There are drainage holes on this concrete wall that have allowed residual uranium contamination to slowly percolate through so that the radioactive materials are now directly below these drainage holes and on Museum property (Figures 2 and 3). These tailings have also seeped through expansion cracks in the retaining wall.

CDPHE conducted a Targeted Brownfields Assessment screening in 2002. The screened locations with levels as high as 100 to 120 Microroentgens per hour (µR/h) were located along the concrete barrier wall that divides the site from US Highway 550. (CDPHE, 2003; Portage Environmental, 2005). In 2005, readings at some locations with pure tailings were as high as 2,000 µR/h. Each of these locations appeared to be less than 1 to 2 square feet in size, and was located directly beneath drain holes in the retaining wall. The tailings materials behind the retaining wall will always remain as a source of radiation emanating from the retaining wall along US 550. This immediate area is planned to be a miniature golf course for the Durango Discovery Museum for children.

Lastly, CDPHE found groundwater contamination with benzene and cis-1,2-dichloroethylene. A former gasoline station with a history of leaking underground storage tanks is probably the source of this plume of benzene. The source of the cis-1,2-dichloroethylene is unknown but appears to be following the Animas River in a predominantly parallel fashion. The city of Durango prohibits the drilling of private wells within the city limits. As such, the downtown area of Durango including the Durango Power Plant is served by municipal water (CDPHE, 2003). Therefore, groundwater contamination is not evaluated further in this health consultation since no one will be drinking the water.

Much remediation has taken place with contaminated soil and hot spots physically removed from the site. As discussed below, site remediation was focused on preventing future exposure to surface contaminants and to mitigate possible groundwater contamination.

Previous Remediation Activities under Brownfields

During the summer of 2005, approximately 30 cubic yards of radioactive contaminated soils were removed from the site. The site was re-screened and confirmed to have been cleaned up to a regional background level (20 µR/h). In the interim, the drain holes were packed with pea gravel, and drain caps installed to prevent further transport of the tailings materials (CDPHE, 2003, 2006). As already mentioned above, the tailings materials behind the retaining wall will always remain as a source of gamma radiation emanating from the retaining wall along US 550.

In late summer 2005, more than 1000 cubic yards of PAH-contaminated soils were excavated and removed. These soils were excavated to more than 12 feet depth interval at some locations (CDPHE, 2006).

Purpose

The Durango Power Plant property will be developed as a children's museum (Durango Discovery Museum) with outdoor recreational opportunities. The Hazardous Materials and Waste Management Division of the Colorado Department of Public Health and Environment (CDPHE) requested assistance from the Colorado Cooperative Program for Environmental Health Assessments (CCPEHA) to evaluate the potential public health hazards with respect to radiation emanating from the concrete retaining wall along US Highway 550 and from radioactive mine tailings that may be percolating out through drain holes along this retaining wall. The findings of this evaluation would help guide risk management decision-making regarding the need for: (1) reducing or preventing exposures; and (2) routine maintenance of already implemented measures for reducing exposures.

Site visit

Representatives from the Hazardous Materials and Waste management Division (HMWMD) of the CDPHE have visited the site of the Durango Discovery Museum on several occasions. These visits have confirmed that a fence with locked gates restricts access to the site. The site is zoned industrial/commercial. The closest residence is located immediately across the river to the west of the site. HMWMD personnel did not observe any physical hazards on the site.

Demographics

The demographic data listed herein is U.S. Census 2000 data describing the city of Durango. Durango is southwest Colorado's largest town, with a population of approximately 14,000 persons and nearly 45,000 persons in La Plata County. The population density within the city was 792.8/km² (2,052.4/mi²). The racial makeup of the city was 86.8% White, 0.5% African American, 5.5% Native American, 0.7% Asian, 0.1% Pacific Islander, 4.1% from other races, and 2.2% from two or more races.

Hispanic or Latino of any race were 10.3% of the population. The average household size was 2.23 and the average family size was 2.83. In the city, 16.6% of residents were under the age of 18 and 10.7% who were 65 years of age or older. The median age was 29 years. The median income for a household in the city was $34,892, and the median income for a family was $50,814. In the city, 17.2% of the population and 7.3% of families lived below the poverty line. (The United States Census Bureau, 2000 Census).

Discussion

Environmental Sampling and Data

As already mentioned above, the tailings materials behind the retaining wall will always remain as a source of gamma radiation emanating from the retaining wall along US 550. In addition, these tailings could continually percolate from behind the wall onto the Museum site. Both scenarios affect future potential exposures at the Museum site.

Data available for this assessment include samples of the tailings material taken by Portage Environmental, Inc, a contractor to CDPHE, in March 2005. Two samples of the tailings material were excavated and analyzed. One excavated sample was a mixture of tailings and soil, the other sample was pure tailings as determined by the CDPHE site manager. The results of the sampling analysis and summary statistics are presented in Tables 1a-b. CDPHE Laboratory and Radiation Services analyzed Radium-226 by the EPA 903.0 method, and thorium and uranium isotopes were analyzed by alpha spectrometry.

Other data available include measures of gamma radiation taken by CDPHE in July 2006 where scintillometer readings for gamma radiation ranged from background levels (15-20 µR/h) to 120 µR/h. There are four main expansion joints along the wall. Scintillometer readings were taken in line with these joints at distances that range from 0-20 feet away from the wall at ground level. Other readings were taken along the wall at 4-foot intervals. The readings along the wall were measured at ground level, 2, 4, and 6 feet high. The results of the sampling analysis and summary statistics are presented in Tables 2 and 3.

Exposure Evaluation

<u>Selection of Radionuclides of Potential Concern (ROPCs)</u>

CCPEHA compared the maximum level of each radionuclide in the pure tailings materials with conservative health based environmental guidelines (or comparison values) to select ROPCs for further evaluation of potential health effects. Exposures to contaminants below the environmental guidelines are not expected to result in adverse or harmful health effects. Yet, exceeding the comparison value (CV) does not necessarily mean that the contaminant poses a public health hazard. The amount of contaminant, duration and route of exposure, exposure probability, and the health status and lifestyle of the exposed individual are important factors in determining the potential for adverse health effects. ATSDR develops site-specific CVs for radionuclides; however, the CVs used in this evaluation are the Environmental Protection Agency's (EPA) Preliminary Remediation Goals (PRG) for outdoor workers and residents which are further explained Appendix C.

Samples of the tailings materials from the drains near the retaining wall exceeded the CV for 7 of 8 radionuclides (Table 4). Although Lead-210 was not analyzed, it is conservatively assumed to be equal to Radium-226 in order to address the complete decay series. Radium-226, Thorium-228, Thorium-230, Uranium-234, Uranium-235, Uranium-238, and Lead-210 were selected as ROPCs and were retained for further evaluation. Radon was not retained as a COPC based on the data collected inside the building which is being converted to Children's Discovery Museum (the Durango power plant building) (ATSDR, 2008). These data showed radon levels at the main level (2.3 Picocuries per liter; pCi/L) below EPA's guideline for radon in air inside homes of 4.0 pCi/L. A curie is the quantity of radioactive material and a picocurie is one-trillionth of a curie. However, the average radon levels detected in the basement (18.1 to 18.7 pCi/L) and in the boiler room (4.2 pCi/L) of the Power House exceeded 4.0 pCi/L and therefore required mitigation.

For gamma radiation, it is important to compare the hazards of site-specific data with background levels of radiation. Here, the measured levels of gamma radiation exceeded site-specific background levels of radiation. Therefore, gamma radiation was retained for further evaluation (Tables 2 and 3). .

The Conceptual Site Model

The conceptual site model describes the primary contaminants of concern, contaminated sources, and the potential exposure pathways by which different types of populations (e.g., museum visitors and workers) might come in contact with contaminated media. Exposure pathways are classified as either complete, potential, or eliminated. Only complete exposure pathways can be fully evaluated and characterized to determine the public health implications. A complete exposure pathway consists of five elements: a source, a contaminated environmental medium and transport mechanism, a point of exposure, a route of exposure, and a receptor population.
Only future exposures are evaluated in this assessment because there is no current exposure among any known population; the area of contamination is fenced and locked. The plan for future use of this area is recreational, as such, the general population and young children may be exposed. Workers may also be exposed as they develop the

existing area into a miniature golf course. This site will not be re-zoned to allow residential development without further remediation. Therefore no residential scenarios will be evaluated in this assessment.

At this site, individuals may be exposed to the tailings materials percolated through to the Museum property (the soil surface) due to accidental removal of drain hole covers. Child and adult museum visitors and workers could be exposed to radionuclides in the tailings materials and gamma radiation emanating from the tailings materials behind the concrete retaining wall through three primary pathways: ingestion, inhalation, and external exposure. The potential exposure pathway for gamma radiation is external exposure. The overall conceptual site model for gamma radiation and contaminated soil pathways at the Durango Discovery Museum site is presented below.

Conceptual Site Model

Pathway Name	Exposure Pathway Elements						
	Source	**Medium and contaminant**	**Point of Exposure**	**Receptor Population**	**Route of Exposure**	**Time Frame**	**Pathway Status**
Soil	Uranium mine tailings behind retaining wall and in surface soils near drains	Radionuclides in soil	Surface soil (Tailings materials percolated through on soil surface due to accidental removal of drain covers)	Workers Child & Adult visitors to museum building	Inhalation Ingestion External exposure Inhalation Ingestion External exposure	Future Future	Potential Potential
Ambient Air	Uranium mine tailings behind retaining wall and in surface soils near drains	Gamma radiation in ambient air	Wall and ambient air	Workers Child & Adult visitors to museum site	External exposure to radiation External exposure to radiation	Future Future	Potential Potential

Public Health Implications

The purpose of the health evaluation is to determine whether exposures to ROPCs that exceed the CVs might be associated with adverse health outcomes. This requires an estimation of site-specific doses, and comparison with an appropriate toxicity value (or health guideline). For this assessment, the following ROPCS were selected for further evaluation: radium (Ra-226), thorium (Th 228 and Th 230), uranium (U 238, U 235, and U 234), and lead 210 (Pb-210), and gamma radiation.

To estimate doses, one must make assumptions such as how much soil will be accidentally ingested over a period of time. These assumptions can be based on scientific literature, site-specific information, or professional judgment. The actual values for soil ingestion or exposure duration may be higher or lower than the values used in this evaluation, which means that the actual health risk may also be higher or lower than what is presented in this document. In addition, many factors determine individual responses to radionuclides. These factors include the dose, duration, and the type of radiation. Furthermore, individual factors such as age, gender, diet, family traits, lifestyle, and state of health also may determine an individual's response to radionuclides. For these reasons, this evaluation cannot determine the actual health risk to any one particular individual. Rather, this evaluation provides estimates of risk using conservative and reasonably maximum exposure assumptions in order to estimate doses. Thus, this evaluation should be viewed as a semi-quantitative estimation of doses.

Radiogenic Theoretical Cancer Risks

Radionuclides in Soil

The EPA classifies all radionuclides as known human carcinogens (Class A) based on their property of emitting radiation and on extensive evidence of radiogenic cancers in humans from epidemiological studies (EPA-HEAST, 2001). Generally, EPA evaluates potential human health risks based on the radiotoxicity caused by ionizing radiation, rather than the chemical toxicity of each radionuclide because, in most cases, cancer occurs at lower doses than mutagenesis or teratogenesis. Uranium is an exception where both radiotoxicity and chemical toxicity are evaluated as uranium has been shown to be a kidney toxicant.

As summarized in Tables 5 and 6, the total predicted theoretical cancer risk from exposure to radionuclides in the tailings materials is 3.1×10^{-5} for children (31 cancer cases per million children exposed) and 1.1×10^{-4} for workers (110 cancer cases per million workers exposed). It should be noted that this is an annual risk and it is not corrected for background risks.

It should be noted that the total predicted theoretical cancer risks are due entirely to radium-226 and lead-210 and their associated short-lived radioactive decay products found in the tailings materials percolated on to the surface soil. For radium-226, these risks are almost exclusively due to external exposure to photons emitted by radium-226. For lead-210, these risks are almost entirely due to soil ingestion (EPA 1999b). The predicted theoretical increased cancer risks from all other radionuclides and exposure pathways (e.g., inhalation of particulates in air) would be significantly below the CDPHE acceptable cancer risk level of 1 cancer per million people exposed (10^{-6}) as well as EPA's acceptable range of 1 in a million to 100 in a million (10^{-6} to 10^{-4}), and are considered negligible in this assessment.

Overall, the short-term exposure to radionuclides in the tailings materials is not expected to harm the health of child visitors. However, exposure to radionuclides in the tailing materials could harm children's health if exposure would continue for more than 3 years. For example, the risk estimates would be 4-fold higher (i.e., 1.2E-04) if children visiting the museum more frequently are exposed for 4 years. This longer duration of exposure would place the theoretical cancer risk above acceptable cancer risk range, which is considered a public health hazard. It should be noted that radiation risk is an inherent part of daily life. In geographical areas with high radiation exposure rates, the health risk from radiation to the general public is greater than in areas where radiation exposure rates are lower. Because of the variability of background radiation exposures within and among homes, and the variability of background radiation within a given region, state, and county, generalizations regarding background exposures within a given geographical location must be used with a degree of caution. For comparison, many groups have estimated that medical radiation workers in the US receive annual effective dose between 2.5 and 5 mSv (NCRP, 1996). The limit on radiation dose, from licensed activities, for individual members of the general public is 1mSv per year. The annual effective dose from natural background radiation is on the order of 3 mSv. To place this in perspective, if an unexposed population of 1000 persons was exposed to doses of 5mSv per year for 40 years there could be eight cancers in addition to the 210 cancer deaths that would occur in that population due to the normal incidence of cancer in the population of the US (NCRP, 1996). Since cancer rates are not static but vary, the chance of determining which of the 8 excess cancers resulting from the radiation would be essentially impossible. 210 cancers +/- 5% variation would be 10 cancers and that does not include the 8 estimated from the radiation exposure.

For adult workers, the short-term exposure (1-year) to radionuclides in the tailings materials could harm their health. This exposure is considered to pose a public health hazard as these workers are not considered radiation workers who have different dose limits than members of the public. However, there is uncertainty associated with this conclusion as the predicted theoretical cancer risks from the major exposure pathways (e.g., external exposure to radiations and soil ingestion) are based on conservative exposure assumptions. For example, the maximum detected concentration of radionuclides in pure tailings materials, without any dilution by mixing of soil, is used as the exposure point concentration (EPC) in order to estimate dose. In addition, lead-210 was not analyzed in the tailings materials. Therefore, the risk estimates are based on a conservative assumption where lead-210 concentrations are considered to be equal to the concentration of radium-226. Finally, the assumptions made here regarding the amount of time workers spend exposed to the maximum concentration of tailings materials probably results in an overestimate of exposure and likely overestimation of true risk (240 hours in 1 year).

Gamma Radiation emanating from the retaining wall

Cancer is the major latent harmful effect produced by all types of ionizing radiation including gamma radiation (ATSDR 1999a). However, both cancer and noncancer effects are evaluated for gamma radiation in this health consultation.

For more information on health effects of gamma radiation, see health effects of ionizing radiation in Appendices E and G.

The predicted increased risk of cancer mortality and morbidity associated with exposure to gamma radiation was calculated in accordance with the EPA Federal Guidance Reports (FGR) risk assessment methodology (EPA, 1999b). Additional information on the estimated doses for young children (for one year) and adult workers (for 25 years) is provided in Appendix D (Tables D.6 to D.10) and risk factors (or health guidelines) for gamma radiation are provided in Appendix E (Table E.2). Noncancer hazards are not likely to occur as a result from exposure to gamma radiation nor have any non-cancer health effects been observed following gamma radiation exposure. The estimated doses for all visitors and workers are significantly below the ATSDR acute and chronic duration Minimal Risk Levels (MRLs, 100 millirem per year) for ionizing radiation as described in Tables C.8 and C.9 of Appendix C (ATSDR, 1999a).

As summarized in Tables 7 and 8, the predicted cancer morbidity and mortality risks from exposure to gamma radiation are low, ranging from 6.9×10^{-7} to 7.4×10^{-6} (0.7 to 7.4 cancer cases per million exposed) for various types of visitor subpopulations (e.g., infant, child, and adults). The high-end risk estimates are associated with female child cancer morbidity. It should, however, be noted that these are mathematical probabilities and that conclusively tying a health outcome to radiation at these levels of exposure would be very difficult if at all possible. Because the estimated risk of developing cancer is low, it is concluded that exposure to gamma radiation is not expected to harm the health child or adult visitors over short-term exposure duration of one year.

For outdoor workers on-site, the predicted cancer morbidity and mortality risks from exposure to gamma radiation range from 2.0 x 10^{-4} to 3.6 x 10^{-4}(200 to 360 cancer cases per million exposed). These predicted cancer risk estimates are above the high-end (10^{-4}) of acceptable cancer risk levels and are associated with an increased risk of developing cancer. This exposure is considered to pose a public health hazard for long-term exposures of 25 years. These are mathematical probabilities and that conclusively tying a health outcome to radiation at these levels of exposure would be very difficult if at all possible. It is, however, important to note that the site-specific long-term background risks for outdoor workers from exposure to gamma radiation range from 1.2 x 10^{-4} to 2.14 x 10^{-4} (120 to 214 cancer cases per million exposed) and are also above the acceptable cancer risk levels because this area is known to have elevated levels of naturally occurring uranium.

Noncancer Health Hazards of Uranium

For natural uranium, there is an additional consideration of chemical toxicity. Overall, the kidneys have been identified as the most sensitive target of uranium toxicity in acute-, intermediate-, and chronic-duration exposures to uranium compounds in animal and humans (ATSDR, 1999c). Here, the screening level evaluation for chronic health hazards compares the ATSDR residential environmental health guidelines for soil (100 mg/kg) with the site-specific maximum concentration (241.6 mg/kg), and suggests potential for chronic health hazards (daily lifetime exposures) to young children. In addition, the site-specific maximum concentration is significantly below the US EPA industrial worker comparison value of 3100 mg/kg (EPA Regional screening values, 2009); thereby, indicating that noncancer health effects are not expected for workers. However, the chronic health hazards are not further evaluated here because the focus of this assessment is to evaluate shorter-term health hazards to prevent exposures to child visitors under accidental circumstances.

Therefore, more realistic short-term (20 days exposure duration based on 20 visits to the museum per year) hazards for young children are quantitatively evaluated in Tables F.1 and F.2 of Appendix F. The estimated dose is two times higher than the ATSDR intermediate-duration (15 to 364 days) health guideline of 0.002 mg/kg/day. However, the estimated dose is significantly below the observed health effects levels. Thus, no significant potential noncancer health hazards are expected under short-term (15 days to 364 days) exposures at this site. It should be noted that acute exposure could not be evaluated due to the unavailability of acute health guideline (1 to15 days) for uranium.

Limitations

This section is not intended to be an in-depth discussion of all uncertainties that may exist in this type of an evaluation. Rather, the focus is to highlight the major assumptions and limitations that are specific to this evaluation. In any risk assessment there is uncertainty that is likely to cause over- or underestimation of doses and health hazards. The magnitude of this uncertainty is generally unknown. However, this Durango Discovery Museum Health Consultation incorporates a purposeful attempt to err on the side of conservatism (or overestimation of risk). A listing of the known major uncertainties is noted below:

- Only two samples were collected for radionuclides in soil. The maximum detected concentration of radionuclides in pure tailings materials, without any dilution by mixing of soil, is used as the EPC in order to estimate dose.

- Lead-210 was not analyzed in the tailings materials. Therefore, the risk estimates are based on a conservative assumption where lead-210 concentrations are considered to be equal to the concentration of radium-226. An alternative approach would be to use a concentration of 50% of the radium-226 concentration.

- Not all risks were evaluated quantitatively, namely the risks to all decay series of the ingested Pb-210 and risks due to polonium-210.

- The assumptions made regarding the amount of time workers and children spend exposed to the maximum concentration of tailings materials probably results in an overestimate of exposure and likely overestimation of true risk.
- External exposure to radiations from all isotopes cannot be fully evaluated quantitatively.
- Gamma radiation readings, taken by using a Ludlum Scintillometer, may be associated with some uncertainty based on the type of isotope used to calibrate the scintillometer.
- Gamma radiation doses are estimated without subtracting background levels. It is important to note that all living organisms are exposed to small levels of ionizing radiations from several sources every day, including cosmic and terrestrial sources. Most (81%) of our radiation exposure comes from natural sources (ATSDR, 1999a). Recent estimates indicate that 73% of our background radiation dose is from radon (NCRP, 2009). Higher levels of radon are normally found indoors, especially in the basement. We may also be exposed to radiation from x ray exams, nuclear medicine exams, and consumer products including TV and smoke detectors, as well as other sources; however, these are not considered part of the natural background.

Child Health Considerations

In communities faced with air, water, or food contamination, the many physical differences between children and adults demand special emphasis. Children could be at greater risk than are adults from certain kinds of exposure to hazardous substances. Children play outdoors and sometimes engage in hand-to-mouth behaviors that increase their exposure potential. Children are shorter than are adults; this means they breathe dust, soil, and vapors close to the ground. A child's lower body weight and higher intake rate results in a greater dose of hazardous substance per unit of body weight. If toxic exposure levels are high enough during critical growth stages, the developing body systems of children can sustain permanent damage. Finally, children are dependent on adults for access to housing, for access to medical care, and for risk identification. Thus adults need as much information as possible to make informed decisions regarding their children's health.

Like adults, children are exposed to small background levels of ionizing radiation that comes from soil around where they live, in the food and water that they eat, in the air that they breathe, and from sources that reach earth from space. There are no peer-reviewed reports that demonstrate exposure to normal levels of background ionizing radiation causes health effects in children or adults. If children are exposed to higher than background levels of ionizing radiation, they are likely to have the same possible health effects as adults exposed to similar levels (ATSDR, 1999a). Young children are considered in this health consultation as the most sensitive subpopulation. The results of this assessment demonstrate that some of the site contaminants (radium-226, lead-210, and gamma radiation) pose a public health hazard to young children under chronic, long-term, exposure conditions, based on the increased theoretical cancer risk.

Conclusions

Based on the estimated theoretical cancer risk as a result of exposures to the tailings materials percolating out through drain holes along the retaining wall, especially Radium 226 and Lead 210, and gamma radiation emanating through the retaining wall, CCPEHA and ATSDR reached the following two conclusions

> *Assuming that the proposed barriers and covers are <u>not</u> implemented as recommended in this health consultation, short-term exposure (20 days or less in a year), to radionuclides in the tailings materials and gamma radiation at the Durango Discovery Museum is not likely to harm the health of child visitors. It is important to note here that exposures (for 20 days in a year) of neighborhood children to the tailings materials are unlikely to occur. Therefore, this conclusion is based on conservative exposure assumptions resulting in overestimation of risk.* The reason for this conclusion is that predicted theoretical increased cancer risks are either within or below the acceptable cancer risk levels (1 in a million to 100 in a million).

In addition, the estimated noncancer hazard for short-term exposure to uranium (up to 20 days) is below levels of health concern (i.e., “safe dose”). Children can be exposed to radionuclides through incidental ingestion, inhalation, and external body exposure to radiations emanating from radionuclides in soil and gamma radiations emanating through the retaining wall. The available data indicate that the estimated amount of radionuclides and gamma radiations that could get into children’s body while playing near the retaining wall is associated with a low increased risk of developing cancer and noncancer health effects.

Assuming that the proposed barriers and covers are <u>not</u> implemented as recommended in this health consultation, exposure to radionuclides in the tailings materials for a longer period than three years (e.g., 4 years) could potentially harm the health of child visitors and on-site workers (1 year or longer). It is important to note here that extended exposure to the tailings materials is unlikely to occur. Therefore, this conclusion is based on conservative exposure assumptions resulting in overestimation of risk. The reason for this conclusion is that The available data indicate that the estimated amount of radionuclides and gamma radiations that could get into children’s or worker’s body while playing or working near the retaining wall is associated with a high increased risk of developing cancer. It is important to note that steps are being taken to prevent children or workers from playing or working near the retaining wall while construction is in progress, and barriers are recommended to prevent children from playing near the wall once construction is completed.

Recommendations

Based upon the data and information reviewed, CCPEHA has made the following recommendations:

- Currently the site is fenced and there are no trespassers. Durango Discovery Museum staff must continue to reduce or eliminate exposures by securing physical barriers that prevent access to the site (fence and lock).

- Permanently eliminate exposure to the contaminated soils by installing structurally secure seep hole covers over the drainage areas that do not allow the contaminated soils to percolate to the Museum property (soil surface). In addition, these seep hole covers must be inspected annually.

- As site development is completed, Durango Discovery Museum must provide appropriate barriers that will discourage museum visitor traffic in the immediate area near the retaining wall. Also, seal cracks in the retaining wall to keep the tailing materials from eroding back on to the remediated ground surface. In addition, sealed cracks must be inspected annually.

- Durango Discovery Museum under CDPHE oversight must ensure that appropriate measures for worker protection and worker safety should be implemented to prevent workers from exposures to site-related contaminants in soil and by gamma radiation, especially during any on-site activities that involve disturbing soil.

Public Health Action Plan

Overall, the health consultation supports the interim remedial actions implemented by CDPHE risk managers to redevelop this Brownfield site. CCPEHA will work with the CDPHE project/site managers to carry out the following activities.

Past and On-going Activities:

- In 2005, more than 1000 cubic yards of PAH contaminated soils and 30 cubic yards of radioactive contaminated soils were excavated and removed.
- CDPHE project/site managers continue to ensure that the site is fenced and locked until the Children's Discovery Museum is open for public use.
- CDPHE project/site managers are making sure that seep hole covers and drainage nets are permanently secured.
- CCEPHA completed a letter Health Consultation in 2008 in order to evaluate the potential health risks associated with indoor air exposures inside the Durango Discovery Museum (ATSDR, 2008).

Future Activities:

- CDPHE project/site managers should develop a plan to regularly inspect, at least annually, the seep hole covers to make sure they are still in place and functioning.
- CDPHE project/site managers must ensure periodic monitoring of the appropriate barriers and covers of the cracks in the retaining wall to determine that they are still limiting potential exposure to gamma radiation in the area immediately near the retaining wall.
- CDPHE project/site managers should consider taking measurements of gamma radiation readings after the cracks are sealed and appropriate barriers are in place in order to ensure that gamma radiation reading have reduced to background levels.

- CCPEHA will conduct the appropriate health education and outreach activities, for example, by collaborating with museum staff to educate concerned citizens and future visitors.

- CCPEHA will evaluate new data for gamma radiations (obtained after the implementation of control measures) upon request.

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APPENDICES

Appendix A: Tables and Figures

Appendix A: Tables and Figures

Figure 1. Aerial photograph outlining approximate location of Durango Discovery Museum, Google Earth

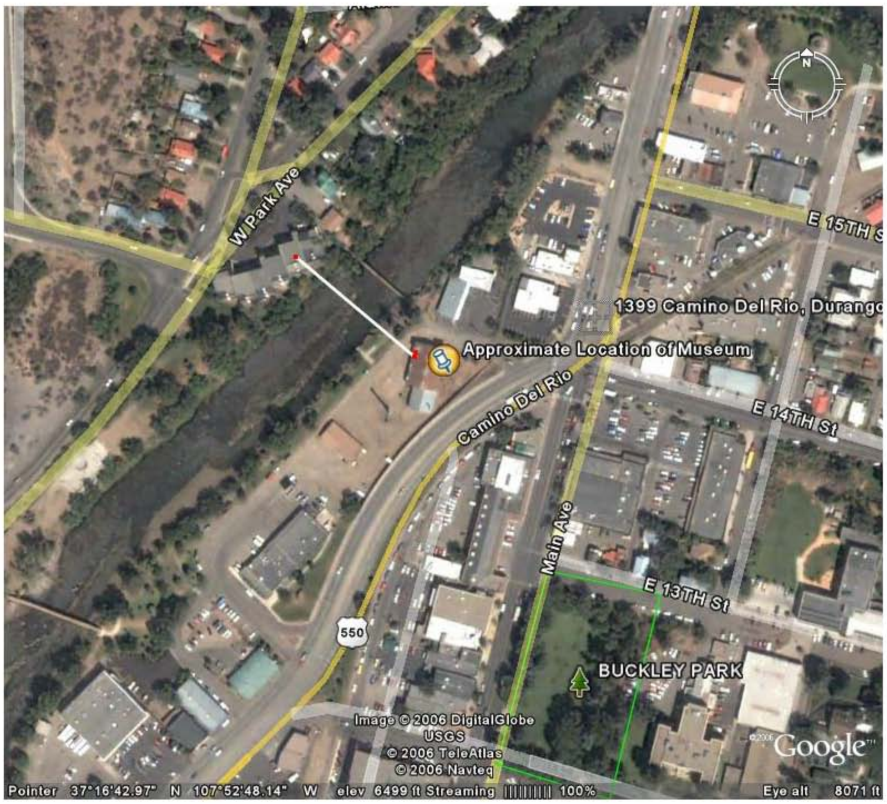

Figure 2. Photograph depicting hole in retaining wall that allows percolation of radioactive tailings materials onto the Durango Discovery Museum site

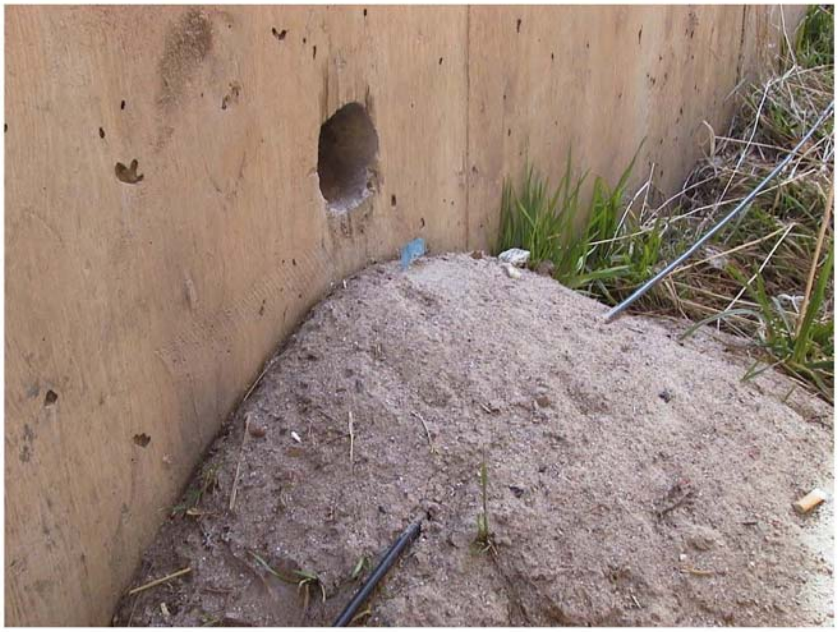

Figure 3. Photograph depicting hole-cover in retaining wall that needs to remain in place in order to prevent percolation of radioactive tailings materials onto the Durango Discovery Museum site.

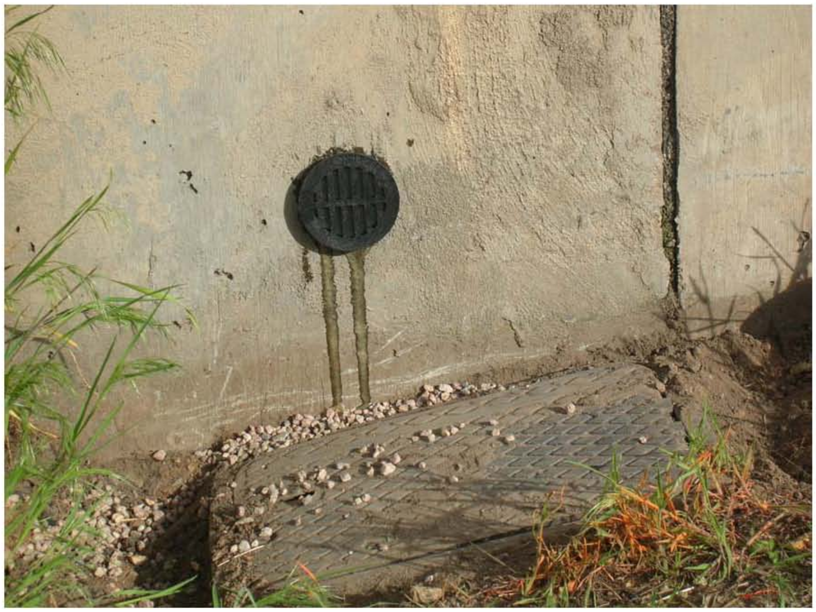

Figure 4. Photograph depicting the Durango Discovery Museum building, the retaining wall next to US 550, and the adjacent land that is proposed as a future miniature golf course.

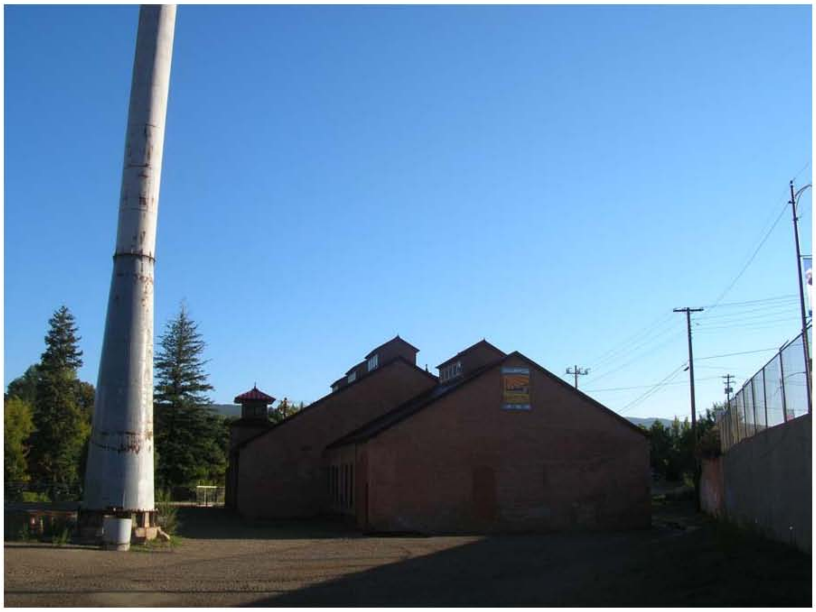

Table 1a. Concentration of radionuclides in the tailings materials taken along the retaining wall, March 2005, Sample 1.

Radionuclide	Detected value (pCi/g)
Radium 226	31
Th-228	0.83
Th-230	28
Th-232	0.50
U-234	3.5
U-235	0.45
U-238	3.8
Pb-210+D	31

Table 1b. Concentration of radionuclides in the tailings materials taken along the retaining wall, March 2005, Sample 2.

Radionuclide	Detected value (pCi/g)
Radium 226	419
Th-228	3.1
Th-230	301
Th-232	0.28
U-234	76
U-235	4.5
U-238	79
Pb-210+D	419

Note:

- pCi/g = Picocuries Per Gram
- Although Pb-210 was not analyzed, it is conservatively assumed to be equal to Radium-226 in order to address complete decay series

Table 2: Gamma Radiation levels at increasing distances from the retaining wall, as measured at ground level

Distance away from wall (feet)	# Readings	Min Value (µR/h)	Max Value (µR/h)	Mean Value (µR/h)
0	4	38	120	63
2	4	28	32	30
3	4	26	30	28
4	4	24	28	26.5
5	4	24	28	25.5
6	4	22	24	24
7	4	22	24	23.5
8	4	20	24	22.5
9	4	20	22	21.5
10	4	18	22	21
20	4	18	20	18.5

Note:
- µR/h = Microroentgens per hour
- # Readings = the number of readings taken
- Max = Maximum
- Min = Minimum

Table 3: Gamma radiation levels at increasing height along retaining wall, as measured at the wall

Height on wall (feet)	# Readings	Min Value (µR/h)	Max Value (µR/h)	Mean Value (µR/h)	EPC 95% UCL (µR/h)
0	57	15	80	30.14	33.5
2	56	15	75	30.57	33.9
4	55	17	70	30.51	33.5
6	53	16	75	30.79	33.9

Note:

- µR/h = Microroentgens per hour
- # Readings = the number of samples taken
- Max = Maximum
- Min = Minimum
- UCL = Upper Confidence Limit
- EPC = Exposure Point Concentration

Table 4: Selection of Radionuclides of Potential Concern (ROPC) using Environmental Comparison Values (or Risk-Based Concentration)

Radionuclide	Maximum detected value (pCi/g)	Comparison Values		ROPC? (if >CV)
		Residential (pCi/g)	Workers (pCi/g)	
Radium 226+D	419	0.0124	0.0258	Yes
Th-228	3.1	0.154	0.255	Yes
Th-230	301	3.49	20.2	Yes
Th-232	0.28	3.1	19.0	No
U-234	76	4.01	32.4	Yes
U-235	4.5	0.195	0.398	Yes
U-238	79	0.74	1.80	Yes
Pb-210+D	419	0.15	1.23	Yes

Note:

- The CVs used within this document are the Environmental Protection Agency's (EPA) Preliminary Remediation Goals (PRG) for outdoor workers and residents (EPA, 2007). PRGs collectively consider a variety of exposure pathways over lifetime (e.g., soil ingestion, food ingestion, inhalation, and external exposure to radiation) in the derivation of values for each specific type of media.
- The maximum detected value represents the concentration of radionuclides in pure uranium tailings, and no mean value is calculated because only two samples were analyzed.
- pCi/g = Picocuries Per Gram
- ROPC = Radionuclides of Potential Concern
- Pb-210 was not analyzed and is conservatively assumed to be equal to radium 226

Table 5: Summary of child theoretical cancer risk from exposure (1-year) to radionuclides in the tailings materials (percolated on the soil surface) while playing

Radionuclide	Risk from inhalation	Risk from soil ingestion	Risk from external exposure	Total Theoretical Risk
Ra 226+D	1.3E-10	1.2E-06	2.4E-05	2.6E-05
Th-228+D	1.2E-11	1.0E-08	1.6E-07	1.8E-07
Th-230	2.3E-10	2.4E-07	1.7E-09	2.5E-07
U-234	2.4E-11	4.8E-08	1.3E-10	4.8E-08
U-235+D	1.2E-12	2.9E-09	1.7E-08	1.9E-08
U-238+D	2.0E-11	6.6E-08	6.2E-08	1.3E-07
Pb-210+D	1.6E-10	4.5E-06	1.2E-08	4.5E-06
Total	5.8E-10	6.1E-06	2.5E-05	3.1E-05

Note:

- Chronic, long-term, risk for children (0-6 years age) would be 6-fold higher; for example, the total risk = 3.1E-05 x 6 = 1.8E-04
- Here, site-specific information about the frequency and duration of exposure was used. All child visitors to the museum were assumed to spend no more than 60 hours at the site; this accounts for twenty 3-hour visits over the course of 1 year. Market analysis for the museum has priced memberships such that families do not achieve any cost-savings until the fourth visit (Durango Discovery Museum, *August 2004 BusinessPlan)*. Therefore, there is the expectation that families make at least 4 visits over the course of a year, but a family making 20 visits is unlikely and thus allows for a conservative estimation of exposure

Table 6: Summary of outdoor worker theoretical cancer risk from exposure (1-year) to radionuclides in the tailings materials during soil intrusive activities

Radionuclide	Risk from inhalation	Risk from soil ingestion (normal)	Risk from soil ingestion (soil intrusive)	Risk from external exposure	Total AnnualTheoretical Risk
Ra 226+D	8.8E-10	3.7E-07	1.2E-06	9.7E-05	9.9E-05
Th-228+D	8.1E-11	1.5E-09	4.9E-09	6.6E-07	6.6E-07
Th-230	1.6E-09	6.9E-08	2.3E-07	6.8E-09	2.4E-07
U-234	1.6E-10	1.2E-08	3.8E-08	5.2E-10	3.9E-08
U-235+D	8.3E-12	6.8E-10	2.2E-09	6.7E-08	6.9E-08
U-238+D	1.3E-10	1.3E-08	4.4E-08	2.5E-07	2.9E-07
Pb-210+D	1.1E-09	2.6E-06	8.5E-06	4.8E-08	8.5E-06
Total	**3.9E-09**	**3.0E-06**	**1.0E-05**	**9.85E-05**	**1.1E-04**

Note:

- Chronic, long-term risk for workers over 25 years of exposure duration would be 25-times higher; for example, the total risk for normal soil activities =1E-04 x 25= 2.5E-03
- Total Risk includes the ingestion risk from soil intrusive activities; therefore the total risk is likely an overestimation of the total theoretical risk. Please note that ingestion risk from soil intrusive activities is not included in calculation of the theoretical risk for children in Table 5 because the nature of the potential exposure of these 2 groups is different.
- For exposure to the radionuclides, workers were assumed to be exposed for 8 hours per day, 30 days per year, for 1 year. This conservative assumption is based on the amount of time that a worker could spend working in the areas where the soil is percolating out from underneath the retaining wall. This area is so small that exposure for 8-hours a day for 30 days is highly unlikely.

Table 7 - Summary of risk of cancer mortality and morbidity to young children and adults from exposure (1-year) to gamma radiation emanating from the retaining wall.

EPC/receptor (μR/h)	Combined cancer mortality	Combined cancer morbidity	Male cancer mortality	Female cancer mortality	Male cancer morbidity	Female cancer morbidity
Child/Adult						
120	4.14E-06	6.09E-06	3.33E-06	4.92E-06	4.69E-06	7.42E-06
32	1.10E-06	1.62E-06	8.87E-07	1.31E-06	1.25E-06	1.98E-06
20[1]	6.90E-07	1.02E-06	5.54E-07	8.20E-07	7.81E-07	1.24E-06

[1]The EPC of 20 μR/h is equivalent to background levels of radiation measured on-site.

Note:

- Please see Appendices D and E for a detailed explanation of how risk was calculated using EPA guidance provided in Federal Guidance No. 13 (EPA, 1999b).
- μR/h = Microroentgens per hour
- EPC = Exposure Point Concentration
- The EPC value represents gamma radiation levels vertically along the wall height as well as horizontally away from the wall. Additionally, the predicted chronic risk for young children will be 6-times higher, based on the assumption of 6 years exposure duration. For example, female cancer morbidity risk = 7.42E-06 x 6 = 4.45E-05
- The EPC of 120 μR/h represents the maximum value at the wall (0-foot away from the wall).
- The EPC of 32 μR/h represents the maximum value at 2-feet away from the wall.
- The EPC of 20 μR/h is equivalent to background levels of radiation measured on-site.

Table 8: Summary of theoretical risk of cancer mortality and morbidity to workers from exposure (25-year) to gamma radiations emanating from the retaining wall.

EPC (µR/h)	Combined cancer mortality	Combined cancer morbidity	Male cancer mortality	Female cancer mortality	Male cancer morbidity	Female cancer morbidity
33.5	2.00E-04	2.95E-04	1.61E-04	2.38E-04	2.27E-04	3.59E-04
20	1.20E-04	1.76E-04	9.61E-05	1.42E-04	1.35E-04	2.14E-04

[1]The EPC of 20 µR/h is equivalent to background levels of radiation measured on-site.

Note:

- µR/h = Microroentgens per hour
- EPC = Exposure Point Concentration
- The EPC value represents gamma radiation levels vertically along the wall height as well as horizontally away from the wall.
- The EPC of 33.5 represents the 95th percent upper confidence limit on the mean value

Appendix B. ATSDR Plain Language Glossary of Environmental Health Terms

Absorption: How a chemical enters a person's blood after the chemical has been swallowed, has come into contact with the skin, or has been breathed in.

Acute Exposure: Contact with a chemical that happens once or only for a limited period of time. ATSDR defines acute exposures as those that might last up to 14 days.

Additive Effect: A response to a chemical mixture, or combination of substances, that might be expected if the known effects of individual chemicals, seen at specific doses, were added together.

Adverse Health Effect: A change in body function or the structures of cells that can lead to disease or health problems.

Antagonistic Effect: A response to a mixture of chemicals or combination of substances that is **less** than might be expected if the known effects of individual chemicals, seen at specific doses, were added together.

ATSDR: The **A**gency for **T**oxic **S**ubstances and **D**isease **R**egistry. ATSDR is a federal health agency in Atlanta, Georgia that deals with hazardous substance and waste site issues. ATSDR gives people information about harmful chemicals in their environment and tells people how to protect themselves from coming into contact with chemicals.

Background Level: An average or expected amount of a chemical in a specific environment. Or, amounts of chemicals that occur naturally in a specific environment.

Bioavailability: See **Relative Bioavailability.**

Biota: Used in public health, things that humans would eat - including animals, fish and plants.

Cancer: A group of diseases, which occur when cells in the body become abnormal and grow, or multiply, out of control

Carcinogen: Any substance shown to cause tumors or cancer in experimental studies.

CERCLA: See **C**omprehensive **E**nvironmental **R**esponse, **C**ompensation, and **L**iability **A**ct.

Chronic Exposure: A contact with a substance or chemical that happens over a long period of time. ATSDR considers exposures of more than one year to be *chronic*.

Completed Exposure Pathway: See **Exposure Pathway**.

Comparison Value (CVs): Concentrations or the amount of substances in air, water, food, and soil that are unlikely, upon exposure, to cause adverse health effects. Comparison values are used by health assessors to select which substances and environmental media (air, water, food and soil) need additional evaluation while health concerns or effects are investigated.

Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA):
CERCLA was put into place in 1980. It is also known as **Superfund**. This act concerns releases of hazardous substances into the environment, and the cleanup of these substances and hazardous waste sites. ATSDR was created by this act and is responsible for looking into the health issues related to hazardous waste sites.

Concern: A belief or worry that chemicals in the environment might cause harm to people.

Concentration: How much or the amount of a substance present in a certain amount of soil, water, air, or food.

Contaminant: See **Environmental Contaminant**.

Delayed Health Effect: A disease or injury that happens as a result of exposures that may have occurred far in the past.

Dermal Contact: A chemical getting onto your skin. (see **Route of Exposure**).

Dose: The amount of a substance to which a person may be exposed, usually on a daily basis. Dose is often explained as "amount of substance(s) per body weight per day".

Dose / Response: The relationship between the amount of exposure (dose) and the change in body function or health that result.

Duration: The amount of time (days, months, years) that a person is exposed to a chemical.

Environmental Contaminant: A substance (chemical) that gets into a system (person, animal, or the environment) in amounts higher than that found in **Background Level**, or what would be expected.

Environmental Media: Usually refers to the air, water, and soil in which chemical of interest are found. Sometimes refers to the plants and animals that are eaten by humans. **Environmental Media** is the second part of an **Exposure Pathway**.

U.S. Environmental Protection Agency (EPA): The federal agency that develops and enforces environmental laws to protect the environment and the public's health.

Exposure: Coming into contact with a chemical substance(For the three ways people can come in contact with substances, see **Route of Exposure**.)

Exposure Assessment: The process of finding the ways people come in contact with chemicals, how often and how long they come in contact with chemicals, and the amounts of chemicals with which they come in contact.

Exposure Pathway: A description of the way that a chemical moves from its source (where it began) to where and how people can come into contact with (or get exposed to) the chemical.

ATSDR defines an exposure pathway as having 5 parts:

- Source of Contamination,
- Environmental Media and Transport Mechanism,
- Point of Exposure,
- Route of Exposure; and,
- Receptor Population.

When all 5 parts of an exposure pathway are present, it is called a **Completed Exposure Pathway**. Each of these 5 terms is defined in this Glossary.

Frequency: How often a person is exposed to a chemical over time; for example, every day, once a week, and twice a month.

Federal Guidance Reports: Federal guidance is a set of guidelines developed by EPA, for use by Federal and State agencies responsible for protecting the public from the harmful effects of radiation. Federal guidance helps protect both the general public and the people who work with and around radiation every day. The Technical Reports provide current scientific and technical information for radiation dose and risk assessment.

Gamma Ray Transformation: A radioactive decay in which gamma rays are emitted. Radioactive decay is the process in which an unstable atomic nucleus loses energy by emitting radiation in the form of particles or electromagnetic waves.

Hazardous Waste: Substances that have been released or thrown away into the environment and, under certain conditions, could be harmful to people who come into contact with them.

Health Effect: ATSDR deals only with **Adverse Health Effects** (see definition in this Glossary).

Indeterminate Public Health Hazard: The category is used in Public Health Assessment documents for sites where important information is lacking (missing or has not yet been gathered) about site-related chemical exposures.

Ingestion: Swallowing something, as in eating or drinking. It is a way a chemical can enter your body (See **Route of Exposure**).

Inhalation: Breathing. It is a way a chemical can enter your body (See **Route of Exposure**).

LOAEL: **L**owest **O**bserved **A**dverse **E**ffect **L**evel. The lowest dose of a chemical in a study, or group of studies, that has caused harmful health effects in people or animals.

MRL: **M**inimal **R**isk **L**evel. An estimate of daily human exposure - by a specified route and length of time -- to a dose of chemical that is likely to be without a measurable risk of adverse, noncancerous effects. An MRL should not be used as a predictor of adverse health effects.

NPL: The **N**ational **P**riorities **L**ist. (Which is part of **Superfund**.) A list kept by the U.S. Environmental Protection Agency (EPA) of the most serious, uncontrolled or abandoned hazardous waste sites in the country. An NPL site needs to be cleaned up or is being looked at to see if people can be exposed to chemicals from the site.

NOAEL: **N**o **O**bserved **A**dverse **E**ffect **L**evel. The highest dose of a chemical in a study, or group of studies, that did not cause harmful health effects in people or animals.

No Apparent Public Health Hazard: The category is used in ATSDR's Public Health Assessment documents for sites where exposure to site-related chemicals may have occurred in the past or is still occurring but the exposures are not at levels expected to cause adverse health effects.

No Public Health Hazard: The category is used in ATSDR's Public Health Assessment documents for sites where there is evidence of an absence of exposure to site-related chemicals.

PHA: **P**ublic **H**ealth **A**ssessment. A report or document that looks at chemicals at a hazardous waste site and tells if people could be harmed from coming into contact with those chemicals. The PHA also tells if possible further public health actions are needed.

Point of Exposure: The place where someone can come into contact with a contaminated environmental medium (air, water, food or soil). Some examples include: the area of a playground that has contaminated dirt, a contaminated spring used for drinking water, the location where fruits or vegetables are grown in contaminated soil, or the backyard area where someone might breathe contaminated air.

Population: A group of people living in a certain area; or the number of people in a certain area.

Public Health Assessment(s): See **PHA**.

Receptor Population: People who live or work in the path of one or more chemicals, and who could come into contact with them (See **Exposure Pathway**).

Reference Dose (RfD): An estimate, with safety factors (see **safety factor**) built in, of the daily, life-time exposure of human populations to a possible hazard that is <u>not</u> likely to cause harm to the person.

Relative Bioavailability: The amount of a compound that can be absorbed from a particular medium (such as soil) compared to the amount absorbed from a reference material (such as water). Expressed in percentage form.

Route of Exposure: The way a chemical can get into a person's body. There are three exposure routes:

- breathing (also called inhalation),
- eating or drinking (also called ingestion), and/or
- getting something on the skin (also called dermal contact).

Safety Factor: Also called **Uncertainty Factor**. When scientists don't have enough information to decide if an exposure will cause harm to people, they use "safety factors" and formulas in place of the information that is not known. These factors and formulas can help determine the amount of a chemical that is <u>not</u> likely to cause harm to people.

SARA: The **S**uperfund **A**mendments and **R**eauthorization **A**ct in 1986 amended CERCLA and expanded the health-related responsibilities of ATSDR. CERCLA and SARA direct ATSDR to look into the health effects from chemical exposures at hazardous waste sites.

Sample: A small number of people chosen from a larger population (See **Population**).

Source (of Contamination): The place where a chemical comes from, such as a landfill, pond, creek, incinerator, tank, or drum. Contaminant source is the first part of an **Exposure Pathway**.

Special Populations: People who may be more sensitive to chemical exposures because of certain factors such as age, a disease they already have, occupation, sex, or certain behaviors (like cigarette smoking). Children, pregnant women, and older people are often considered special populations.

Statistics: A branch of the math process of collecting, looking at, and summarizing data or information.

Superfund Site: See **NPL**.

Survey: A way to collect information or data from a group of people (**population**). Surveys can be done by phone, mail, or in person. ATSDR cannot do surveys of more than nine people without approval from the U.S. Department of Health and Human Services.

Synergistic effect: A health effect from an exposure to more than one chemical, where one of the chemicals worsens the effect of another chemical. The combined effect of the chemicals acting together is greater than the effects of the chemicals acting by themselves.

Toxic: Harmful. Any substance or chemical can be toxic at a certain dose (amount). The dose is what determines the potential harm of a chemical and whether it would cause someone to get sick.

Toxicology: The study of the harmful effects of chemicals on humans or animals.

Tumor: Abnormal growth of tissue or cells that have formed a lump or mass.

Uncertainty Factor: See **Safety Factor**.

Urgent Public Health Hazard: This category is used in ATSDR's Public Health Assessment documents for sites that have certain physical features or evidence of short-term (less than 1 year), site-related chemical exposure that could result in adverse health effects and require quick intervention to stop people from being exposed.

Appendix C. Explanation of Comparison Values (PRGs): Selection of Radionuclides of Potential Concern (ROPCs)

In evaluating the available environmental data, CDPHE used comparison values (CVs) to determine which radionuclides to examine in greater detail. CVs incorporate assumptions of daily exposure to the contaminant and a standard amount of air, water, or soil that someone might inhale or ingest each day.

As health-based thresholds, CVs are set at a concentration below which no known or anticipated adverse health effects are likely to occur. Different CVs are developed for cancer and noncancer health effects. Cancer levels are based on a one-in-a-million excess cancer risk for an adult eating contaminated soil o every day for a period of 30 years. Exceeding a CV at this point does not indicate that adverse health effects will occur; only that further evaluation is necessary.

The CVs used within this document are the Environmental Protection Agency's (EPA) Preliminary Remediation Goals (PRG) for outdoor workers and residents (EPA, 2007). PRGs collectively consider a variety of exposure pathways (e.g., soil ingestion, food ingestion, inhalation, and external exposure to radiation) in the derivation of values for each specific type of media. Adverse health effects are not expected to occur below the PRG values.

Although there are no CVs available for gamma radiation, it is important to compare the hazards of site-specific data with background levels of radiation. Background radiation is the natural radioactivity of an area. Background radiation varies due to the influence of natural mineral deposits, building materials, and elevation. In Western Colorado, the background levels can range from 8 to 30 microroentgens per hour (µR/h). At this site, the background levels are approximately 20 µR/h.

Appendix D: Exposure Parameters and Estimation of Exposure Dose

Estimation of Exposure Point Concentration

The Exposure Point Concentration (EPC) is a high-end, yet reasonable concentration of a contaminant that people could be exposed to based on the available environmental data. The standard procedure for calculating EPCs is to use the 95% Upper Confidence Interval on the mean of the data for each ROPC. To calculate the EPC, the data was inserted into the EPA's statistical software package, ProUCL Version 3.02. The available data for gamma radiation were analyzed by this method and thus, the EPC for gamma radiation to workers and the general population is the 95% UCL.

If the data is not normally distributed, ProUCL recommends an alternative value to use in lieu of the 95% UCL depending on the type of data distribution. One such alternative is to us the maximum value as the EPC when the calculated UCL exceeds the maximum value.

If there were less than ten samples available, the 95% UCL was not used to represent the EPC. There were less than ten soil samples available for the calculation of the EPC for the various radionuclides. Therefore, in this instance, the EPC becomes the maximum value of the data instead of the 95% UCL. The EPC for Lead-210 was conservatively approximated to be equal to the EPC for Radium-226. Lead-210 was not analyzed in the collected samples.

The EPC in air for Particulate Inhalation Pathway was estimated using EPA's particulate emission factor (PEF) approach identified in EPA (1996: Soil Screening Guidance, User's Guide), based on the maximum detected concentration of radionuclides in the tailings materials, because no measured data for air concentration of particulate were available.

EPC for Particulate concentration in air (pCi/m^3) = radionuclide concentration in soil (pCi/kg) x 9.1E-10 m^3/kg (PEF)

Estimation of Dose

Exposure doses are estimates of the concentration of contaminants that people may come into contact with or be exposed to under specified exposure conditions. These exposure doses are estimated using: (1) the estimated exposure point concentration as well as intake rate; and (2) the length of time and frequency of exposure to site contaminants.

Here, site-specific information about the frequency and duration of exposure was used. All visitors (adult and children) to the museum were assumed to spend no more than 60 hours at the site; this accounts for twenty 3-hour visits over the course of 1 year. Market analysis for the museum has priced memberships such that families do not achieve any cost-savings until the fourth visit (Durango Discovery Museum, *August 2004 BusinessPlan)*. Therefore, there is the expectation that families make at least 4 visits over the course of a year, but a family making 20 visits is unlikely and thus allows for a conservative estimation of exposure.

For **dose from the radionuclides, workers** were assumed to be exposed for 8 hours per day, 30 days per year, for 1 year. This conservative assumption is based on the amount of time that a worker could spend working in the areas where the soil is percolating out from underneath the retaining wall. This area is so small that exposure for 8-hours a day for 30 days is highly unlikely. The exposure dose was calculated for a 1-year period in order to evaluate short-term risks to museum visitors and workers on-site. These short-term risk calculations also facilitate an estimate of the shortest frequency interval for the inspection of the drainage areas and protective covers along the wall. These exposures are considered protective of adult visitors as well.

For **dose from gamma radiation**, **workers** were assumed to be exposed for 52 days per year for 25 years. The potential area for exposure to gamma radiation is much larger than that for radionuclides. The estimated exposure duration is much longer than is probable for construction workers on site and therefore the estimates of risk are likely to be conservative.

Table D.1 -Exposure Parameters for Child (0-6 year age) Visitors

Exposure/Intake parameter	Reasonable Maximum Exposure (RME) value
Soil ingestion rate	200 mg/day (milligrams per day)
Inhalation rate	12 m3/day (cubic meters per day)
Particulate Emission Factor (PEF)	9.1E-10 m3/kg for Colorado (cubic meters per kilogram)
Exposure duration	1 year
Exposure Frequency	20 days/year (days per year)
Exposure time	3 hr/day (Hours per day)

Table D.2-Exposure Parameters for Outdoor Worker

Exposure/Intake parameter	RME value
Soil ingestion rate	100 mg/day (milligrams per day)
Soil ingestion rate (soil intrusive activities)	330 mg/day (milligrams per day)
Inhalation rate	20 m3/day (cubic meters per day)
Particulate Emission Factor (PEF)	9.1E-10 m3/kg for Colorado (cubic meters per kilogram)
Exposure duration	1 year
Exposure Frequency	30 days/year (days per year)
Exposure time	8 hr/day (hours per day)

Quantification of Dose and Cancer Risk from Exposure to Radionuclides in Tailings Materials

Method of Dose and Risk Calculation for Radionuclides in Tailings Materials

Exposure Dose from soil ingestion and inhalation pathways:

Total Dose (TD) = C x (IR x EF x ED)

Exposure Dose from external exposure to radiation:

External radiation dose = C x EF x ET x ED/ 365 days

Cancer Risk:

Radiation Cancer Risk = Dose x Slope Factor (Provided in Table D.1 of Appendix D)

Where:

TD = Total dose or intake of radionuclide (pCi) Picocuries

C = Concentration of radionuclide (pCi/g) Picocuries Per Gram

ED = Exposure duration (years)

EF = Exposure Frequency (days/year)

ET = Exposure Time (hours/day)

Table D.3 - Child dose from exposure to radionuclides in the tailings materials.

Radionuclide	Ingestion Dose (pCi/lifetime)	Inhalation Dose (pCi/lifetime)	External Exposure (pCi-year/g)
Radium226+D	1676.00	0.01	2.87
Th-228+D	12.40	8.46E-05	0.02
Th-230+D	1204.00	0.008	2.06
U-234	304.00	0.002	0.52
U-235	18.00	1.23E-04	0.03
U-238+D	316.00	0.002	0.54
Lead-210+D	1676.00	0.01	2.87

Table D.4 - Worker dose from exposure to radionuclides in the tailings materials

Radionuclide	Ingestion Dose at 100 mg/day (pCi/lifetime)	Ingestion Dose at 330 mg/day (pCi/lifetime)	Inhalation Dose (pCi/lifetime)	External Exposure (pCi-year/g)
Radium 226+D	1257.00	4148.10	0.08	11.48
Th-228+D	9.30	30.69	5.64E-04	0.08
Th-230+D	903.00	2979.90	0.05	8.25
U-234	228.00	752.40	0.01	2.08
U-235	13.50	44.55	8.19E-04	0.12
U-238+D	237.00	782.10	0.01	2.16
Lead-210+D	1257.00	4148.10	0.08	11.48

Table D.5- Exposure Parameters for All Museum Visitors

Exposure/Intake parameter	RME value
Adult effective dose	1.0 (ATSDR Pers. Communication)
Exposure duration	1 year
Exposure Frequency	20 days/year (days per year)
Exposure time	3 hr/day (hours per day)

Table D.6-Exposure Parameters for Outdoor Worker

Exposure/Intake parameter	RME value
Adult effective dose	1.0 (ATSDR Pers. Communication)
Exposure duration	25 years
Exposure Frequency	52 days/year (days per year)
Exposure time	8 hr/day (hours per day)

Method of dose and risk calculation for gamma radiation as per EPA's Federal Guidance No. 13 (EPA 1999b)

Exposure Dose:

Total Dose in Gy (TD) = R (Gy/hr) x AED x EF x ED

Cancer Risk:

Cancer Risk = Dose (GY) x RF (cancer cases or cancer death per person-Gy)

Where:

ED = Exposure duration (years)

EF = Exposure Frequency (days/year)

R = Gamma radiation as measured by scintillometer and converted to Gy/hr

AED = Adult effective dose

RF = Cancer morbidity or mortality risk factor (cancer cases or cancer death per person-Gy; provided in Table E.2 of Appendix E)

Table D.8 - Dose from exposure to gamma radiation for child

Gamma radiation (μR/h)	Child Exposure dose (Gy)
20	6.90E-05
32	1.91E-05
120	7.20E-05

Table D.9 - Worker dose from exposure to gamma radiation

Gamma radiation (μR/h)	Exposure dose (Gy)
20	2.10E-03
33.5	3.47E-03

Evaluation of Noncancer Hazards from Exposure to Gamma Radiation

CHILD

Gamma radiation dose for child at the highest level of 120 µR/h = 7.20E-05 Gy

7.2E-05 Gy = 7.2 E-05 sv = 0.0072 rem (or 7.20 mrem)

- Acute exposure duration ATSDR MRL (ATSDR, 1999a) for ionizing radiation = 0.004 sv or 0.4 rem is significantly higher than gamma radiation dose of 0.0072 rem.
- Chronic exposure duration ATSDR MRL (ATSDR, 1999a) for ionizing radiation = 100 mrem/year is significantly higher than the child visitor gamma radiation dose of 7.2mrem/year)

OUTDOOR WORKER

Gamma radiation dose for adult worker at the highest level of 33.5 µR/h = 3.47E-03 Gy for 25 years = 1.39E-04 Gy per year = 1.39E-04 sv per year = 0.0139 rem (or 13.9 mrem)

- Acute exposure duration ATSDR MRL (ATSDR, 1999a) for ionizing radiation = 0.004 sv or 0.4 rem is significantly higher than gamma radiation dose of 0.0139 rem.
- Chronic exposure duration ATSDR MRL (ATSDR, 1999a) for ionizing radiation = 100 mrem/year is significantly higher than the outdoor worker gamma radiation dose of 13.9 mrem/year)

Appendix E: Toxicological Evaluation

The basic objective of a toxicological evaluation is to identify what adverse health effects a chemical causes, and how the appearance of these adverse effects depends on dose. In addition, the toxic effects of a chemical frequently depend on the route of exposure (oral, inhalation, dermal) and the duration of exposure (acute, subchronic, chronic or lifetime). It is important to note that estimates of human health risks may be based on evidence of health effects in humans and/or animals depending on the availability of data. This evaluation, like most other toxicity assessments, is divided into two parts: the cancer effects and the non-cancer effects of the radionuclide or chemical.

Ionizing radiation, received in sufficient quantities over a period of time, can result in tissue damage and disruption of cellular function at the molecular level. The effect on deoxyribonucleic acid (DNA) is of particular interest. The effects of ionizing radiation can either be acute (occurring within several hours to several months after exposure) or delayed (occurring several years after the exposure). Cancer is the major latent harmful effect produced by ionizing radiation. The development of cancer is not an immediate effect and may take several years to develop, if it develops at all. Radiation-induced cancers are the same types that are normally found in an unexposed individual. Studies so far have not shown that low dose of ionizing radiation exposure on a daily basis causes any harm. Please see Appendix G for health effect fact sheet (ToxFaQs) on the health effects from ionizing radiation, radium, and uranium.

The dose determines whether an effect will be seen and its severity. To determine how likely it is that a certain dose of radiation will cause cancer, scientists rely on measurements of the radiation dose that specific populations (like the Japanese atomic bomb survivors) have been exposed to. Scientists then calculate risk factors or cancer slope factors for various types of cancer. Using these factors, it is possible to estimate the chance of getting cancer from a dose of radiation. A cancer slope factor is an estimate of the probability of an individual developing cancer per unit intake, or external exposure to a specific carcinogen over a lifetime. Inhalation and ingestion cancer slope factors are central estimates in a linear model of the age-averaged, lifetime radiation cancer risk for incidence of both fatal and nonfatal cancers per unit of activity ingested or inhaled. External exposure cancer slope factors are central estimates of the lifetime radiation cancer incidence risk for each year of exposure to external radiation from radionuclides distributed uniformly in a thick layer of soil. These slope factors are applicable to either chronic or acute exposure to a radionuclide. The radiation risk coefficients for cancer incidence that are the basis of cancer slope factors take into account age and gender differences in radionuclide intake, metabolism, dosimetry, radiogenic risk and competing causes of death. Radiation risk models consider 14 cancer sites in the body to calculate gender-specific values for risk. The cancer sites considered are esophagus, stomach, colon, liver, lung, bone, skin, breast, ovary, bladder, kidney, thyroid, red marrow (leukemia), and residual (all remaining cancer sites combined) (EPA, 1999: FGR 13).

The cancer slope factors are intended to apply to general public who may be exposed to low-levels of radionuclides in the environment. Cancer slope factors (CSF) used in this assessment were adopted from EPA's Table of Radionuclide Toxicity and Preliminary Remediation Goals EPA (2007) and are listed below in Table E-1. These CSFs are obtained from *Federal Guidance Report No. 13*, EPA402-R-99-001 (EPA, 1999b). When the CSFs are not available in FGR 13, EPA adopts data from *Health Effects Assessment Summary Tables*; HEAST (EPA-HEAST, 2001). Selected radionuclides and radioactive decay chain products are designated with the suffix "+" (e.g., U-238+D) to indicate that cancer risk estimate for these radionuclides include the contributions from their short-lived decay products, assuming equal activity concentration with the parent nuclide in the environment. Cancer risk factors for gamma radiation were adopted from Tables 7.3 and 7.6 of FGR 13 (EPA, 1999), and ATSDR acute and chronic MRLs for ionizing radiation were used to evaluate noncancer effects of gamma radiation (ATSDR, 1999a). The noncancer toxicity values (or health guidelines) for uranium were adopted from the ATSDR MRL (ATSDR, 1999c).

Table E-1. Cancer Slope Factors for Radionuclides

Radionuclide	CSF Inhalation (risk/pCi)	Child CSF soil ingestion (risk/pCi)	Adult CSF soil ingestion (risk/pCi)	CSF external exposure (risk/y per pCi/g)
Radium 226 +D	1.16E-08	7.3E-10	2.95E-10	8.49E-06
Th-228+D	1.43E-07	8.09E-10	1.62E-10	7.76E-06
Th-230	2.85E-08	2.02E-10	7.73E-11	8.19E-10
U-234	1.14E-08	1.58E-10	5.11E-11	2.52E-10
U-235 +D	1.01E-08	1.63E-10	5.03E-11	5.43E-07
U-238 +D	9.35E-09	2.1E-10	5.62E-11	1.14E-07
Pb-210 +D	1.39E-08	2.66E-09	2.04E-09	4.21E-09

Note:

- "+D" designates principal radionuclide with associated decay chains
- pCi = Picocuries
- pCi/g - Picocuries Per Gram
- risk/y = Risk per year

Table E.2-Risk Factors for gamma radiation cancer mortality and morbidity

Combined Mortality Risk Factor	Combined Morbidity Risk Factor	Male Mortality Risk Factor	Female Mortality Risk Factor	Male Morbidity Risk Factor	Female Morbidity Risk Factor
0.0575	0.0846	0.0462	0.0683	0.0651	0.103

Note:

- Mortality and morbidity risk factors are expressed as cancer deaths or cancer cases per person-Gy (EPA Federal Guidance No. 13, Table 7.3 and 7.6)

Appendix F: Uranium Noncancer Health Assessment: Subchronic (Intermediate) Health Hazard

Table F-1. Subchronic exposure parameters for young children (0-6 years)

Exposure parameter	Subchronic input value
EPC (ppm)	241.6 parts per million(ppm) [a] (Maximum value)
Soil Intake rate (mg/day)	400
Body Weight (kg)	15
Exposure Frequency (EF)	20 days
Averaging Time (AT)	30 days
Conversion Factor (CF)	0.000001 kg/mg (kilogram per milligram)

[a] EPC for uranium was calculated using the following mass and activity relationship in accordance with EPA (2000 SSL User's Guide available athttp://www.epa.gov/superfund/health/contaminants/radiation/radssg.htm#guide) :

1 mg/kg of U–238 has an activity of 0.33 pCi/g; 1 mg/kg of U–235 has an activity of 2.1 pCi/g; and1 mg/kg of U–234 has an activity of 6200 pCi/g.

The mass concentration (mg/kg) of Uranium = mass concentration of U-238+U-235+ U-234.

Table F-2. Calculation of subchronic (intermediate) hazards to uranium tailings for young children (0-6 years)

Chemical	EPC (ppm)	Exposure dose (mg/kg/day)	Intermediate Health guideline (mg/kg/day)	Intermediate LOAEL (mg/kg/day)	HQ Health guideline	HQ_{LOAEL}
Uranium	241.6	0.0042	0.002	0.05	2.2	0.04

Note:

- Subchronic Exposure Dose = EPC x Soil intake rate (mg/day) x EF x CF/ Body wt.(kg)x AT
- EPC = Exposure Point Concentration
- PPM = Parts per million
- Mg/kg/day – milligram per kilogram per day
- HW = Hazard Quotient

Appendix G: ATSDR ToxFAQs for Ionizing Radiation Radium, and Uranium

ToxFAQs™
for
Ionizing Radiation
(Radiación Ionizante)

This fact sheet answers the most frequently asked health questions about ionizing radiation. For more information, you may call the ATSDR Information Center at 1-888-422-8737. This fact sheet is one in a series of summaries about hazardous substances and their health effects. This information is important because this substance may harm you. The effects of exposure to any hazardous substance depend on the dose, the duration, how you are exposed, personal traits and habits, and whether other chemicals are present.

HIGHLIGHTS: Ionizing radiation, like heat and light, is a form of energy. It includes particles and rays given off by radioactive material, stars, and high-voltage equipment. Most of it occurs naturally and some is produced by human activities. At very high doses, ionizing radiation can cause illness or death. Any dose could possibly cause cancer, after a several-year delay. It is not known how many of the 1,517 National Priorities List sites identified by the Environmental Protection Agency give off ionizing radiation above background levels.

What is ionizing radiation?
Ionizing radiation is any one of several types of particles and rays given off by radioactive material, high-voltage equipment, nuclear reactions, and stars. The types that are normally important to your health are alpha particles, beta particles, x rays, and gamma rays.

Alpha and beta particles are small, fast-moving bits of atoms that a radioactive atom gives off when it changes into another substance. X rays and gamma rays are types of electromagnetic radiation. These radiation particles and rays carry enough energy to knock out electrons from atoms and molecules (such as water, protein, and DNA) that they hit or pass near. This process is called ionization, which is why this radiation is called "ionizing radiation."

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What happens to ionizing radiation when it enters the environment?
Ionizing radiation, which travels as fast as the speed of light, hits atoms and

molecules in its path and loses some of its energy with each hit. When all the energy is gone, there is essentially nothing left. Ionizing radiation does not make you radioactive - it just leaves some of its energy inside you or whatever else it hits.

When ionizing radiation from outer space hits the upper atmosphere, it produces a shower of cosmic rays that constantly expose everything on earth. Some hit gases in the air and change them into radioactive material (such as tritium and carbon 14). Other radioactive materials are naturally part of the environment, such as the uranium that has been here since the earth was formed. Still other radioactive materials are made by industry for smoke detectors, medical tests, and other uses. These radioactive materials give off their ionizing radiation over time until all of the radioactive atoms have decayed.

Whenever radioactive material enters the environment, it behaves like other substances, getting into the air, water, soil, plants, and animals while also giving off radiation.

Some ionizing radiation is made on demand, such as when doctors take x rays.

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How might I be exposed to ionizing radiation?

You are exposed to low levels of ionizing radiation from the sun, rocks, soil, natural sources in your body, fallout from past nuclear weapons tests, some consumer products, and radioactive materials released from hospitals and from nuclear and coal power plants.

You are exposed to more if you work as a pilot, flight attendant, astronaut, industrial and nuclear power plant worker, or x ray or medical personnel.

You receive additional exposure with each x ray exam and nuclear medicine test, and the amount depends on the type and number of tests.

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How can ionizing radiation affect my health?

Exposure to low levels of ionizing radiation from the environment has not been shown to affect human health. Exposure to high doses of ionizing radiation can result in skin burns, hair loss, nausea, birth defects, illness, and death. How you are affected depends on how much ionizing radiation you received and over what period of time, and personal factors such as sex, age at the time of exposure, and your health and nutritional status. Increasing the dose results in a more severe effect. Increased psychological stress has been shown in large populations exposed to small doses of radiation from nuclear accidents. Mental function has been affected in people exposed before birth to high doses of ionizing radiation.

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How likely is ionizing radiation to cause cancer?
Exposure to ionizing radiation may increase your chance of getting cancer. As with other health effects, how likely you are to get cancer depends on how much ionizing radiation you received, your age when exposed, and the type of cancer.

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How does ionizing radiation affect children?
Like adults, children are exposed to small amounts of ionizing radiation that comes from the soil where they live, the food and water they eat and drink, the air they breathe, and from sources that reach earth from space. There is no evidence that exposure to normal background levels of ionizing radiation causes health effects in children or adults.

If a pregnant woman is exposed to high levels of ionizing radiation, it is possible that her child may be born with some brain abnormalities. There is an 8-week period during early pregnancy when an unborn child is especially sensitive to the effects of higher-than-normal levels of ionizing radiation. As the levels of ionizing radiation increase, so does the chance of brain abnormalities.

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How can families reduce the risk of exposure to ionizing radiation?
When you or your children receive an x ray, be sure to correctly wear the protective garments that are provided. The technician will make sure that only the area that needs to be x rayed will be exposed to the x ray beam. If you or your children are treated with a chemical that has some amount of radioactive material in it to help a doctor diagnose or treat a disease, be sure to follow the doctor's directions after you have been treated.

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Is there a medical test to show whether I've been exposed to ionizing radiation?
There are different kinds of tests to see if you have been exposed to very high doses of ionizing radiation. One test examines changes in blood cell counts, but only exposure to high levels of ionizing radiation will produce detectable changes in blood cell counts. Another test studies your chromosomes. This test is useful for doses several times the maximum permissible dose for radiation workers.

There are many ways to see if you have radioactive material in your body. Radioactive material can be measured in your blood, feces, saliva, urine, and your entire body by specialized instruments. The instrument is chosen based on the type of radiation that is to be measured. These tests are not available at your doctor's office.

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Has the federal government made recommendations to protect human

health?

The EPA limits the dose from radionuclides released to the air to 0.1 millirems (mrem)/year. The EPA has set a drinking water standard for radionuclides of 4 mrem/year for man-made sources of beta emitters.

The current federal and state regulations limit workers' doses to 5 rem/year; the limit for an unborn child of a female radiation worker is 0.5 rem/year; the limit for the general public is 0.1 rem/year, with provisions for a limit of 0.5 rem/year under special circumstances.

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References

Agency for Toxic Substances and Disease Registry (ATSDR). 1999. Toxicological Profile for ionizing radiation. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service.

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Where can I get more information?

ATSDR can tell you where to find occupational and environmental health clinics. Their specialists can recognize, evaluate, and treat illnesses resulting from exposure to hazardous substances. You can also contact your community or state health or environmental quality department if you have any more questions or concerns.

ToxFAQs™

for
Radium
(Radio)

CAS#	7440-14-4

This fact sheet answers the most frequently asked health questions about radium. For more information, you may call the ATSDR Information Center at 1-888-422-8737. This fact sheet is one in a series of summaries about hazardous substances and their health effects. This information is important because this substance may harm you. The effects of exposure to any hazardous substance depend on the dose, the duration, how you are exposed, personal traits and habits, and whether other chemicals are present.

HIGHLIGHTS: Radium is a radioactive substance formed from the breakdown of uranium and thorium. Exposure to high levels results in an increased risk of bone, liver, and breast cancer. This chemical has been found in at least 18 of the 1,177 National Priorities List sites identified by the Environmental Protection Agency (EPA).

What is radium?

Radium is a naturally occurring silvery-white radioactive metal that can exist in several forms called isotopes. Radium is formed when uranium and thorium break down in the environment. Uranium and thorium are found in small amounts in most rocks and soil. Two of the main radium isotopes found in the environment are radium-226 and radium-228.

Radium undergoes radioactive decay. It divides into two parts-one part is called radiation and the other part is called a daughter. The daughter, like radium, is not stable, and it also divides into radiation and another daughter. The dividing of daughters continues until a stable, nonradioactive daughter is formed. During the decay process, alpha, beta, and gamma radiation are released. Alpha particles can travel only a short distance and cannot travel through your skin. Beta particles can penetrate through your skin, but they cannot go all the way through your body. Gamma radiation can go all the way through your body.

Radium has been used as a radiation source for treating cancer, in radiography of metals, and combined with other metals as a neutron source for research and radiation instrument calibration. Until the 1960s, radium was a component of the luminous paints used for watch and clock dials, instrument panels in airplanes, military instruments, and compasses.

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What happens to radium when it enters the environment?

- Radium is constantly being produced by the radioactive decay of uranium and thorium.
- Radium is present at very low levels in rocks and soil and may strongly attach to those materials.
- Radium may also be found in air.
- High concentrations are found in water in some areas of the country.
- Uranium mining results in higher levels of radium in water near uranium mines.
- Radium in the soil may be absorbed by plants.
- It may concentrate in fish and other aquatic organisms.

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How might I be exposed to radium?

- Everyone is exposed to low levels of radium in the air, water, and food.
- Higher levels may be found in the air near industries that burn coal or other fuels.
- It may be found at higher levels in drinking water from wells.
- Miners, particularly miners of uranium and hard rock, are exposed to higher levels of radium.
- It may also be found at radioactive waste disposal sites.

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How can radium affect my health?

Radium has been shown to cause effects on the blood (anemia) and eyes (cataracts). It also has been shown to affect the teeth, causing an increase in broken teeth and cavities. Patients who were injected with radium in Germany, from 1946 to 1950, for the treatment of certain diseases including tuberculosis were significantly shorter as adults than people who were not treated.

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How likely is radium to cause cancer?

Exposure to high levels of radium results in an increased incidence of bone, liver, and breast cancer. The EPA and the National Academy of Sciences, Committee on Biological Effects of Ionizing Radiation, has stated that radium is a known human carcinogen.

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Is there a medical test to show whether I've been exposed to radium?

Urine tests can determine if you have been exposed to radium. Another test measures the amount of radon (a breakdown product of radium) in exhaled air. Both types of tests require special equipment and cannot be done in a doctor's office. These tests cannot tell how much radium you were exposed to, nor can they be used to predict whether you will develop harmful health effects.

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Has the federal government made recommendations to protect human health?

The EPA has set a drinking water limit of 5 picocuries per liter (5 pCi/L) for radium-226 and radium-228 (combined).
The EPA has set a soil concentration limit for radium-226 in uranium and thorium mill tailings of 5 pCi per gram (5 pCi/g) in the first 15 centimeters of soil and 15 pCi/g in deeper soil.
The federal recommendations have been updated as of July 1999.

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Glossary

Anemia: A decreased ability of the blood to transport oxygen.
Carcinogen: A substance that can cause cancer.
CAS: Chemical Abstracts Service.
National Priorities List: A list of the nation's worst hazardous waste sites.
Picocurie (pCi): A unit used to measure the quantity of radio-active material.
rem: A unit used to measure radiation dose.

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References

Agency for Toxic Substances and Disease Registry (ATSDR). 1990. Toxicological Profile for radium. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service.

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Where can I get more information?

ATSDR can tell you where to find occupational and environmental health clinics. Their specialists can recognize, evaluate, and treat illnesses resulting from exposure to hazardous substances. You can also contact your community or state health or environmental quality department if you have any more questions or concerns.

ToxFAQs™

for
Uranium
(Uranio)

CAS# 7440-61-1

This fact sheet answers the most frequently asked health questions about uranium. For more information, you may call the ATSDR Information Center at 1-888-422-8737. This fact sheet is one in a series of summaries about hazardous substances and their health effects. This information is important because this substance may harm you. The effects of exposure to any hazardous substance depend on the dose, the duration, how you are exposed, personal traits and habits, and whether other chemicals are present.

HIGHLIGHTS: Uranium is a naturally occurring chemical substance that is mildly radioactive. Everyone is exposed to low amounts of uranium through food, air, and water. Exposure to high levels of uranium can cause kidney disease. It is not known to cause cancer, but can decay into other radioactive materials that may. Uranium above natural levels has been found in at least 54 of the 1,517 National Priorities List sites identified by the Environmental Protection Agency (EPA).

What is uranium?

Uranium is a common naturally occurring and radioactive substance. It is a normal part of rocks, soil, air, and water, and it occurs in nature in the form of minerals - but never as a metal. Uranium metal is silver-colored with a gray surface and is nearly as strong as steel. Natural uranium is a mixture of three types or isotopes called U-234 (^{234}U), U-235 (^{235}U), and U-238 (^{238}U). All three are the same chemical, but they have different radioactive properties.

Typical concentrations in soil are a few parts per million (ppm). Some rocks contain high enough mineral concentrations of uranium to be mined. The rocks are taken to a chemical plant where the uranium is taken out and made into uranium chemicals or metal. The remaining sand is called mill tailings. Tailings are rich in the chemicals and radioactive materials that were not removed, such as radium and thorium.

One of the radioactive properties of uranium is half-life, or the time it takes for half of the isotope to give off its radiation and change into another substance. The half-lives are very long (around 200,000 years for ^{234}U, 700 million years for ^{235}U, and 5 billion years for ^{238}U. This is why uranium still exists in nature and has not all decayed away.

The isotope ^{235}U is useful as a fuel in power plants and weapons. To make fuel, natural uranium is separated into two portions. The fuel portion has more ^{235}U than normal and is called enriched uranium. The leftover portion with less ^{235}U than normal is called depleted uranium, or DU. Natural, depleted, and enriched uranium are chemically identical. DU is the least radioactive and enriched uranium the most.

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What happens to uranium when it enters the environment?

- Uranium is already naturally present throughout the environment. Human activities, wind, streams, and volcanoes can move the uranium around and change the levels that you are exposed to.
- Uranium is found in soil where it may stay for billions of years.
- It exists as dust in the air and the dust settles onto surface water, soil, and plants.
- Uranium enters water by dissolving soil, eroding soil and rocks, or in releases from processing plants. Larger particles settle into the bottom of lakes, rivers, and ponds and join uranium that is there naturally.
- Some plants may absorb uranium or it may stick to the root surface.

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How might I be exposed to uranium?

- Breathing air or drinking water in a place that has higher than background levels of uranium.
- Eating food grown in areas with higher than background levels of uranium.
- Working in factories that process uranium or with phosphate fertilizers, or living near any type of mine.
- Living near a coal-fired power plant.

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How can uranium affect my health?

All uranium mixtures (natural, depleted, and enriched) have the same chemical effect on your body. Large amounts of uranium can react with the tissues in your body and damage your kidneys. The radiation damage from exposure to high levels of natural or depleted uranium are not known to cause cancer (see next section).

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How likely is uranium to cause cancer?

Humans and animals exposed to high levels of uranium did not have higher cancer rates. The Committee on the Biological Effects of Ionizing Radiation (BEIR IV) reported that eating food or drinking water that has normal amounts of

uranium will most likely not cause cancer.
Uranium can decay into other radioactive substances, such as radium, which can cause cancer if you are exposed to enough of them for a long enough period of time. Studies have reported lung and other cancers in uranium miners; however, the miners also smoked and were exposed to other substances that cause cancer, such as radon and silica dust.

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How does uranium affect children?

Like adults, children are exposed to small amounts of uranium in air, food, and drinking water. If children were exposed to very large amounts of uranium, it is possible that they might have kidney damage like that seen in adults. We do not know whether children differ from adults in their susceptibility to the health effects of uranium exposure.

It is not known if exposure to uranium can affect the developing human fetus. In laboratory animals, high doses of uranium in drinking water resulted in birth defects and an increase in fetal deaths. Measurements of uranium have not been made in pregnant women, so we do not know if uranium can cross the placenta and enter the fetus. In an experiment with pregnant animals, only a small amount of the injected uranium reached the fetus.

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How can families reduce the risk of exposure to uranium?

If your doctor finds that you have been exposed to significant amounts of uranium, ask whether your children might also be exposed. Your doctor might need to ask your state health department to investigate.

It is possible that higher-than-normal levels of uranium may be in the soil at a hazardous waste site. If you live near such a hazardous waste site, you should prevent your children from eating dirt and make sure that they wash their hands frequently and before eating. You should also wash fruits and vegetables grown in that soil well, and consider discarding the outside portion of root vegetables.

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Is there a medical test to show whether I've been exposed to uranium?

Uranium is in your normal diet, so there will always be some level of uranium in all parts of your body. Uranium is normally measured in a sample of urine collected and sent to a laboratory. Blood, feces, and tissue samples are rarely used. Because most uranium leaves the body within a few days, higher than normal amounts in your urine shows whether you have been exposed to larger-than-normal amounts within the last week or so. Some highly sensitive radiation methods can measure uranium levels for a long time after you take in a large amount. Also, some radiation equipment can tell if uranium is on your skin.

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Has the federal government made recommendations to protect human health?

The EPA requires that spills or accidental releases of uranium waste into the environment containing 0.1 curies or more of radioactivity must be reported to the EPA.
The EPA is currently working to develop an appropriate drinking water limit for uranium based on a broad range of human and animal health studies.
The Occupational Safety and Health Administration has set occupational exposure limits for uranium in breathing air over an 8-hour workday, 40-hour workweek. The limits are 0.05 milligrams per cubic meter (0.05 mg/m^3) for soluble uranium dust and 0.25 mg/m^3 for insoluble uranium dust.

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References

Agency for Toxic Substances and Disease Registry (ATSDR). 1999. Toxicological Profile for uranium. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service.

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CERTIFICATION

This Durango Discovery Museum health consultation was prepared by the Colorado Department of Public Health and Environment under a cooperative agreement with the Agency for Toxic Substances and Disease Registry (ATSDR). It is in accordance with approved methodology and procedures existing at the time the health consultation was conducted. Editorial review was completed by the Cooperative Agreement partner.

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The Division of Health Assessment and Consultation, ATSDR, has reviewed this health consultation, and concurs with its findings.

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