Public Health Assessment for

JACKPILE-PAGUATE URANIUM MINE
LAGUNA PUEBLO
LAGUNA, CIBOLA COUNTY, NEW MEXICO

EPA FACILITY ID: NMN000607033

NOVEMBER 29, 2017

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
PUBLIC HEALTH SERVICE
Agency for Toxic Substances and Disease Registry

Comment Period Ends:

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THE ATSDR PUBLIC HEALTH ASSESSMENT: A NOTE OF EXPLANATION

This Public Health Assessment-Public Comment Release was prepared by ATSDR pursuant to the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA or Superfund) section 104 (i)(6) (42 U.S.C. 9604 (i)(6), and in accordance with our implementing regulations (42 C.F.R. Part 90). In preparing this document, ATSDR has collected relevant health data, environmental data, and community health concerns from the Environmental Protection Agency (EPA), state and local health and environmental agencies, the community, and potentially responsible parties, where appropriate. This document represents the agency's best efforts, based on currently available information, to fulfill the statutory criteria set out in CERCLA section 104 (i)(6) within a limited time frame. To the extent possible, it presents an assessment of potential risks to human health. Actions authorized by CERCLA section 104 (i)(11), or otherwise authorized by CERCLA, may be undertaken to prevent or mitigate human exposure or risks to human health. In addition, ATSDR will utilize this document to determine if follow-up health actions are appropriate at this time.

This document has previously been provided to EPA and the affected state in an initial release, as required by CERCLA section 104 (i)(6) (H) for their information and review. Where necessary, it has been revised in response to comments or additional relevant information provided by them to ATSDR. This revised document has now been released for a 90-day public comment period. Subsequent to the public comment period, ATSDR will address all public comments and revise or append the document as appropriate. The public health assessment will then be reissued. This will conclude the public health assessment process for this site, unless additional information is obtained by ATSDR which, in the agency's opinion, indicates a need to revise or append the conclusions previously issued.

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Prepared by:

Central Branch
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Summary

Introduction

The Agency for Toxic Substances and Disease Registry (ATSDR) evaluates community exposures and makes recommendations to prevent harmful exposures to hazardous substances in the environment. This public health assessment report evaluates exposures near the Jackpile-Paguate Uranium Mine, a closed open-pit uranium mine near Laguna, New Mexico.

The Jackpile-Paguate Uranium Mine operated from the early 1950s to 1982 and was once the largest open-pit uranium mine in the world. Wastes from mining operations have contaminated streams and reservoirs in the area with uranium, other naturally occurring radioactive materials, and heavy metals. The United States Environmental Protection Agency (EPA) proposed the site to the National Priorities List in March 2012; it was listed in December 2013. ATSDR is responsible for evaluating public health issues related to National Priorities List sites.

The purpose of this report is to evaluate whether exposures to radioactive or other hazardous chemicals from the site are or were high enough to affect the nearby community's health. ATSDR identifies public health actions needed to reduce harmful exposures or better characterize exposures. ATSDR considered exposure to people who:

- Live in villages near the site
- Swim or wade in rivers or the reservoir downstream from the site
- Eat plants, animals, or fish collected or processed near or downstream from the site
- Lived or spent time in the housing area on the site property in the past

ATSDR's evaluation uses environmental data from other groups and agencies, as well as assumptions about how and how often community members may come in contact with contaminants from the site. In February 2017, ATSDR shared an initial draft of this report with the Laguna Pueblo government and EPA to gather feedback on the data and exposure assumptions used. We incorporated comments received in this public comment version of the report. ATSDR will give the public a chance to share additional health concerns and other comments on this draft report during the public comment period. We will issue a final report that includes public comments and concerns and provides responses.

Conclusions

ATSDR reached four important conclusions in this report. These conclusions may change following Pueblo or other community input or availability of new environmental sampling data.

Conclusion 1

Current radon or radiation exposures of most people living in villages near the site that have undergone assessment and abatement activities are not expected to cause harmful effects. However, people could be at an increased risk of harmful health effects, including cancer, if their homes contain sources of radiation or radon that have not been fully assessed or if they do not use their abatement system as directed. We do not know whether past exposures might have harmed health.

Basis for Conclusion

- EPA assessed hundreds of properties in nearby villages and identified properties with radiation levels above background and homes with elevated radon levels. EPA removed radioactive materials or installed radon abatement systems, reducing potentially harmful exposures. Levels of elemental uranium in surface soils were too low to cause harmful effects.
- Not all properties in the villages were fully assessed. Also, radon levels can fluctuate seasonally, and ATSDR received anecdotal information that not all homeowners are able to maintain and run the installed radon abatement systems continuously. Elevated exposures are still possible if sources have not been removed or radon abated.
- Not enough data exist to describe past exposures in the villages.

Next Steps

- ATSDR recommends that EPA continue to offer radiation surveys to residents who may not have participated previously and address any source materials identified. EPA has informed ATSDR that they will continue to support radiation monitoring for interested tribal residents and address source material as necessary and to the extent possible.
- ATSDR recommends that EPA or the Pueblo conduct ongoing radon monitoring and offer assistance to ensure radon abatement systems are operated continuously and maintained effectively. EPA has informed ATSDR that their Radon Program is consulting with the Pueblo on how they can potentially develop an ongoing radon program that best suits the Pueblo's needs.
- ATSDR recommends that EPA sample soils residents might contact in the villages near the site and analyze for other contaminants associated with uranium mining, such as metals. ATSDR will review the data and comment on the health implications of the results, upon request. EPA has informed ATSDR that they will conduct additional environmental sampling to characterize the site through the remedial investigation and feasibility study phase of the Superfund process.

Conclusion 2

Adults and children who swim or wade in the rivers and reservoir downstream from the mine site are unlikely to be harmed by exposure to contaminants in surface water and sediment. We do not know whether past exposures might have harmed health.

Basis for Conclusion

- Estimates of exposure to the highest levels of chemicals and radioactive materials detected in surface water and sediment after closure of the mine were below respective harmful effect levels identified in toxicological literature.
- To reach this conclusion, we assumed that people spend, on average, two hours a day, every day, swimming or wading in surface water downstream from the site. We did not evaluate other possible uses of surface water, such as for drinking, because people in the area are on a public water supply.
- Not enough data exist on downstream surface water or sediment while the mine was operating to allow us to estimate past exposures.

Next Steps

- Based on the limited information on how people might access the site and downstream areas, ATSDR recommends the Pueblo continue to restrict access to the mine and inform the public of the presence of potentially hazardous materials in the watershed downstream. EPA has informed ATSDR that they will continue to work with the Pueblo to maintain public health and safety.
- ATSDR encourages the public to tell us how and how often they use the site and surrounding areas. This will allow us to more accurately estimate possible exposure to community members near the site. ATSDR will hold a public availability session to gather this information and additional health concerns from the community. These concerns will be addressed in the final release of this report.

Conclusion 3

ATSDR does not have enough information to conclude whether eating fish, animals or plants collected or processed near or downstream from the site could harm health.

Basis for Conclusion

- ATSDR has no data on contaminant levels in plants, animals, or fish from near the site or information on how much and how often nearby residents consume them.

Next Steps

- ATSDR recommends EPA sample plants, animals, and fish near the site for metals and radiological contaminants. ATSDR will review the data and comment on the health implications of the results, upon request. EPA has informed ATSDR that they will consider all current and future risk and uptake scenarios and determine the need for bioassay sampling during the iterative sampling process.

Conclusion 4

ATSDR does not have enough information to conclude whether past exposure of people living or spending time in the former mine housing area could harm their health.

Basis for Conclusion

- Little to no data exist to describe contaminant levels in air, soil, or the wells used at the housing area itself. The wells have been removed, and sampling air or soil now will not be representative of possible exposures during mine operations, so we will never have data to estimate past exposures.
- The mine housing area contained residences for mine staff and their families, a school, several other buildings, and recreational facilities. The housing area was within an area considered disturbed by mine operations. People who lived or spent time in this area could have been exposed to contaminants in air, soil, or groundwater used for drinking.
- No one currently lives in the mine housing area, and the residential buildings have been removed. People might have used other facilities in the area until recently, but ATSDR does not have information about when or how often people were there.

Community Recommendations

It will take several years for the site's contamination to be fully understood so plans for cleanup can proceed. In the meantime, ATSDR makes the following general recommendations for community members who want to reduce their potential exposure to uranium, radon, and other contaminants related to mining operations.

- Stay away from the mine site.
- Don't gather plants or take rocks, gravel, dirt, sand, or water from the mine site.
- Graze livestock away from the mine site.
- Allow EPA to survey your property for radiation and your home for radon.
- Use the public water system for all your family's household needs – don't use untreated water.
- Talk with your doctor if you are worried you may have exposure to uranium or radon.
- Follow your doctor's advice to stay healthy. Staying healthy helps your body deal with stressors like uranium or radiation.

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Purpose and Health Issues

The U.S. Environmental Protection Agency (EPA) proposed the Jackpile-Paguate Uranium Mine to the National Priorities List (NPL) in March 2012 and listed it on December 11, 2013. Congress requires the Agency for Toxic Substances and Disease Registry (ATSDR) to conduct public health activities on all sites proposed for the NPL.

This public health assessment evaluates how the Jackpile-Paguate Uranium Mine site might affect public health. ATSDR reviewed available environmental data, ways in which people could come in contact with contaminants from the site, and community health concerns to determine whether adverse health effects are possible as a result of contamination on and near the site. We make recommendations to prevent or reduce harmful exposures, to better understand exposures at the site, or to educate the public about exposures.

In this report, we discuss the different ways people might be or might have been exposed to contamination from the site. We discuss exposures of:

- People who live in villages near the site
- People who swim or wade in rivers or the reservoir downstream from the site
- People who eat plants, animals, or fish collected or processed near or downstream from the site
- People who spent time in the housing area on the site property in the past

We describe data available to characterize the above exposures and use the data to evaluate how exposure might affect public health. If data are limited, we identify information that would be needed to evaluate the exposure. We make recommendations to protect public health by reducing harmful exposures or collecting more information to assess exposures.

ATSDR's Work with the Laguna Pueblo and EPA

The Jackpile-Paguate Uranium Mine site lies within lands owned by the Laguna Pueblo, one of 19 federally recognized pueblos in New Mexico. ATSDR cooperates with tribal governments to conduct public health assessment activities on NPL sites on their lands. The evaluation in this report uses environmental data from other groups and agencies, as well as assumptions about how and how often community members may come in contact with contaminants from the site. In February 2017, ATSDR shared an initial draft of this report with the Laguna Pueblo government and EPA to gather feedback on the data and exposure assumptions used. We incorporated comments received in this public comment version of the report. We plan to hold a public availability session to discuss our findings with community members; meet with representatives of the Laguna Pueblo government and other stakeholders; and conduct a site visit. We will then revise the evaluation to address public comments received during the public comment period and address additional community concerns.

Background

Site Location and Description

The following background comes from site documents [1-3]. The Jackpile-Paguate Uranium Mine is located on the Laguna Pueblo in Cibola County, New Mexico, about 40 miles west northwest of Albuquerque. It operated from about 1953-1982 and was once the largest open-pit uranium mine in the world. The mine property encompassed over 7,600 acres in an area of canyons and arroyos directly east of the village of Paguate. About 2,600 acres of the property were disturbed for mining operations and are considered the “mine site,” shown in Figure 1. The mine site included 3 large open pits, several adits, and numerous waste piles and stockpiles of unprocessed ore scattered throughout the entire facility. The remaining areas outside the mine site were used for facility operations or remained undeveloped and used for limited livestock grazing. Facility operations included a housing area where certain employees and their families lived.

The Jackpile Mine is on the far eastern edge of the Grants Mining District, the main focus of uranium extraction and production operations in New Mexico from the 1950s until the 1990s. The district includes production facilities along the Grants Mineral Belt, which contains most of the uranium in New Mexico and extends along the San Juan Basin through Cibola, McKinley, Sandoval, and Bernalillo Counties as well as on tribal lands [4].

After the mine closed in 1982, the reclamation of the mine was performed to allow land uses including light industrial use, limited livestock grazing, major equipment storage, and some mining. Excluded land uses included farming and any residential use. Although the reclamation project was completed in 1995, subsequent investigations of the site identified the need for further cleanup of radioactive materials and other contaminants at the site or released into the environment around the site. Specifically, releases of hazardous substances from the site into two rivers, the Rio Moquino and Rio Paguate, contaminated fishing areas identified in the Rio Paguate and Paguate Reservoir [3].

Demographics

The mine is in a sparsely populated area. Figure 2 illustrates that about 1,000 people live within a 5-mile radius of the site. The population is almost all Native American. Additional demographic information is shown in Figure 2.

Villages near the mine include the Laguna Pueblo villages Paguate, Laguna, Mesita, Encinal, Paraje, and Seama; and the Spanish Land Grant villages Bibo, Moquino, and Seboyeta. Paguate, with a population of approximately 420, is the closest, immediately west of the mine property boundary and within 1,000 feet of one of the former open pit areas. Residents in other villages, while further from the mine, have reported use of old mine materials and rocks in building materials or as decorative items in or near homes and so are included in our consideration of potentially affected communities.

Figure 1. Location of the Jackpile-Paguate Uranium Mine site showing nearby villages and potentially affected surface water bodies

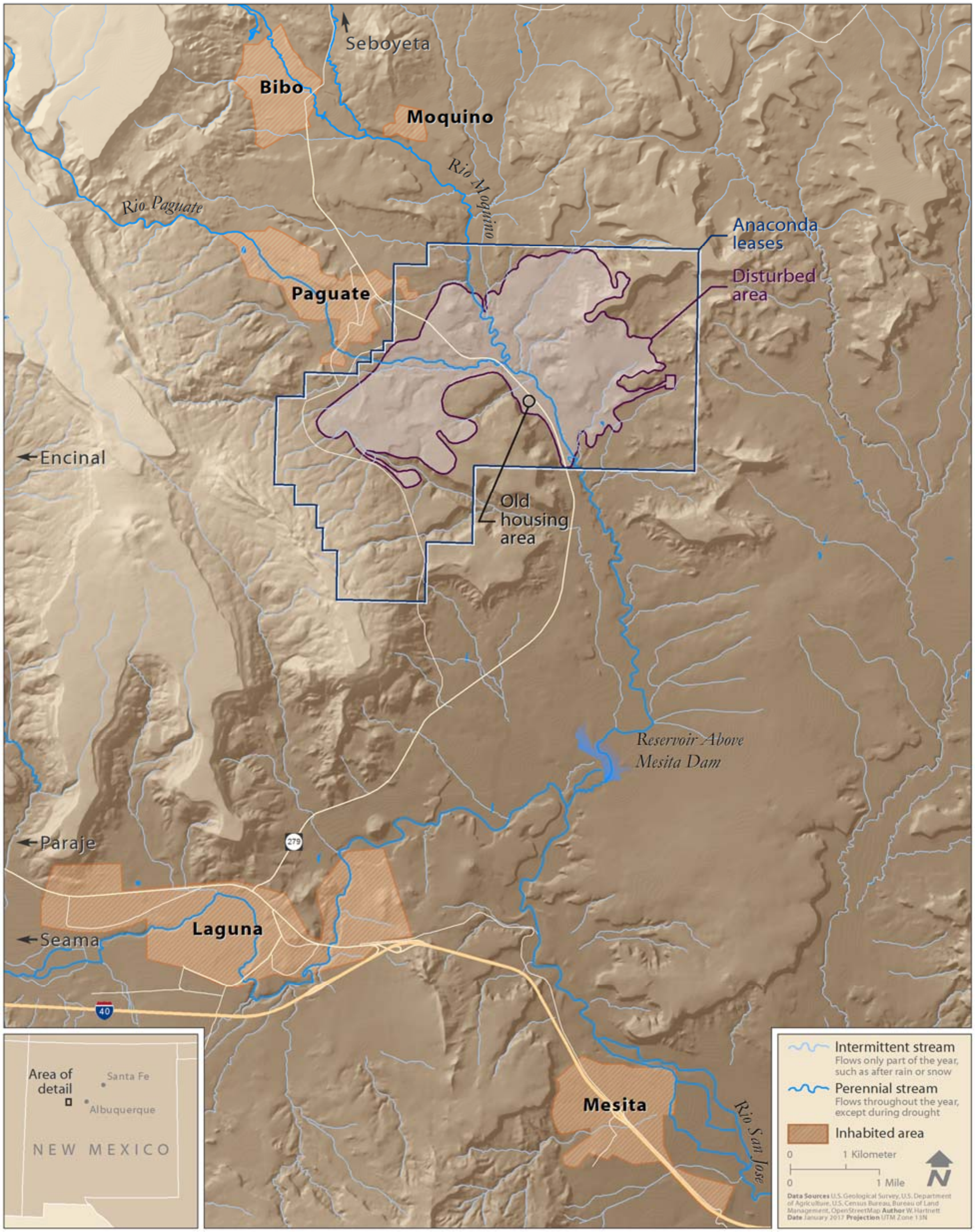
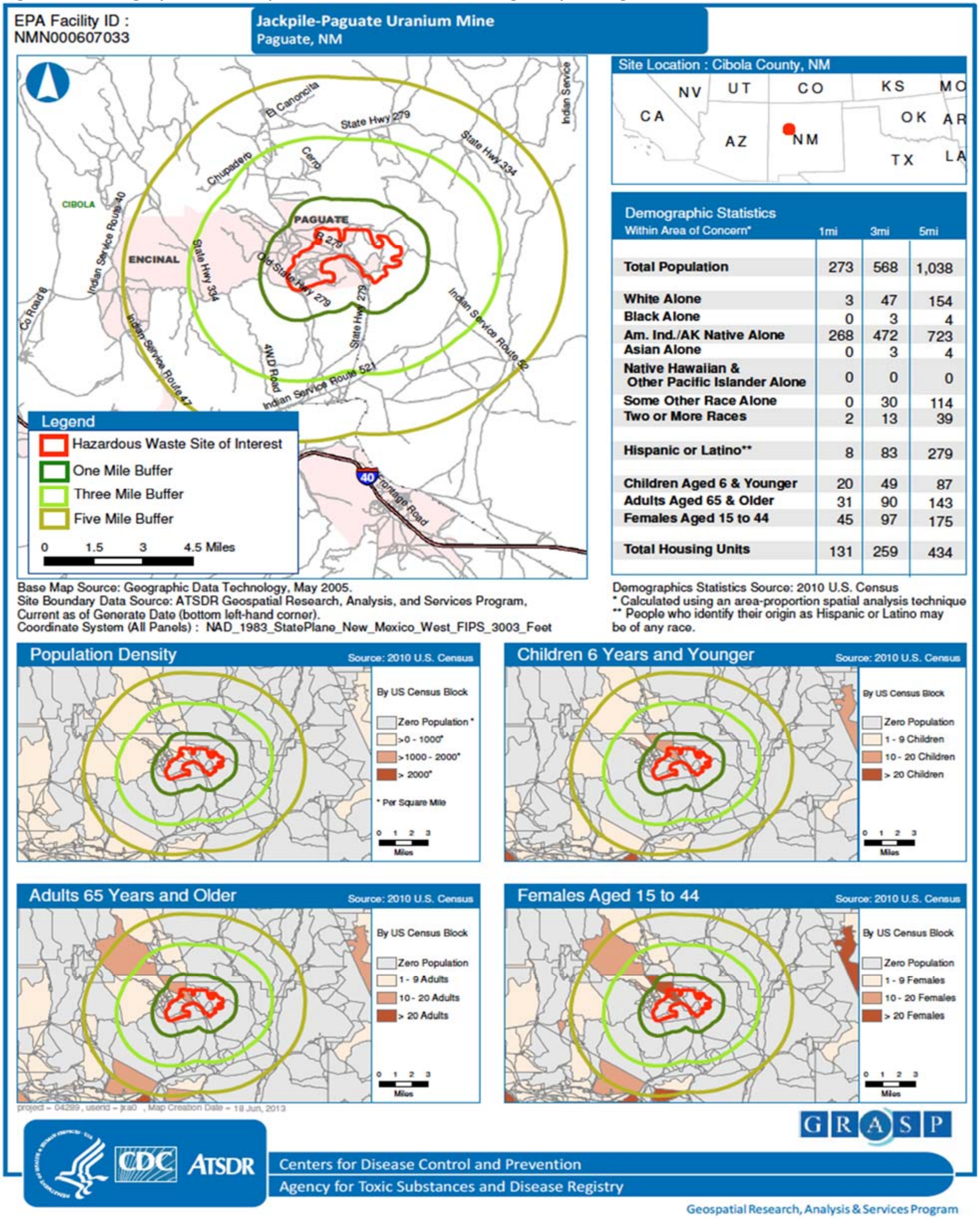


Figure 2. Demographics and Population of Area Surrounding Jackpile-Paguate Uranium Mine, New Mexico



Natural Setting

Geology and Soil

The site contains numerous canyons, mesas, and arroyos and a wide range of soil types. The ore-bearing layer at the mine is the Jackpile Sandstone, and other sandstones and shale are present. Broken rock and gravel from landslides as well as mining activities are present, and volcanic structures and rocks may also be found in the area. Surface soils may be of igneous or sedimentary origin and may contain clay, silt, sand, and gravel [5]. The prevalent fine, sandy soils allow moderate water permeability, but are easily eroded by water or wind. Soils downstream from the mine support more grasses and shrubs that can sustain wildlife or livestock [6].

Water

The Jackpile-Paguate Uranium Mine's location in the desert southwest makes water an important facet of life for the surrounding communities. The following sections only briefly describe the surface water and groundwater characteristics important to the exposure evaluation in this report.

Surface Water

As shown in Figure 1, two rivers flow through the mine site: the Rio Paguate flows from west of the site and out to the south. About midway through the site, the Rio Moquino, flowing from the north, joins the Paguate. Both rivers bisect the mine and contact source materials, and both can interact with groundwater in the vicinity of the mine. After the confluence, the Rio Paguate flows southeasterly about 5 miles into a reservoir above the Mesita Dam. This reservoir was constructed by 1940 and so predates mining activities; much of the reservoir has been filled with sediment. The Rio Paguate flows out of the reservoir across the Mesita Dam and then flows less than a mile before joining the Rio San Jose. Both the Rio Paguate and Moquino flow year-round at the mine site, but south of the site the Rio Paguate becomes intermittently dry [1].

Groundwater

The Jackpile-Paguate Uranium Mine site and surrounding area is underlain by two groundwater aquifers. The aquifer closest to the ground surface is the Alluvium aquifer; it is unconfined, and wells in it can generally produce 15-90 gallons per minute of water. Groundwater in the Alluvium is similar to surface water in the rivers flowing nearby, indicating fairly strong interaction between them [1]. Water in the deeper Jackpile Sandstone Aquifer is of a different chemical nature than that of the Alluvium; however modeling and tests at the facility predict that the aquifers participate in complex interactions with each other, surface water, and backfilled pits remaining at the facility. Groundwater at the facility flows either towards the west-southwest or south, depending on the area of the facility [1].

Climate

The area around the mine is part of a high desert landscape and receives only about ten inches of rain a year, with most rain coming in heavy thunderstorms during the summer months. Snow can also fall in higher elevations during the winter. Winds are affected by local topography and time of day. In the immediate vicinity of the mine, winds are generally from the west.

Natural Resource Use

The Rio Paguate and Rio Moquino are both used for irrigation upstream from the villages of Paguate and Seboyeta, respectively. No drinking water intakes for human consumption are within 15 miles downstream of the site. However, livestock and wildlife drink water from the Rio Paguate and reservoir south of the mine site. Limited fishing has also been reported. No fish advisories are in place at this time.

Public water in the area comes from groundwater north of (upgradient from) the mine site. The village of Paguate's drinking water source is two wells in the Alluvium aquifer north of the mine. A well survey reported 11 wells within a 4-mile radius of the site: two domestic wells not used for the Pueblo's public water, one sanitary well associated with a commercial use, five wells used for mining, milling or oil, and three monitoring wells. All 11 wells were 1.5 miles or more north (upgradient) from the mine [7].

The road to the mine is barred, and the mine site is fenced. The fence does not completely prevent people or animals from getting on the site. Species reported on or near the mine site include elk, Barbary sheep, mule deer, and domestic cattle (personal communication, Adam Ringia, Laguna Pueblo Environmental and Natural Resources Department, May 4, 2017). Also, local streams and the reservoir downstream of the site support fish and waterfowl. People are known to fish and hunt in the general area.

Discussion

Evaluation Process

In this section, ATSDR evaluates the environmental data collected from the Jackpile-Paguate Uranium Mine and nearby areas to evaluate whether harmful exposures to chemicals or radioactive materials are occurring. ATSDR's evaluation process can be briefly summarized in three steps [8]:

- First, we identify possible exposure pathways at the site. An exposure pathway consists of an uninterrupted path from a contaminant source; through the water, air, or soil; and to a person's body where it can possibly cause harm. Chemicals have to get into a person's body to cause harm. The energy from radioactive contaminants may cause bodily harm even when the person is only close to the material, depending on the type of radiation. We look at exposures that occurred in the past, are occurring, or could occur in the future.
- Next, for each exposure pathway we use data describing the contaminants in the water, air, or soil and find the contaminants that are of most concern. For chemicals, we compare the highest concentration of each chemical with levels unlikely to cause harm, even with ongoing exposures. These levels are called comparison values. For radiation and radioactive materials, we compare the exposure rates and concentrations with health-based regulatory limits, recommendations, and typical background radiation levels. If any chemicals or radionuclides are found higher than these values, they aren't necessarily harmful, but we look further at how people may be exposed to see if harmful effects are possible.
- For the chemical substances being evaluated further, we use information about how much and how often people may have come in contact with those substances to estimate the

dose (usually expressed as the amount of contaminant taken in per kilogram of body weight per day) a person might have received through the exposure pathway of interest. Radionuclide evaluation requires more detail as we examine the amount of energy absorbed by various tissues of the body, target organs, and type of radiation emitted based on the contaminant intake. For each substance evaluated, we compare the estimated dose with health guidelines or other scientific literature describing noncancer effects levels in animals and humans to determine if the exposure could cause harm. We also consider substances' potential to cause cancer and estimate to what extent exposures may increase the risk of cancer.

Based on the evaluation, ATSDR makes appropriate recommendations, such as reducing harmful exposures, conducting more sampling to characterize exposure, or educating the local community about environmental exposures and health.

Further details of ATSDR's evaluation process, including tables showing contaminants detected at this site above comparison values, assumptions used to estimate exposure doses, and a description of the comparison values and health guidelines used, are presented in Appendix A.

Exposure Pathways at Jackpile-Paguate Uranium Mine

ATSDR determined that four exposure pathways are or were completed for community members near the Jackpile-Paguate mine site. We recognize that some local residents may be exposed through more than one pathway. The following paragraphs describe the exposures of potential concern for each pathway:

People who live in villages near the site

- People living in homes containing radioactive materials could be exposed to elevated levels of radiation. Although many homes in the area were constructed before the mine began operations, several residents reported that materials and rocks from the mine were used in home repairs or for decorative purposes.
- People in the villages could have breathed mine contaminants suspended in the air, both when the mine was operating and, to a lesser extent, now. People could also breathe radon, a gas produced both naturally and from mine waste products, in either indoor or outdoor air.
- People living in the villages could accidentally swallow soil or particles of soil in dust or get it on their skin. The village soil may contain site contaminants blown or tracked in from the mine.
- People in villages near the site are not exposed to mine contaminants in their drinking water. All the villages around the mine site are on a public water system.

People who wade or swim in rivers or the reservoir downstream from the site

- People wading or swimming in the river or reservoir downstream of the site can be exposed to site contaminants by accidentally swallowing surface water or sediment or getting it on their skin. Site contaminants have affected downstream surface water and sediment, and activities such as fishing, hunting, and gathering plants have been reported in and near the rivers and reservoirs downstream of the site.

People who eat plants, animals, or fish collected or processed near the site

- People could be exposed to site contaminants if they eat plants, animals, or fish collected or processed near or downstream from the site. Plants, animals, or fish from near the mine site or downstream waters could have contaminants from the site on them or they might take up contaminants that could be passed on to people who eat them. Local and EPA officials have reported that people in the area hunt and fish and eat their catch. Also, livestock for consumption graze near the site or downstream.

People who spent time at the housing area on the site property in the past

- People living or spending time in the housing area on the site in the past could have been exposed to mine contaminants in their drinking water. The housing area was near mine operations, and its buildings were supplied with drinking water from five groundwater wells. ATSDR could not determine the exact locations of the wells from available information.
- People living on the site in the past could have accidentally swallowed small amounts of soil or gotten it on their skin. Soil, including tailings and waste piles, on the mine site have been affected by site contaminants.
- People living on the site in the past could have breathed contaminants in the air. Studies from the late 1970s showed that while the mine was operating, outside air at the mine contained radioactive contaminants at higher levels than the surrounding areas and higher than current regulatory standards. Certain activities, such as washing worker clothing, might have exposed some people to higher levels of contaminants than was present in outside air.
- The above pathways are not currently complete. No one currently lives in the mine housing area, and the housing units have been removed. People might have used maintenance facilities in the area until recently. ATSDR does not have information about when or how often people were in this area.

In addition to completed exposure pathways, ATSDR identified potential pathways that might be complete, but we do not have enough information to know for sure. People might occasionally go onto the mine property (for example, for mine tours, to hunt, or to gather rocks). We don't know how often this happens or the exact locations where people might go. We do not have data on contaminant levels remaining in areas that have been reclaimed. Because of the lack of information, ATSDR does not evaluate current exposures on the mine site in this report. However, we recommend people follow posted warning signs and avoid entering the site.

Environmental Sampling Data

Several reports describe results of sampling of water, soil, sediment, and air for site contaminants. Most of the historical water, soil, sediment, and air monitoring data collected was from the mine and processing facility itself and from along the rivers entering and exiting the mine site. Very few samples were collected to describe conditions in residential areas either on the site or in nearby villages. Community assessments near the site have been performed recently (in 2011-2012) by EPA as part of its larger work in the Grants Mining District, also called the Grants Mineral Belt.

Briefly, the data considered in evaluating potential exposures at this site are:

- Radiation surveys, soil sampling, and indoor radon sampling performed by EPA in 2011 and 2012 as part of its community assessment work in the Grants Mining District, which includes the Laguna Pueblo. These are described in emergency removal memos from EPA and include results from sampling at hundreds of properties in Paguate, Bibo, Seboyeta, Moquino, Encinal, Laguna, Paraje, Mesita, and Seama. [9-14].
- Limited indoor and outdoor air sampling for radon and air particulate sampling for radiological materials collected in the late 1970s [15]. These data included one year of monthly sampling for radon at three locations in various communities, one year of monthly particulate radiological sampling at five locations in various communities, and one month of ambient radon measurements at about 10 locations in various communities in and around the mine.
- Limited groundwater sampling for radionuclides, selenium, vanadium and water quality parameters collected by EPA in 1975 [16]. These regional groundwater data included three wells on the mine property and the Paguate municipal well. The results only included one point in time.
- Groundwater and surface water sampling for radionuclides, certain metals and water quality parameters reported in the Environmental Impact Statement [2]. These data included results summarized from historical reports representing 10 locations on surface water bodies upstream, downstream, and on the mine site and 15 groundwater samples whose locations were not identified.
- Groundwater, surface water, and radon sampling collected from 1986-2006 and described in the Record of Decision Compliance Assessment [3]. These data included summarized results from groundwater and surface water sampling at various locations. ATSDR considered these data; but chose not to include them in quantitative exposure estimates because of quality control questions raised in the Compliance Assessment.
- Surface water and sediment sampling for radionuclides and metals collected in 2010 as part of the Site Investigation [17]. These results represent surface water and sediment samples from 10 locations downstream of the mine site.
- Groundwater, surface water and sediment sampling for radionuclides and metals collected in 2011 as part of the Expanded Site Investigation [7]. These results represent groundwater samples from 8 wells on and downgradient of the site and surface water and sediment samples from 8 locations downstream of the mine site.

The data in each report were considered, though not all results could be used to evaluate potential exposures. Later in the report, we describe which specific data results were used to represent potential exposures.

Although ATSDR used the best available data, we recognize that use of some of these reports' data is limited. The types of radiation surveys conducted by EPA could not be used to quantify individual doses. For historical data, only a few samples were collected to describe contaminant levels across miles of areas potentially affected by the site.

For example, discrete surface water and sediment samples were collected from each river exiting the site, the rivers' confluence, and the reservoir five miles downstream. Any one of these sample locations could represent an exposure point that someone could regularly access. For this reason, ATSDR used the maximum concentrations measured to estimate potential exposures from surface water or sediment.

ATSDR is aware that Laguna Pueblo collects surface water samples on a quarterly basis and that academic researchers at University of New Mexico have sampled surface water and plan to sample air in the vicinity of the site (personal communication, Adam Ringia, Laguna Pueblo Environmental and Natural Resources Department, November 2, 2016). This initial report does not include or assess these data. If the data are provided to ATSDR, we will consider including them in the final version of this report.

The next section evaluates the data available for each completed pathway and exposure scenario to determine possible exposures and the likelihood for resulting harmful health effects.

Evaluation of Available Data for Completed Exposure Pathways

People who live in villages near the site

Exposure to Drinking Water (past, present, future)

People who live near the site are <u>not</u> exposed to contaminants in their drinking water. All the villages near the site are on a public water system that obtains its water from a well north of (upgradient from) the site. Based on a well survey reported by EPA, all groundwater wells within 4 miles of the site are 1.5 miles or more upgradient from the site and would not be affected by the site. People do not use surface water downstream from the site for drinking: no drinking water intakes exist for at least 15 miles downstream of the site on the Rio Paguate, Rio Moquino, Paguate Reservoir, or Rio San Jose past the village of Mesita [1].

Exposure to Radiation (past, present, future)

People living in the villages near the site could have been or could still be exposed to radiation from mine materials. Reportedly, some people used rocks from the mine to repair or construct building foundations or other structural units of their homes, and people also used rocks, petrified wood, or other materials for decorative uses in and around their homes. Items that contain high levels of radioactivity could expose people nearby to elevated levels of ionizing radiation.

EPA worked with the local community and the Pueblo to conduct assessments of individual properties in villages near the mine in 2011 and 2012 [9-14]. The assessment results were used to determine the need for time-critical removals of radioactive source materials, installation of radon abatement systems, or (in two cases where cleanup/abatement was not feasible) provision of replacement residences. See Table 1 for a summary of the assessments.

EPA documents describe the properties assessed and the assessment protocols [10,11]. In Paguate, assessment included a combination of outdoor gamma radiation measurements, soil sampling for radium-226 and elemental uranium, and 7-day radon sampling indoors. If indicated by initial testing, EPA followed up with 91-day radon sampling and additional indoor gamma measurements [10]. For assessments in villages further from the site, 7-day radon sampling and further indoor sampling was offered if warranted by initial outdoor results. This section describes the results and actions taken in response to elevated radiation measurements. Radon results are discussed in the air section below, and soil results for uranium in the soil section following.

EPA assessed 143 residential properties (more than 98% of the occupied housing units) in Paguate, the village closest to the Jackpile mine. Of these, 27 (about 18% of those assessed) had some form of removal or radon abatement [9,10]. EPA also took action at 11 of 185 properties assessed in other Laguna Pueblo villages near the site (Encinal, Laguna, Mesita, Paraje, and Seama) and at 13 of 74 properties assessed in Bibo, Seboyeta, and Moquino (three villages north of the mine site and not on Laguna Pueblo land) [11,12]. EPA provided replacement residences in two cases: in one, the home's foundation was the source of elevated gamma radiation and could not be removed feasibly and in the other installation of a radon abatement system was not structurally feasible [13,14].

ATSDR cannot perform a quantitative risk assessment from the information collected during residential assessments because the data are not detailed enough to perform a dose estimate. Removing sources contributing to higher-than-background radiation measurements will reduce harmful exposures in residents and are thus protective of public health.

Table 1. Summary of EPA Assessments at Properties near Jackpile-Paguate Uranium Mine in 2011-2012

Site (Villages Included)	***Residential Properties Assessed***	***Properties Requiring Removal or Radon Abatement***
Oak Canyon (Paguate)	145	27
Bear Canyon (Bibo*, Seboyeta*, Moquino*)	74	13
Rio San Jose (Encinal, Laguna, Mesita, Paraje, Seama)	185	11
Sun Clan Road (New Laguna)	1	1
Middle Reservoir Road (Paguate)	1	1
*Not on Laguna Pueblo land		

Exposure to Contaminants in Air, Including Radon (past, present, future)

People living in the villages near the site could have been or could still be exposed to contaminants in air. In 1975-1976, EPA sampled for airborne particulates in villages near the mine, including Paguate, Bibo, Mesita, and Old Laguna [15]. As summarized in Table 2 below, the annual average activities for several isotopes were lower than air levels thought to harm health. However, the radiological data only covered one year. Only limited data for particulates was available, and no information on metals, organics, or other contaminants in the air were found. Because of these limitations, the data cannot be used to reach a definite conclusion about health effects of past exposure to these contaminants for people who lived in the villages during mine operations.

The mine has been closed for many years, so particulates are no longer released from mining operations. Particulates from mine waste piles or other unreclaimed areas may still reach nearby villages, and people in villages may also be exposed to radon in the air. Radon is a natural radiological decay product of both uranium and radium, which may be present in soil or structures in the villages from past uses.

Table 2. Summary of Historical Radiological Contaminants in Air Particulates in Outdoor Air from December 1975 to December 1976 – Villages Near the Jackpile-Paguate Uranium Mine, New Mexico

Isotope	***Annual Average in pCi/m³***				***Typical Background in pCi/m³***	***Levels Generally Regarded as Unlikely to be Harmful****
	Paguate	Bibo	Mesita	Old Laguna		
Uranium (total)	0.002	0.0008	0.0006	0.0005	0.0002	0.03 pCi/m³
Radium 226	0.001	0.0002	0.0003	0.0002	0.0001	0.9 pCi/m³
Thorium 232	0.0001	0.00006	0.00008	0.00002	0.00003	0.02 pCi/m³
Thorium 230	0.001	0.0003	0.0002	0.00008	0.00005	0.004 pCi/m³

pCi/m³ = picocuries of activity per cubic meter of air. Samples were collected on filters over approximately one month (i.e., annual average is the mean of 12 filter analysis results collected over the year).
"Annual Average" and "Typical Background" are site-specific data derived from [15]. Total uranium was calculated by adding the results of each detected isotope.
The village of Bibo is not on Laguna Pueblo land.
*Level for uranium is ATSDR's minimal risk level converted to radioactivity units using natural abundances of uranium in ore. Level for radium and thorium are regulatory effluent limits to air that would give a member of the public a dose of no more than 50 millirem per year, a dose that is not expected to harm health [18].

In the community assessments, if 91-day sampling showed radon levels indoors at or greater than EPA's recommended long-term residential level of 4 pCi/L (equivalent to 4,000 pCi/m³), EPA installed a radon abatement system [10,11,19]. This action was protective against harmful exposures.

However, not all homes had long-term radon sampling. Some homeowners declined any sampling at all, and some could not be scheduled for radon sampling. Radon levels in homes may fluctuate seasonally. Also, abatement systems must be run continuously and properly maintained to be effective. ATSDR recommends that EPA or the Pueblo conduct ongoing radon monitoring in all homes and offer assistance to ensure radon abatement systems are operated continuously and maintained effectively.

Exposure to Contaminants in Soil (past, present, future)

People living in the villages near the site could have been or could still be exposed to contaminants in soil by touching soil or accidentally swallowing particles of soil in dust. The village soil could have contaminants from the site either from airborne deposition or from contaminated soil being brought or otherwise tracked into the village.

EPA collected composite surface soil samples from each property as part of the 2011-2012 residential removal assessments. The samples were analyzed for elemental uranium by X-ray fluorescence in the field, and a fraction were sent for laboratory analysis. For over 300 properties sampled in the villages of Paguate, Laguna, Mesita, Paraje, and Seama, elemental uranium concentrations in the field were consistently between 8 and 15 milligrams uranium per kilogram of soil (mg/kg); one property had a field measurement for elemental uranium of around 90 mg/kg [10,11]. Laboratory analysis of elemental uranium (including the one property with a higher field reading) were all less than 3 mg/kg. The concentrations were all lower than EPA's action level for residential soil, 230 mg/kg. All of the laboratory results are below, and the field results at or slightly higher than, ATSDR's chemical comparison value for intermediate child exposure to soluble uranium salts of 11 mg/kg. Uranium in soil would include insoluble as well as soluble uranium. These findings indicate that residential exposures to elemental uranium in soil are unlikely to result in harm [18].

Limited soil sampling was performed by EPA in 1975 [15]. Samples of the top 5 centimeters of soil were collected in Paguate, Mesita, Bibo, and Moquino and analyzed for Radium-226. Village soils contained from 0.78 to 1.1 pCi/g Ra-226, compared to a background sample from Laguna which had 0.62 pCi/g Ra-226. Those samples would not be considered significantly different from background. These results cover only a single point in time, not enough to determine health effects that may have resulted from past exposure.

No past or current data on other contaminants in village soils are available. ATSDR recommends EPA sample soils residents might contact for other contaminants associated with uranium mining, such as metals, to allow us to better estimate recent and current exposures to residents of villages near the site.

People who wade or swim in the rivers or the reservoir downstream from the site

People who wade or swim in the rivers and reservoir downstream from the site could be exposed to site contaminants by accidentally swallowing water or sediment or by getting water or sediment on their skin.

Exposure of Adults and Children to Contaminants in Surface Water and Sediment (past, present, future)

ATSDR evaluated results of surface water and sediment sampling from rivers downstream of the site to the Paguate Reservoir. Radiological and chemical contaminants have been detected in both surface water and sediment. To focus on the contaminants of most potential concern, ATSDR screened the maximum surface water or sediment concentration of each contaminant against health-based comparison values, as described in Appendix A. Table A2 in Appendix A shows surface water contaminants that were detected above drinking water comparison values, and Table A3 shows sediment contaminants that were detected at concentrations above soil comparison values. Drinking water and soil comparison values are protective and were used because values for surface water or sediment are not available. The contaminants detected at or above comparison values were antimony, arsenic, sodium, sulfate, thallium, and uranium for surface water; and antimony, arsenic, and uranium for sediment. These contaminants were selected for further analysis and described below.

People could be exposed to contaminants in surface water by getting the water on their skin, or accidentally swallowing water. While people are swimming or wading in the rivers or reservoir, they could stir up sediment particles and get them on their skin or accidentally swallow them. Because these water bodies are remote, we assumed only older children (age 6 and above) or adults would be exposed. To estimate potential exposure dose, ATSDR assumed children and adults spent, on average, 2 hours each day on and in the rivers and reservoir downstream of the site.

Only a few data points covering a large area from the site to the reservoir were available. Because people might visit the same location frequently, we assumed people would be exposed to the highest concentration measured in both surface water and sediment the entire time they spent on and in the rivers and reservoir.

We used the above assumptions to estimate a combined oral dose, from accidental ingestion and skin contact with surface water and sediment, to each of the six contaminants that exceeded a comparison value. For estimating the risk of cancer, we assumed exposure would continue for 33 years, a high-end estimate for occupancy in one location based on population mobility [22]. Details of the exposure assumptions and exposure estimation process are presented in Appendix A. Each contaminant is discussed below.

Antimony

Child exposure doses were estimated as 0.0005 to 0.0008 milligrams of antimony per kilogram of body weight per day (mg/kg/day), and the adult dose was estimated as 0.0001 mg/kg/day. The adult dose is lower than the oral reference dose (RfD) of 0.0004 mg/kg/day and is not expected to result in harmful non-cancer health effects. The child doses are slightly higher than the RfD. The RfD is based on a toxicological study in which rats fed 0.35 mg/kg/day antimony had decreased lifespans and altered blood glucose and cholesterol levels [23]. The oral RfD was obtained by applying an uncertainty factor of 1000 (10 for interspecies conversion, 10 to protect sensitive individuals, and 10 for use of an effect level rather than a no-effect level) to the effect level. It is unlikely that children with doses only slightly higher than the RfD would experience any harmful health effects.

Arsenic

Child exposure doses were estimated as 0.0001 to 0.0002 milligrams of arsenic per kilogram of body weight per day (mg/kg/day), and the adult dose was estimated as 0.00004 mg/kg/day. Child and adult arsenic doses are lower than the minimal risk level (MRL) of 0.0003 mg/kg/day and are not expected to result in harmful non-cancer health effects [24]. Arsenic is classified by the National Toxicology Program (NTP) as a known human carcinogen, and it has been associated with liver, kidney, lung, and skin cancer, especially basal and squamous cell carcinoma [25]. Based on EPA's oral cancer slope factor for arsenic of 1.5 $(mg/kg/day)^{-1}$, exposure to the highest concentration of arsenic measured at this site in surface water and sediment for two hours a day, for 33 years starting at age 6 would increase the lifetime risk of cancer by 5 out of 100,000. This is considered to be a very low increased cancer risk.

Sodium

Sodium is needed in the body for proper muscle and nerve function, but high sodium intake can affect blood pressure. Therefore, sensitive groups (such as some people with high blood pressure or kidney problems) may be on sodium-restricted diets. The Centers for Disease Control and Prevention recommends sensitive groups consume no more than 1,500 milligrams per day (mg/day) of sodium [26,27]. Children and adults swimming or wading in the surface waters downstream from the site are estimated to take in 80-120 mg/day of sodium, mostly from accidentally swallowing the water. This could add to a person's daily sodium intake, but is unlikely to result in harmful effects by itself.

Sulfate

Human studies have shown that sulfate induces a laxative effect in people who are suddenly exposed to concentrations in their drinking water greater than 500,000 µg/L [28]. The highest concentration of sulfate measured in surface water contained sulfate at a concentration slightly higher than this level. People develop a tolerance to the sulfate in drinking water if the levels remain high over several days. Because people swimming or wading in surface water are assumed to only accidentally swallow small amounts of water, it is unlikely anyone would experience any effects from sulfate in the surface water, even at the highest concentration measured.

Thallium

Child exposure doses were estimated as 0.00007 to 0.0001 milligrams of thallium per kilogram of body weight per day (mg/kg/day), and the adult dose was estimated as 0.00004 mg/kg/day. Chronic toxicity studies of thallium are limited. EPA has developed a provisional chronic oral reference dose of 0.00001 mg/kg/day for screening at Superfund sites based on a study of rats fed soluble thallium directly to the stomach at various doses for 3 months [29]. EPA considered atrophy of hair follicles seen in some rats at a dose of 0.04 mg/kg/day as a lowest effect level and applied an uncertainty factor of 3,000 to derive the provisional chronic oral RfD. California's Office of Environmental Health Hazard Assessment used the same study to develop a Public Health Goal for thallium in drinking water, using a dose of 0.04 mg/kg/day as a no-effect level for hair loss and an uncertainty factor of 3,000 [30,31].

Although the child and adult estimated doses for exposure to the highest concentration of thallium are higher than the provisional chronic oral RfD, harmful health effects such as loss of hair are very unlikely for this exposure. Conservative, protective assumptions are incorporated both into the site-specific exposure estimate and the general provisional RfD derivation. Both study effect levels and exposures in which actual health effects were observed in humans are many times greater than the estimated exposures for people using the rivers and reservoir downstream from the site.

Uranium

Child exposure doses were estimated as 0.001 to 0.002 milligrams of uranium per kilogram of body weight per day (mg/kg/day), and the adult dose was estimated as 0.0006 mg/kg/day. These doses are higher than the intermediate oral MRL for soluble forms of uranium of 0.0002 mg/kg/day. The intermediate oral MRL is based on a study in which rats fed uranium for 3 months at doses as low as 0.06 mg/kg/day showed microscopic structural changes in kidney cells; higher doses caused the kidneys to function improperly [18]. The intermediate MRL was obtained by multiplying the 0.06 mg/kg/day minimal effect level by an uncertainty factor of 300 (3 for use of a minimal lowest effect level, 10 for extrapolation from animals to humans and 10 for human variability). Some studies have shown that the kidney can repair or regenerate cells damaged by low doses of uranium; thus the intermediate MRL may also be protective of chronic (years) exposure. The estimated exposure is unlikely to cause harm to kidney function or other health effects.

Besides acting as a metal, uranium emits radiation that may cause health effects. The radiation from naturally occurring uranium such as the amounts found in the surface waters and sediment downstream from the mine site, only slightly above background radiation levels, would not be expected to cause any measurable effects on health. The International Agency for Research on Cancer has found inadequate evidence in humans for the carcinogenicity of natural uranium [21].

Summary

In summary, doses based on regular exposure to the highest contaminant concentrations measured in surface water or sediment are likely too low to cause harmful health effects. These conclusions are based on the assumption that children and adults use the waters downstream of the site, on average, 2 hours a day, for activities that may involve swimming or wading. Different uses or frequencies of use may change these conclusions.

People who eat plants, animals, or fish collected or processed near the site

People could also be exposed to contaminants by eating plants, animals, or fish affected by the site. Metals and radiological contaminants associated with the site have the potential to build up in organisms and be passed on to people who eat the organisms. Contaminants could also settle on food processed outdoors near the site. No data were provided to ATSDR on contaminant levels in plants, animals, or fish; nor do we have information on how much and how often nearby residents might consume them. Therefore, we do not have enough information to evaluate whether eating plants, animals, or fish from near the site could harm people's health. ATSDR recommends collecting samples of plants, animals, and fish representing what local residents consume to allow us to estimate recent past and current exposures from this pathway.

People who spent time in the housing area on the site property in the past

The mine property included facilities areas covering about 66 acres in at least two section of the site. The "housing area" included 18 residences for certain mine employees and their families, playground equipment and tennis/ basketball courts, and various facility buildings including a school, miners' education building, and maintenance and repair shops. This area was supplied with drinking water from five groundwater wells (named Jackpile well #1 through #5). [2]. The "P-10" site included various office and shop buildings and was supplied with drinking water from two groundwater wells (named P-10 well and New Shop well) [2].

ATSDR's evaluation focuses on exposure of nearby community members rather than occupational exposures. For this reason, we focus the following discussion on people who lived or spent time in the housing area. This area was more likely to be occupied by people who were not directly involved in mining or other worker-related processing activities, but may have experienced exposure nonetheless. People at the housing area could have been exposed to site contaminants through groundwater used for drinking, through air, or through soil.

Exposure to Contaminants in Groundwater (past)

The 1986 Environmental Impact Statement report lists utilities in the housing area as including five wells, a water distribution system, and water storage tanks [2]. There is no mention of any treatment system for the groundwater, nor could ATSDR locate any specific water quality sampling data or discussion in historical documents. Two early reports mention a well referred to as #4 which was a major source of groundwater used at the site and was tested and shown to contain very little radiological or metals contamination [2,16]. However, sampling of another potable well (the New Shop well) found slightly elevated levels of radium-226 (Ra-226), and later reports documented radiological and metals contamination of monitoring wells on the site [16,17,7]. We do not know how the housing area wells compare in depth, construction, or location to any of these wells, so we are unable to reach a conclusion about health effects from past exposure to contaminants in drinking water at the housing area. The wells have been closed and cannot be sampled now.

Exposure to Contaminants in Air (past)

People living or spending time in the housing area in the past could have been exposed to contaminants in air. Air samples collected within and around the mine, including samples collected specifically at the housing area, showed elevated levels of naturally occurring radioactive materials including radon and ore-related products [15]. As summarized in Table 3 below, the annual average activities of several isotopes in air at the housing area were higher than background. The measured levels were lower than air levels thought to harm health. Radon was also tested both in ambient air and in one of the houses in the housing area; radon did not appear to be elevated over recommended levels.

These air data are very limited. The particulate sampling only covered one year of the operation, and the radon sampling was a single point in time. Concentrations could have changed over time. Also, no information on other contaminants that might have been present in particulates was found. The available data cannot be used to reach a definite conclusion about health effects of past air exposures at the housing area.

Table 3. Summary of Historical Radiological Contaminants in Air Particulates from December 1975 to December 1976 – Mine Housing Area, Jackpile-Paguate Uranium Mine, New Mexico

Isotope	*Annual Average in pCi/m^3*	*Typical Background in pCi/m^3*	*Levels Generally Regarded as Unlikely to be Harmful**
Uranium (total)	0.005	0.00024	0.03 pCi/m^3
Radium 226	0.002	0.0001	0.9 pCi/m^3
Thorium 232	0.00004	0.00003	0.02 pCi/m^3
Thorium 230	0.003	0.000045	0.004 pCi/m^3

pCi/m^3 = picocuries of activity per cubic meter of air. Samples were collected on filters over approximately one month (i.e., annual average is the mean of 12 filter analysis results collected over the year).

"Annual Average" and "Typical Background" are site-specific data derived from [15]. Total uranium was calculated by adding the results of each detected isotope.

*Level for uranium is ATSDR's minimal risk level converted to radioactivity units using natural abundances of uranium in ore. Level for radium and thorium are regulatory effluent limits to air that would give a member of the public a dose of no more than 50 millirem per year, a dose that is not expected to harm health [18].

Exposure to Contaminants in Soil (past)

People living or spending time in the housing area in the past could have been exposed to contaminants in soil by touching soil or accidentally swallowing particles of soil in dust. The only available soil data from the housing area were reported in a 1979 report [15]. One sample of the top 5 centimeters of soil was collected and analyzed for Radium-226. The results showed a Ra-226 activity of 3.9 pCi/g, which is higher than typical Ra-226 backgrounds of about 1 pCi/g. Although this result suggests that soil exposures at the housing area could be higher than background, a single point is not enough to determine health effects that may have resulted from past exposure.

Exposure to Contaminants in Plants, Animals, or Fish (past)

People living or spending time in the housing area in the past could have been exposed to contaminants in plants or animals gathered, hunted, or grazed near the mine site, or in fish caught downstream from the mine site. However, we do not have data on these possible exposures.

Summary

Those people who lived or spent time in the housing area could have been exposed to contaminants in air, soil, or groundwater. The limited data on contaminants in air and soil, and no data on groundwater used at the housing area, are insufficient to evaluate the health impacts of past exposures.

Local officials informed ATSDR that, until a year or two ago, people still used remaining facilities in or near the old housing area. We do not have enough information to evaluate possible exposures to these people.

Community Health Concerns

ATSDR considers community health concerns and other information from the community as it estimates and evaluates exposures at sites. The community health concerns listed below were shared by a private citizen, representatives of the Laguna Pueblo, and EPA. We will update this section with additional concerns shared during the public comment period for this report.

Concern Raised: Increased rates of cancer due to historic mining activities and ongoing exposure from the open pit.

ATSDR Response: ATSDR will contact the New Mexico Department of Health and refer the community concern about cancer incidence to them. Historic mining activities have been shown to have released radioactive material into the surrounding area. The reclamation work that has been done to date in formerly disturbed mine areas included cover materials designed to reduce release of radioactive material and prevent radiological contamination. As part of the Superfund process, EPA will oversee investigations of the nature and extent of radiological and chemical contamination related to the site and develop plans for addressing contamination.

Concern Raised: We are still being exposed to high levels of radiation in the air close to the mine.

ATSDR Response: Very recent air sampling data were not available to ATSDR for this evaluation. If air data become available, we will consider evaluating them in a later version of this report. General areas of higher radiation have been identified during aerial flyovers by EPA's Airborne Spectral Photometric Environmental Collection Technology (ASPECT) program. Detailed ground surveys were conducted in 2011 and 2012 in these areas through EPA's community assessments to identify source materials. Radiation sources were removed by EPA.

Concern Raised: Radon is slowly killing us.

ATSDR Response: Radon is a naturally occurring radioactive gas. Long-term exposure to elevated levels of radon and its decay products in air increases the risk of lung cancer. The risk is even greater in people who smoke cigarettes. EPA recommends action to remove radon from homes if the long-term concentration of radon is 4 pCi/L or greater [19]. EPA has assessed hundreds of homes in the area around the mine site and installed radon abatement systems in homes where long-term radon concentrations were above the action level. However, not all homes were assessed, and the installed systems have to be run continuously and maintained to be effective. ATSDR recommends that EPA or the Pueblo conduct ongoing radon monitoring particularly homes that have not yet been assessed and offer assistance to ensure radon abatement systems are operated continuously and maintained effectively.

Concern Raised: Young people who started working at the mine in their early teens were exposed to radiation.

ATSDR Response: We don't have enough information to estimate exposures of former mine workers to radioactive materials. People exposed to radiation at an earlier age may be at an increased risk for harmful effects. Younger workers may have taken in proportionately higher amounts of radionuclides, because their duties may have involved more contact with contaminated materials (more potential intake) or more physical exertion (higher breathing rates) and they may have been smaller/lighter than older workers. Also, certain organs such as the bones can accumulate internally deposited radionuclides faster during periods of growth such as adolescence.

The external radiation dose generally depends on how long the person was exposed; if younger workers stayed in their jobs throughout their lives this could have resulted in a greater external dose compared to workers who started at a later age.

Concern Raised: Lack of quality hospitals/ medical facilities in the local area. All the people in Laguna need to be seen by good doctors and tested.

ATSDR Response: Local residents concerned about their health should first consult with their personal physician or medical provider. The Laguna Pueblo is served by the Acoma Canoncito Laguna Indian Health Service Unit located in Acomita, New Mexico. If asked, ATSDR can facilitate a consultation between a community member's physician and specialists in environmental medicine at the American College of Medical Toxicology. The New Mexico Department of Health also serves as a resource for health questions.

Concern Raised: How can we be sure that the air, water, and clay we use are safe?

ATSDR Response: As part of the Superfund process, EPA will oversee investigations of the nature and extent of radiological and chemical contamination related to the site and develop plans for addressing contamination and minimizing exposures to people. ATSDR will remain engaged and work with EPA, the Pueblo, and other stakeholders to give input on public health questions related to exposure throughout this process.

Concern Raised: Can radiation/radon be baked out of pottery made with radioactive clay?

ATSDR Response: Radon is a gas, and would be greatly removed from clay while working the clay and firing it in a kiln. Other solid radioactive materials such as uranium and radium would not melt or boil at the temperatures in a kiln, so they will remain in the clay (and continue to produce radon as they decay). Potential exposure to radiation from clay pottery would depend on many factors, including how the pottery is finished and used as well as how much radiation is present.

Concern Raised: Are anemia, arthritis, heart attacks, dizziness, loss of appetite, darkening of the skin seen in the community due to radiation exposure?

ATSDR Response: These health effects are not known to be caused by the levels of radiation that have been measured in the communities around the site. Residents should consult with their doctor or medical provider for advice and treatment.

Concern Raised: Can foods processed outdoors near the site be affected by site contamination?

ATSDR Response: ATSDR does not have enough information at this time to answer this concern. ATSDR hopes to gather more information about this practice so we can better understand how to evaluate it. We will address this concern in the final version of this report.

Conclusions

Current radon or radiation exposures of most people living in villages near the site that have undergone assessment and abatement activities are not expected to cause harmful effects. However, people could be at an increased risk of harmful health effects, including cancer, if their homes contain sources of radiation or radon that have not been fully assessed or if they do not use their abatement system as directed. We do not know whether past exposures might have harmed health.

- EPA assessed hundreds of properties in nearby villages and identified properties with radiation levels above background and homes with elevated radon levels. EPA removed radioactive materials or installed radon abatement systems, reducing potentially harmful exposures. Levels of elemental uranium in surface soils were too low to cause harmful effects.
- Not all properties in the villages were fully assessed. Also, radon levels can fluctuate seasonally, and ATSDR received anecdotal information that not all homeowners are able to maintain and run the installed radon abatement systems continuously. Elevated exposures are still possible if sources have not been removed or radon abated.
- Not enough data exist to describe past exposures in the villages.

Adults and children who swim or wade in the rivers and reservoir downstream from the mine site are unlikely to be harmed by exposure to contaminants in surface water and sediment. We do not know whether past exposures might have harmed health.

- Estimates of exposure to the highest levels of chemicals and radioactive materials detected in surface water and sediment after closure of the mine were below respective harmful effect levels identified in toxicological literature.

- To reach this conclusion, we assumed that people spend, on average, two hours a day swimming or wading in surface water downstream from the site. We did not evaluate other possible uses of surface water, such as for drinking, because people in the area are on a public water supply.
- Not enough data exist on downstream surface water or sediment while the mine was operating to allow us to estimate past exposures.

ATSDR does not have enough information to conclude whether eating fish, animals, or plants collected or processed near the site could harm health.

- ATSDR has no data on contaminant levels in plants, animals, or fish from near the site or information on how much and how often nearby residents consume them.

ATSDR does not have enough information to conclude whether past exposure of people living or spending time in the former mine housing area could harm their health.

- Little to no data exist to describe contaminant levels in air, soil, or the wells used at the housing area itself. The wells have been removed, and sampling air or soil now will not be representative of possible exposures during mine operations, so we will never have data to estimate past exposures.
- The mine housing area contained residences for mine staff and their families, a school, several other buildings, and recreational facilities. The housing area was within an area considered disturbed by mine operations. People who lived or spent time in this area could have been exposed to contaminants in air, soil, or groundwater used for drinking.
- No one currently lives in the mine housing area, and the residential buildings have been removed. People might have used facilities in the area until recently, but ATSDR does not have information about when or how often people were there.

Agency Recommendations

- ATSDR recommends that EPA continue to offer radiation surveys to residents who may not have participated previously and address any source materials identified.
- ATSDR recommends that EPA or the Pueblo conduct ongoing radon monitoring and offer assistance to ensure radon abatement systems are operated continuously and maintained effectively.
- ATSDR recommends that EPA sample soils residents might contact in the villages near the site and analyze for other contaminants associated with uranium mining, such as metals. ATSDR will review the data and comment on the health implications of the results, upon request.
- Based on the limited information on how people might access the site and downstream areas, ATSDR recommends the Pueblo continue to restrict access to the mine and inform the public of the presence of potentially hazardous materials in the watershed downstream.
- ATSDR encourages the public to tell us how and how often they use the site and surrounding areas. This will allow us to more accurately estimate possible exposure to community members near the site.

- ATSDR recommends EPA sample plants, animals, and fish near the site for metals and radiological contaminants. ATSDR will review the data and comment on the health implications of the results, upon request.

Next Steps

- ATSDR will hold a public availability session to gather health concerns from the community around the Jackpile-Paguate Uranium Mine. These concerns will be addressed in the final release of this report.
- EPA has informed ATSDR of the following:
    - EPA will continue to support radiation monitoring for interested tribal residents and address source material as necessary and to the extent possible.
    - The EPA Radon Program is consulting with the Pueblo on how they can potentially develop an ongoing radon program that best suits the Pueblo's needs.
    - EPA will conduct additional environmental sampling to characterize the site through the remedial investigation and feasibility study phase of the Superfund process.
    - EPA will continue to work with the Pueblo to maintain public health and safety.
    - EPA will consider all current and future risk and uptake scenarios and determine the need for bioassay sampling during the iterative sampling process.
- New environmental, toxicological, or health outcome data or the results of implementing the above proposed actions could change ATSDR's conclusions and necessitate additional public health actions at this site.

Community Recommendations

It will take several years for the site's contamination to be fully understood so plans for cleanup can proceed. In the meantime, ATSDR makes the following general recommendations for community members who want to reduce their potential exposure to uranium, radon, and other contaminants related to mining operations.

- Stay away from the mine site.
- Don't gather plants or take clay, rocks, gravel, dirt, sand, or water from the mine site.
- Graze livestock away from the mine site.
- Allow EPA to survey your property for radiation and your home for radon.
- Use the public water system for all your family's household needs – don't use untreated water.
- Talk with your doctor if you are worried you may have exposure to uranium or radon.
- Follow your doctor's advice to stay healthy. Staying healthy helps your body deal with stressors like uranium or radiation.

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Appendix A. ATSDR Pathway Analysis, Screening Process, and Exposure Evaluation Process

Pathway Analysis

ATSDR evaluates whether people may have come into contact with chemicals from a site by examining *exposure pathways*. Exposure pathways consist of five elements: a contamination *source*; *transport* of the contaminant through an environmental medium like air, soil, or water; an *exposure point* where people can come in contact with the contaminant; an *exposure route* whereby the contaminant can be taken into the body; and an *exposed population* of people actually coming in contact with site contaminants [8].

Completed exposure pathways are those for which all five pathway elements are evident. If one or more elements is missing or has been stopped (for example, by preventing transport of the chemical from the source to the exposure point), the pathway is *incomplete*. Exposure cannot occur for incomplete exposure pathways. For *potential* exposure pathways, exposure appears possible, but one or more of the elements is not clearly defined.

Radioactive materials have additional considerations of *distance* and *shielding*. The energy given off by these materials (ionizing radiation) can affect a person from a distance, similar to heat given off by a fire. Depending on the type of radiation, radiation pathways may be complete or eliminated based on these considerations.

A completed exposure pathway does not necessarily mean that harmful health effects will occur. A chemical's ability to harm health depends on many factors, including how much of the chemical is present, how long and how often a person is exposed to the chemical, and how toxic the chemical is. Further evaluation of the specific exposure occurring is needed to determine whether the exposure could cause harmful effects.

Screening Process – Comparison Values

In evaluating chemical or radiological contaminant data, ATSDR used comparison values to determine which chemicals to examine more closely. Comparison values are health-based contaminant concentrations found in a specific media (air, soil, or water) and are used to screen contaminants for further evaluation. Comparison values incorporate assumptions of daily exposure to the chemical and a standard amount of air, water, and soil that someone might breathe in or swallow each day.

As health-based thresholds, comparison values are set at a concentration below which no known or anticipated adverse human health effects are expected to occur. Different comparison values are developed for cancer and noncancer health effects. Noncancer levels are based on valid toxicological studies for a chemical, with appropriate safety factors included, and the assumption that small children and adults are exposed every day. Cancer levels are based on a one-in-a-million excess cancer risk for exposure to contaminated soil or drinking contaminated water every day for a lifetime. For chemicals for which both cancer and noncancer comparison values exist, we use the lower level to be protective. Exceeding a comparison value does not mean that health effects will occur, just that more evaluation is needed.

Comparison values used in preparing this document are listed below:

Cancer Risk Evaluation Guides (CREGs) are estimated contaminant concentrations that would be expected to cause no more than one additional excess cancer in one million persons exposed over a lifetime. CREGs are calculated from EPA cancer slope factors.

Environmental Media Evaluation Guides (EMEGs) are estimated contaminant concentrations in a media where noncancer health effects are unlikely. EMEGs are derived from the ATSDR minimal risk level (MRL).

Reference Media Evaluation Guides (RMEGs) are estimated contaminant concentrations in a media where noncancer health effects are unlikely. RMEGs are derived from EPA's reference dose (RfD).

Regional Screening Levels (RSLs) are chemical-specific concentrations developed by EPA for individual contaminants in air, drinking water and soil that may warrant further investigation or site cleanup. RSLs are not cleanup standards.

Maximum Contaminant Levels (MCLs) are enforceable standards set by EPA for the highest level of a contaminant allowed in drinking water. MCLs are set as close to MCL goals (the level of a contaminant in drinking water below which there is no known or expected risk to health) as feasible using the best available treatment technology and taking cost into consideration.

The process by which ATSDR evaluates the potential for adverse health effects to result from exposure to contaminants is described briefly below.

Exposure Evaluation

If a chemical is present at a level higher than the corresponding comparison value, it does not mean that harmful health effects will occur, but further evaluation is needed. The next step is to take those contaminants present at levels above the comparison values and further evaluate whether those chemicals may be a health hazard given the specific exposure situations at this site. For exposures occurring by inhalation, the air concentration of the contaminant can be compared directly with health guideline air concentrations. For other pathways, we estimate the *exposure dose*, or the amount of contaminant that gets into a person's body. The exposure dose is typically expressed as milligrams of contaminant per kilogram of body weight of the person exposed, per day (mg/kg/day). This allows comparison with health guidelines and toxicological studies which express dose in the same units. Exposure that occurs through skin absorption may be converted to either an equivalent oral exposure dose or equivalent air concentration, depending on the other exposure routes being considered.

Evaluating Noncancer Health Effects

The calculated exposure doses are then compared to an appropriate health guideline for that chemical. Health guideline values are considered safe doses; that is, health effects are unlikely below this level. The health guideline value is based on valid toxicological studies for a chemical, with appropriate safety factors built in to account for human variation, animal-to-human differences, and/or the use of the lowest study doses that resulted in harmful health effects (rather than the highest dose that did not result in harmful health effects). For noncancer health effects, the following health guideline values are used.

> *Minimal Risk Level (MRL)* **–** An ATSDR-derived 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 harmful noncancer effects. An MRL should not be used as a predictor of harmful health effects.
>
> *Reference Concentration (RfC)* **–** An EPA-derived estimate (with uncertainty spanning perhaps an order of magnitude) of a continuous inhalation exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of harmful effects during a lifetime. The RfC considers toxic effects both within the respiratory system and other systems of the body.
>
> *Reference Dose (RfD)* – An EPA-derived estimate (with uncertainty spanning perhaps an order of magnitude) of a daily oral exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of harmful, non-carcinogenic effects during a lifetime.

If the estimated exposure dose for a chemical is less than the health guideline value, then the exposure is unlikely to cause a noncancer health effect in that specific situation. If the exposure dose for a chemical is greater than the health guideline, then the exposure dose is compared to known toxicological values for that chemical and is discussed in more detail in the public health assessment. These toxicological values are doses derived from human and animal studies that are summarized in the ATSDR Toxicological Profiles, reports included in EPA's Integrated Risk Information System, and in current scientific literature. A direct comparison of site-specific exposure and doses to study-derived exposures and doses that cause adverse health effects is the basis for deciding whether health effects are likely or not.

Evaluating Cancer Health Effects

The estimated risk of developing cancer resulting from exposure to the contaminants was calculated by multiplying the site-specific estimated exposure dose averaged over a lifetime by an appropriate cancer slope factor or inhalation unit risk, primarily those found on EPA's Integrated Risk Information System. The result estimates the increase in risk of developing cancer after the exposure to the contaminant through the defined exposure scenario. ATSDR describes this estimated increased risk qualitatively and in terms of background rates of cancer occurring in the U.S. population.

There are many uncertainties in estimating cancer risk and risk estimation methods typically employ many conservative assumptions. The actual increased risk of cancer may be lower than the calculated number, which gives an estimated risk of excess cancer. ATSDR uses a weight-of-evidence approach in deciding whether exposures to cancer-causing contaminants are of concern.

Screening and Exposure Assumptions for Jackpile-Paguate Uranium Mine

The following tables list contaminants in groundwater, air, surface water, and sediment from Jackpile-Paguate Uranium Mine or the surrounding areas that were detected at least once at concentrations above comparison values.

Table A1. Groundwater* Contaminants Detected Above Drinking Water Comparison Values

Contaminant	Highest Concentration Measured in Groundwater	Drinking Water CV	CV Source
Antimony	21 µg/L	2.8 µg/L	RMEG
Arsenic	12 µg/L	2.1 µg/L / 0.016 µg/L	EMEG / CREG
Cadmium	160 µg/L	0.7 µg/L	EMEG
Cobalt	200 µg/L	70 µg/L	Intermediate EMEG
Fluoride	2,666 µg/L	350 µg/L	EMEG for sodium fluoride
Iron	139,000 µg/L	14,000 µg/L	RSL
Lead	130 µg/L	15 µg/L	EPA Action Level There is no known safe lead level.
Sodium	1,400,000 µg/L	20,000 µg/L	DWA
Sulfate	5,560,000 µg/L	250,000 µg/L	Secondary MCL
Thallium	11 µg/L	0.2 µg/L	RSL
Total Uranium	232 pCi/L	1.4 µg/L (0.9 pCi/L) ; 30 µg/L (20 pCi/L)	Intermediate EMEG; MCL
Gross Alpha	142 pCi/L	15 pCi/L	MCL
Radium-226	22 pCi/L	3 pCi/L	Fraction of MCL specific for radium-226

*Notes: Groundwater from onsite and downgradient monitoring wells; ATSDR is not aware that anyone in the area is currently drinking from this groundwater. Included onsite and downgradient monitoring or other wells from [16,2,3,7]. Because each study included only 5-10 wells, ATSDR presents only the highest concentrations reported in this table. Not every contaminant was analyzed in every report cited.

CV – comparison value
µg/L – micrograms per liter
pCi/L – picocuries per liter
RMEG – remedial media evaluation guide
EMEG – environmental media evaluation guide
CREG – cancer risk evaluation guide
DWA – drinking water advisory
MCL – maximum contaminant level
RSL – regional screening level

Table A2. Surface Water Contaminants Detected Above Drinking Water* Comparison Values

Contaminant	Highest Concentration Measured in Surface Water	Drinking Water CV	CV Source
Antimony	8 µg/L	2.8 µg/L	RMEG
Arsenic	8 µg/L	2.1 µg/L / 0.016 µg/L	EMEG / CREG
Sodium	420,000 µg/L	20,000 µg/L	DWA
Sulfate	837,000 µg/L	250,000 µg/L	Secondary MCL
Thallium	18 µg/L	0.2 µg/L	RSL
Total Uranium	240 µg/L; 167 pCi/L	1.4 µg/L (0.9 pCi/L) ; 30 µg/L (20 pCi/L)	Intermediate EMEG; MCL

*Notes: ATSDR is not aware of anyone in the area drinking the water; using drinking water comparison values is protective. Included surface water sample results from [3,17,7]. Because each study included 5-10 sampling locations to describe the surface waters between the site and the reservoir several miles downstream, ATSDR only used the highest concentrations reported to estimate exposures. Not every contaminant was analyzed in every report cited.

CV – comparison value
µg/L – micrograms per liter
pCi/L – picocuries per liter
RMEG – remedial media evaluation guide
EMEG – environmental media evaluation guide
CREG – cancer risk evaluation guide
DWA – drinking water advisory
MCL – maximum contaminant level
RSL – regional screening level

Table A3. Sediment Contaminants Detected Above Soil* Comparison Values

Contaminant	Highest Concentration Measured in Sediment	Soil CV	CV Source
Antimony	23 mg/kg	23 mg/kg	RMEG
Arsenic	8 mg/kg	17 mg/kg / 0.25 mg/kg	EMEG / CREG
Sodium**	1500 mg/kg	None	Not applicable
Sulfate**	Not analyzed	Not applicable	Not applicable
Thallium**	0.747 mg/kg	0.78 mg/kg	RSL
Total Uranium	18 mg/kg	11 mg/kg	Intermediate EMEG

*Notes: Sediment comparison values are not available; using soil comparison values is protective since exposure to sediment is not typically as frequent as soil exposure.
**Included all contaminants included in Table A2 above to indicate sediment concentration used to estimate exposure. Included sediment sample results from [17,7]. Because each study included 5-10 sampling locations to describe the surface waters between the site and the reservoir several miles downstream, ATSDR only used the highest concentrations reported to estimate exposures.

CV – comparison value
mg/kg – milligrams per kilogram
pCi/g – picocuries per gram
RMEG – remedial media evaluation guide
EMEG – environmental media evaluation guide
CREG – cancer risk evaluation guide
RSL – regional screening level

The next step is to estimate exposures to the contaminants that exceeded comparison values in the first screening step. For onsite workers and their families, we did not estimate exposures because we don't have information on the drinking water contamination or soils they were exposed to then, and air concentrations are evaluated directly.

For estimating past and present exposure of nearby residents to surface water and sediment downstream from the site, we used assumptions as listed below in Table A4.

Table A4. Exposure Assumptions for Users of Rivers and Reservoir Downstream from the Site

Age	Body Weight, kg*	Incidental Ingestion of Surface Water, liters per hour**	Hours per day†	Sediment Ingestion, milligrams per day††	Skin Surface Area Available for Contact With Surface Water, cm^2‡	Skin Surface Area Available for Contact With Sediment, cm^2‡‡
6-<11	31.8	0.12	2	100	10,800	3,824
11-<16	56.8	0.12	2	100	15,900	5,454
16-<21	71.6	0.12	2	100	18,400	6,083
>21	80	0.071	2	50	19,683	7,325

* ATSDR-recommended body weights [32]
** Recommended values for surface water ingestion rates, reasonable maximum [36]
†Assumed value, professional judgment
††ATSDR-recommended soil and sediment ingestion rates, mean values [34]
‡Recommended values for total body surface area for children and adults, mean values [36]
‡‡Mean surface areas for head, hands, forearms, lower legs, and feet. Feet included for adults and children. [35,36]

The exposure assumptions shown in Table A4 were used with contaminant-specific properties to estimate total exposure dose for surface water and sediment ingestion and dermal contact using the following equations derived from ATSDR and EPA guidance [32-37]. The equations below do not explicitly include an exposure factor term because exposure is assumed to occur daily (that is, the exposure factor would be one.)

Equations and Example Calculations

Daily Exposure Dose from Surface Water Ingestion

$$Dose\ \left(\frac{mg}{kg \cdot day}\right) = \frac{concentration\ \left(\frac{mg}{liter}\right) \times ingestion\ rate\ \left(\frac{liter}{hr}\right) \times \frac{hrs\ exposed}{day}}{body\ weight\ (kg)}$$

For example, a young teenager spending 2 hours a day on surface water, assumed to contain 8 micrograms per liter (µg/L), or 0.008 mg/L, of antimony, will ingest an average dose of:

$$Dose = \frac{\frac{0.008\text{ mg antimony}}{\text{L water}} \times \frac{0.12\text{ L water}}{\text{hr}} \times \frac{2\text{ hrs}}{\text{day}}}{56.8\text{ kg}} = 0.00003\text{ mg/kg/day}$$

$$= 3\times10^{-5}\text{ mg/kg/day}$$

Daily Exposure Dose from Surface Water Skin Exposure

$$Equivalent\ Oral\ Dose\ from\ Dermal\ Exposure\ \left(\frac{mg}{kg \cdot day}\right) = \frac{concentration\ \left(\frac{mg}{L}\right) \times \frac{1\ L}{10^6\ cm^3} \times K_p\left(\frac{cm}{hr}\right) \times time\ \left(\frac{hr}{day}\right) \times SA\ (cm^2)}{body\ weight\ (kg) \times oral\ uptake\ factor}$$

where

- K_p is the dermal permeability coefficient for the compound of interest. For all the inorganic compounds evaluated in this PHA, the K_p is 0.001 cm/hr [37].
- SA is the total skin surface area available for water contact. We assumed the total skin surface was available for water contact for all age groups.
- The oral uptake factor is a correction for substances that have limited gastrointestinal uptake. All the inorganic compounds evaluated in this PHA, except for antimony with a 15% (0.15) oral uptake factor, have uptake factors of 100%.

For example, a young teenager spending 2 hours a day on surface water, assumed to contain 8 µg/L, or 0.008 mg/L, of antimony, will take in, from skin exposure, an average dose of:

$$Dose = \frac{\frac{0.008\ \text{mg antimony}}{\text{L}} \times \frac{1\ \text{L}}{10^6\ cm^3} \times 0.001\frac{cm}{hr} \times \frac{2\ hr}{day} \times 15{,}900\ cm^2}{56.8\ \text{kg}\ \times 0.15}$$
$$= 0.00000003\ \text{mg/kg/day}$$

$= 3\times10^{-8}$ mg/kg/day

Daily Exposure Dose from Sediment Ingestion

$$Dose\ \left(\frac{mg}{kg \cdot day}\right) = \frac{concentration\ \left(\frac{mg}{kg\ sediment}\right) \times ingestion\left(\frac{mg\ sediment}{day}\right) \times \frac{1\ kg}{10^6\ mg}}{body\ weight\ (kg)}$$

For example, a young teenager spending time every day around sediment, assumed to contain 23 mg/kg of antimony, will ingest an average dose of:

$$Dose = \frac{\frac{23\ \text{mg antimony}}{\text{kg sediment}} \times \frac{100\ \text{mg sediment}}{\text{day}} \times \frac{\text{kg}}{10^6\ \text{mg}}}{56.8\ \text{kg}} = 0.00004\ \text{mg/kg/day}$$

$= 4\times10^{-5}$ mg/kg/day

Daily Exposure Dose from Sediment Skin Exposure

$$Equivalent\ Oral\ Dose\ from\ Dermal\ Exposure\ \left(\frac{mg}{kg \cdot day}\right)$$
$$= \frac{concentration\ \left(\frac{mg}{kg}\right) \times \frac{1\ kg}{10^6\ mg} \times AF\left(\frac{mg}{cm^2\ day}\right) \times ABS_d \times SA_{sed}\ (cm^2)}{body\ weight\ (kg) \times oral\ uptake\ factor}$$

where

- AF is the adherence factor of soil/sediment to skin per event (assumed here to be once per day). Using professional judgment to select conservative adherence factors from those tabulated in ATSDR guidance, we used AFs of 3.3 mg/cm^2 for children (95th percentile for children playing in wet dirt) and 0.6 mg/cm^2 for adults (95th percentile for rugby players) [35].
- ABS_d is the dermal absorption fraction for soil and sediment [37]:
- 0.01 for antimony, sodium, thallium, and uranium
- 0.03 for arsenic
- SA_{sed} is the skin surface area available for sediment contact. We assumed, for all age groups, that the SA includes the head, hands, forearms, lower legs, and feet. Values not tabulated in ATSDR's guidance were obtained from EPA's Exposure Factors Handbook [35,36].
- The oral uptake factor is a correction for substances that have limited gastrointestinal uptake. All the inorganic compounds evaluated in this PHA, except for antimony with a 15% (0.15) oral uptake factor, have uptake factors of 100%.

For example, a young teenager spending time every day around sediment, assumed to contain 23 mg/kg of antimony, will take in, from skin exposure, an average dose of:

$$Dose = \frac{\frac{23\ \text{mg antimony}}{\text{kg sediment}} \times \frac{\text{kg}}{10^6\ \text{mg}} \times 3.3\frac{mg}{cm^2\ day} \times 0.01\ \times\ 5{,}454\ cm^2}{56.8\ \text{kg}\ \times 0.15}$$
$$= 0.00049\ \text{mg/kg/day}$$

$= 5\times10^{-4}$ mg/kg/day

Total Dose

The total dose for exposure to river and reservoir users is the sum of these doses for ingestion and dermal exposure for surface water and sediment. In the example calculations above, the estimated total antimony dose is

3×10^{-5} mg/kg/day + 3×10^{-8} mg/kg/day + 4×10^{-5} mg/kg/day + 5×10^{-4} mg/kg/day

$= 5.7\times10^{-4}$ mg/kg/day of antimony.

The estimated exposure doses are listed in Table A5.

Table A5. Summary of Estimated River and Reservoir User Exposure Doses – Total of Surface Water and Sediment Ingestion and Dermal Contact

Contaminant	Total Estimated Exposure Dose, mg/kg/day unless indicated otherwise				Health Guideline	Source of Health Guideline
	Children 6 up to 11 years old	Children 11 up to 16 years old	Children 16 up to 21 years old	Adults 21 years old and up		
Antimony	**0.0008**	**0.0006**	**0.0005**	0.0001	0.0004 mg/kg/day	Oral RfD
Arsenic	0.0002	0.0001	0.0001	0.00003	0.0003 mg/kg/day	MRL
Sodium	110 mg/day	115 mg/day	117 mg/day	76 mg/day	1500 mg/day	CDC Guideline – sensitive groups
Sulfate	**	**	**	**	**	**
Thallium	**0.0001**	**0.00009**	**0.00007**	**0.00004**	0.00001	Provisional oral RfD
Total Uranium	**0.002**	**0.001**	**0.001**	**0.0006**	0.0002	Intermediate MRL

*Includes surface water ingestion and dermal intake and sediment ingestion and dermal intake
**Sulfate doses not estimated; health effects based solely on concentration in water
BOLD results indicate an exceedance of the health guideline, requiring further evaluation
mg/kg/day – milligrams per kilogram per day; mg/day – milligrams per day
pCi/L – picocuries per liter; RfD – reference dose
MRL – minimal risk level

The doses shown in bold in Table A5 were above the applicable non-cancer health guideline values and require further evaluation. Arsenic was also evaluated for cancer effects. All the substances listed in Table A5 are discussed in text in the section beginning on page 13.

Cancer Risk Calculation

Arsenic is a carcinogen and requires evaluation for cancer effects. To estimate the lifetime risk of cancer from exposure to arsenic, we assumed exposure begins at age 6 and continues for 33 years [22]. This represents a high-end estimate from population mobility data. The cancer risk is calculated by multiplying arsenic's oral cancer slope factor of 1.5 $(\text{mg/kg/day})^{-1}$ by summing the dose for each age group, scaled by the fraction of a 78-year lifetime spent in that age group, for a total of 33 years.

$$Risk = \sum age\ group\ dose\ (\text{mg/kg/day}) \times CSF\ (\text{mg/kg/day})^{-1} \times \frac{years\ in\ age\ group}{78\ year\ lifetime}$$

or

$$Risk = \frac{CSF\ (\text{mg/kg/day})^{-1}}{78\ years} \times \sum age\ group\ dose\ (\text{mg/kg/day}) \times years\ in\ age\ group$$

For example, excess cancer risk associated with exposure to the highest concentrations of arsenic in sediment and surface water, for 33 years beginning at age 6, using the doses from Table A5 above is:

$$Risk = \frac{1.5\ (\mathrm{mg/kg/day})^{-1}}{78\ years} \times \left(\left(\frac{0.0002\,\frac{\mathrm{mg}}{\mathrm{kg}}}{\mathrm{day}} \times 5\ years \right) + \left(\frac{0.0001\,\frac{\mathrm{mg}}{\mathrm{kg}}}{\mathrm{day}} \times 5\ years \right) + \left(\frac{0.0001\,\frac{\mathrm{mg}}{\mathrm{kg}}}{\mathrm{day}} \times 5\ years \right) + \left(\frac{0.00003\,\frac{\mathrm{mg}}{\mathrm{kg}}}{\mathrm{day}} \times 18\ years \right) \right) = 4.9 \times 10^{-5}$$