Health Consultation

An Evaluation of Radiation in Groundwater and Air

WEST LAKE LANDFILL OPERABLE UNIT I

BRIDGETON, ST. LOUIS COUNTY, MISSOURI

CERCLIS ID: MOD079900932

OCTOBER 16, 2015

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Agency for Toxic Substances and Disease Registry
Division of Community Health Investigations
Atlanta, Georgia 30333

Health Consultation: A Note of Explanation

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

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

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HEALTH CONSULTATION

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Prepared By:

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Agency for Toxic Substances and Disease Registry (ATSDR)
Division of Community Health Investigations
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Table of Contents

List of Tables and Figures

FOREWORD

The Agency for Toxic Substances and Disease Registry, ATSDR, was established by Congress in 1980 under the Comprehensive Environmental Response, Compensation, and Liability Act, also known as the *Superfund* law. This law set up a fund to identify and clean up our country's hazardous waste sites. The Environmental Protection Agency, EPA, and the individual states regulate the investigation and clean up of the sites.

Since 1986, ATSDR has been required by law to conduct a public health assessment at each of the sites on the EPA National Priorities List. The aim of these evaluations is to find out if people are being exposed to hazardous substances and, if so, whether that exposure is harmful and should be stopped or reduced. If appropriate, ATSDR also conducts public health assessments when petitioned by concerned individuals. Public health assessments are carried out by environmental and health scientists from ATSDR and from the states with which ATSDR has cooperative agreements. The public health assessment program allows the scientists flexibility in the format or structure of their response to the public health issues at hazardous waste sites. For example, a public health assessment could be one document or it could be a compilation of several health consultations - the structure may vary from site to site. Nevertheless, the public health assessment process is not considered complete until the public health issues at the site are addressed.

Exposure: As the first step in the evaluation, ATSDR scientists review environmental data to see how much contamination is at a site, where it is, and how people might come into contact with it. Generally, ATSDR does not collect its own environmental sampling data but reviews information provided by EPA, other government agencies, businesses, and the public. When there is not enough environmental information available, the report will indicate what further sampling data is needed.

Health Effects: If the review of the environmental data shows that people have or could come into contact with hazardous substances, ATSDR scientists evaluate whether or not these contacts may result in harmful effects. ATSDR recognizes that children, because of their play activities and their growing bodies, may be more vulnerable to these effects. As a policy, unless data are available to suggest otherwise, ATSDR considers children to be more sensitive and vulnerable to hazardous substances. Thus, the health impact to the children is considered first when evaluating the health threat to a community. The health impacts to other high risk groups within the community (such as the elderly, chronically ill, and people engaging in high risk practices) also receive special attention during the evaluation.

ATSDR uses existing scientific information, which can include the results of medical, toxicologic and epidemiologic studies and the data collected in disease registries, to determine the health effects that may result from exposures. The science of environmental health is still developing, and sometimes scientific information on the health effects of certain substances is not available. When this is so, the report will suggest what further public health actions are needed.

Conclusions: The report presents conclusions about the public health threat, if any, posed by a site. When health threats have been determined for high risk groups (such as children, elderly, chronically ill, and people engaging in high risk practices), they will be summarized in the conclusion section of the report. Ways to stop or reduce exposure will then be recommended in the public health action plan.

ATSDR is primarily an advisory agency, so usually these reports identify what actions are appropriate to be undertaken by EPA, other responsible parties, or the research or education divisions of ATSDR. However, if there is an urgent health threat, ATSDR can issue a public health advisory warning people of the danger. ATSDR can also authorize health education or pilot studies of health effects, full-scale epidemiology studies, disease registries, surveillance studies or research on specific hazardous substances.

Community: ATSDR also needs to learn what people in the area know about the site and what concerns they may have about its impact on their health. Consequently, throughout the evaluation process, ATSDR actively gathers information and comments from the people who live or work near a site, including residents of the area, civic leaders, health professionals and community groups. To ensure that the report responds to the community's health concerns, an early version is also distributed to the public for their comments. All the comments received from the public are responded to in the final version of the report.

Comments: If, after reading this report, you have questions or comments, we encourage you to send them to us.

Letters should be addressed as follows:

Agency for Toxic Substances and Disease Registry
ATTN: Records Center
1600 Clifton Road, NE (Mail Stop F-09)
Atlanta, GA 30333

Summary

Introduction

The Agency for Toxic Substances and Disease Registry (ATSDR) is a federal public health agency. ATSDR's mission is to serve the public by using the best science, taking responsive public health actions, and providing trusted health information to prevent harmful exposures to toxic substances.

In 1973, the West Lake Landfill in Bridgeton, Missouri, received radioactive wastes mixed with soils to use as a cover for municipal wastes. In 1979, an adjoining quarry was licensed to receive more municipal and sanitary wastes. Currently in the adjoining landfill, a subsurface smoldering event 'fire' is believed to be slowly approaching the radioactive wastes.

The surrounding community is concerned that the fire will reach the radioactive waste areas leading to additional contamination in the air and groundwater. They are also concerned that the radiological contamination has impacted their water supply.

The US Environmental Protection Agency (USEPA) Region VII, Lenexa, Kansas, and the Missouri Department of Health and Senior Services (MDHSS) requested in February 2014 that ATSDR review and comment on groundwater, air, and soil data associated with past West Lake Landfill operations. In this public health consultation, ATSDR is evaluating these data with respect to their potential impacts to on-site workers and nearby residents.

Conclusions

After reviewing the data related to the questions asked of ATSDR, we developed four important conclusions and recommendations in this public health consultation.

Conclusion 1

ATSDR concludes that the groundwater pathway will not harm people's health as there is no completed exposure pathway. This groundwater is not being used as a public water supply.

Basis for Conclusion 1

The direction of groundwater flow is toward the northwest and away from residential areas. All concentrations of radioactive substances in the off-site wells are below the levels of contaminants in the on-site wells and the off-site wells also are below the regulatory limits for drinking water. No information was found to indicate if water from any on-site well was ever used as a drinking water source for past employees of the landfill and its operator.

Next Steps

Groundwater should continue to be monitored by the appropriate environmental agency. The sampling should include those wells previously sampled, both on-site and off-site.

Conclusion 2 A review of the off-site soil data collected along the haul roads bordering the landfill indicates there is no evidence of contamination along roads leading to the landfill property.

Basis for Conclusion 2 Multiple haul road surveys leading from St. Louis Airport Site (SLAPS) to the landfill have not detected any unexplained anomalous readings related to landfill contaminants.

Next Steps Although there is no evidence of soil contamination, due diligence is warranted to ensure that there is no off-site migration of contaminants.

Conclusion 3 ATSDR concludes if any surface disturbances occur on the landfill, it may release dust particles containing uranium and thorium decay products which include radium-226, radon 222, and radium-228 to the atmosphere. These particulates may then be available for inhalation by workers. Inhalation of particulates and particulates containing radioactive substances including radon may harm worker health and lead to lung cancer.

Basis for Conclusion 3

- Previous soil sampling in the West Lake Landfill has shown the presence of radioactive materials near the surface as well as various depths within the landfill in excess of past or current regulatory limits
- Soil-derived materials may be re-suspended during any soil disturbances producing dust and other types of particulate pollution
- Particulates in air have been shown to cause serious health problems including asthma and cardiovascular illnesses
- Radioactive particles can deposit in the lungs and irradiate the lung tissue which may result in lung cancer
- The past releases of radon during the landfill operation exceeded the regulatory limits by as much as 10 to 25 times at individual surface test locations. The radon flux standard is 20 pCi/m^2/sec, and the Area 1 and Area 2 average flux measured during the Remedial Investigation was 13 and 28 pCi/m^2/sec, respectively. The USEPA classifies radon gas as a leading cause of lung cancer
- ATSDR is concerned with the health impacts of radon gas to any past, current, and future on-site workers of the landfill. Radon gas could harm people's health.

Next Steps The appropriate agency should continue to monitor for radon both on the landfill and in the surrounding areas as well as implement dust control measures during surface disturbance activities.

Conclusion 4

Although outdoor radon seems to be greater than typical regional and national background levels, the equipment readings may have been affected by environmental conditions. ATSDR does not believe these levels are sufficient to harm people's health as they are well below radon concentrations associated with elevated lung cancer risks. There is no evidence that radon produced in the landfill will migrate to residential areas.

Although unrelated to the landfill, indoor radon testing should be performed to inform residents of their potential exposure to this gas. The Missouri Department of Health and Senior Services (MDHSS) provides free radon test kits to Missouri residents.

Basis for Conclusion 4

Discussions with USEPA field personnel and reviews of off-site radon data and equipment showed variability in the equipment readings that could not be explained by radiological readings in the same areas. These radiological readings should have some correlation to the radon levels detected by the radon specific equipment.

As a general practice, the US Surgeon General and the USEPA recommend that all homes be tested for radon.

Next Steps

Repeat off-site radon measurements using either additional short term monitoring equipment or long-term (greater than 7-day) protocols.

Although unrelated to the landfill, ATSDR recommends that all residents should be informed to have their house interiors tested for radon as recommended by the US Surgeon General.

For more information

For further information about this public health consultation, please call ATSDR at 1.800.CDC.INFO and ask for information about the West Lake Landfill Site, Bridgeton, MO. If you have concerns about your health, you should contact your health care provider.

Statement of Issues

On February 18, 2014, the Agency for Toxic Substances and Disease Registry (ATSDR) received a request for assistance from the US Environmental Protection Agency (USEPA), Region VII office in Lenexa, Kansas. The USEPA requested that ATSDR review sampling data collected on and around West Lake Landfill National Priorities Site, Bridgeton, Missouri. In 1973, the West Lake Landfill received radioactive wastes. The data ATSDR received include radiological results from testing groundwater and air collected in the area as well as historical data of soils contaminated with radioactive wastes. Much of these data were collected during the Remedial Investigation (RI) as reported in 2000.

Adjacent to the portions of the West Lake Landfill that contain the radioactive wastes is a closed municipal and sanitary waste landfill, the Bridgeton Landfill. Since 2010, a subsurface smoldering event, referred to in the rest of this document as "the fire" is occurring within a portion of the Bridgeton Landfill.

The surrounding community is concerned that the landfill fire will move into the area of the landfill that contains radioactive waste; which could lead to additional contamination in the air and groundwater. In addition, the residents of the area believe their health has been adversely impacted by the presence of the radioactive wastes in the West Lake Landfill.

In this public health consultation, ATSDR evaluates radiological sampling at the West Lake Landfill including groundwater sampling results from wells located on the landfill property and properties not impacted by the radioactive waste. The ATSDR also reviews and compares these reports to wells sampled off-site by both the USEPA and the US Geological Survey (USGS). The concentrations in these wells then are compared to existing standards for radioactive materials in drinking water or other health protective guidelines or recommendations to protect the public from exposures and the resulting doses to radioactive materials. Also, ATSDR reviews and comments on any available information related to atmospheric radiologic concentrations present during landfill operations. The State of Missouri Department of Health and Senior Services, an ATSDR Cooperative Agreement Partner, will evaluate the non-radioactive contaminants detected in the Bridgetown Landfill area in a separate Health Consultation.

Discussion

Site Description and History

The West Lake/Bridgeton Landfills are located within the Bridgeton city boundary. The West Lake Landfill covers approximately 200 acres while the Bridgeton Landfill is approximately 52 acres. Both landfills are north of the Interstate 70 and Interstate 270 interchange and west of the Missouri River which lies about 1.5 miles from the landfill boundary. Toward the east is the St. Louis International Airport, Lambert Field, with the end of the closest runway approximately 2 miles from the complex. The surrounding area generally consists of commercial and industrial properties [1]. In this document, the term "landfill complex" refers to both the Bridgeton Landfill and the West Lake Landfill. Figure 1 depicts the landfill complex, as it currently exists. The landfill complex is divided into operable units (OU), which group similar contaminants or tasks that must be performed. OU-1 is the radiologically contaminated area; OU-2 is the remainder of the landfill complex (Figure 1).

Historically, the area around the landfill complex was agricultural. In 1939, a limestone quarry and related operations began. These activities continued until 1988. The quarry operations produced two quarry pits. Beginning in the 1950s, municipal solid wastes, industrial solid wastes, and construction related debris was accepted and deposited on portions of the landfill complex now generally known as the West Lake Landfill. No permits were required as these

1. Engineering Management Support, Inc (2000). Remedial Investigation Report. West Lake Landfill Operable Unit 1. April 10, 2000.

operations began prior to the formation of either state or federal environmental regulatory agencies.

In 1973, waste material from the Mallinckrodt Chemical Works Manhattan activities (approximately 8,700 tons of leached barium sulfate cake residue, the lowest radioactivity-level material from Mallinckrodt, mixed with 39,000 tons of soil [2]) was disposed of at the West Lake Landfill site, later designated OU-1. This waste material was mixed with soils to cover incoming refuse and solid waste. Within OU-1, radioactive material has been found in two areas. Area 1 encompasses an approximately 10-acre portion of the site located immediately to the southeast of the main entrance road to the West Lake Landfill property. Area 2 encompasses an approximately 30-acre portion of the site along the northern boundary of the West Lake Landfill property. Radionuclides are present in surface soil (0-6 inches in depth) over approximately 50,700 square feet (1.16 acres) of Area 1. Approximately 194,000 square feet (4.45 acres) of Area 1 have radionuclides present in the subsurface at depths ranging up to 7 feet, with localized intervals present to depths of 15 feet. Radionuclides are present in surface soil covering approximately 468,700 square feet (10.76 acres) of Area 2. An additional 17,200 square feet in the northeastern portion of Area 2 contains soil/sediment eroded from the surface of Area 2. Radionuclide impacted materials are present in the subsurface beneath approximately 817,000 square feet (18.76 acres) of Area 2 at depths of up to approximately 12 feet, with some localized deeper intervals at depths up to 50 feet below the ground surface [3]. The location of these two areas is shown in Figure 2. Additional investigations are being performed to investigate the extent of the radiological impacted material.

On October 26, 1989, the landfill complex was proposed to the National Priority List (NPL). The listing was finalized on August 30, 1990. The NPL listing divided the landfill complex into operable units based on the waste characteristics. Operable Unit 1 (OU1) contains the radioactive wastes; OU 2 contains the non-radioactive wastes. As part of the NPL listing, the parties responsible for placing wastes in the landfill complex are required to prepare a remedial investigation (RI) and feasibility study that would result in an approved method to remediate the site. Furthermore, a community involvement component is required so that members of the community can follow and comment on the planned actions at the landfill. The RI discusses monitoring and sampling of environmental media, both on- and off-site. The discussion includes the site conditions present at the time of the sampling events, the source of contaminants (where it is located with respect to the overall area), the nature and extent of the contamination (how wide-spread the contaminants are in relation to the area), and its fate and transport (how it will move through the environment and what its disposition will be in the future). The RI released in 2000 pertains only to the Operable Unit 1 where the radiologically-contaminated material was placed, a separate RI was prepared for OU2 [1].

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2. Memorandum from Richard Cunnigham Division of Industrial and Medical Nuclear Safety to Hugh Thompson, JR, Office of Nuclear Material Safety and Safeguards dated January 29, 1988. Uranium Ore Processing Wastes in the West Lake Landfill Summary Report Docket No. 40-881 January 1988. US Nuclear Regulatory Commission.
3. Engineering Management Support, Inc (2011). Supplemental Feasibility Study. Radiological-Impacted Material Excavation Alternatives Analysis West Lake Landfill Operable Unit-1. December 28, 2011.

According to the 2000 RI report, the radiological wastes in Area 1 of OU1 are southeast of the landfill entrance and consist mostly of municipal sanitary wastes with an average thickness of 36 feet. The area covers about 10 acres, most of which is covered by grass [1]. The radiological wastes in Area 2 are in the northwest portion of the landfill and consist mostly of demolition and construction debris mixed with municipal waste. The waste thickness is estimated at 30 feet over a 30-acre area. The surface of Area 2 includes both vegetated and unvegetated areas. The unvegetated areas are covered with soils, gravel, construction debris, and miscellaneous non-organic wastes. Because of the surface characteristics, portions of Area 2 have seasonal ponded water and deep-rooted plants such as cattails. The northern and western segments of Area 2 contain berms that are heavily vegetated [1]. Both areas were used for landfill operations prior to the issuance of a license by the State of Missouri in 1979; that is, the landfill complex was unregulated until the state issued a license in 1979.

The 2000 RI reviewed and consolidated earlier data and information regarding the sampling of groundwater, surface soils, surface waters, radon, and fugitive dusts present at the time of earlier studies, mostly during 1995, 1996, and 1997. Based on the findings of the RI, the USEPA developed both a feasibility study in 2004 and a Record of Decision (ROD) in 2008 for the landfill complex. A feasibility study was also produced which discussed the options to clean up the site. In 2011, a supplement to the feasibility study was released to provide additional evaluation of selected potential remedies.

The feasibility study will not be discussed in this public health consultation other than to state it has been undergoing reevaluation based on public comments received by the regulatory agencies. Since the feasibility study is undergoing additional evaluations, the USEPA in 2012 determined that more groundwater monitoring and sampling would be necessary to ensure that the data collected during the RI (1995-1997) was still valid.

In March 2013, the USEPA's aerial monitoring group flew over the landfill complex to further map areas of elevated radiation as compared to background and, using their thermal screening protocol, determined the extent of the landfill 'fire' in the Bridgeton Landfill [4]. Those results identified elevated radiation readings within the 20 acres West Lake Landfill in the northwest portion of the landfill complex. The USEPA system was not able to detect the subsurface smoldering in Bridgeton Landfill as their equipment sensitivity was insufficient to measure heat signatures at the estimated depth of the fire (about 40 to 60 feet below the ground surface).

Demographics

Demographics describe a population by defining the size, characteristics, locations, and individuals who may be potentially sensitive to exposures to known contaminants. Typically, the maps developed describe the population within a one-mile buffer area around a site. Additional distances and information can be added to the maps when requested.

According to the US Census data, approximately 935 people live within one mile of the landfill complex. The demographic of this selected population is 85% white, 11% black, and about 3.5%

4. US Environmental Protection Agency (2013). Radiological and Infrared Survey of West Lake Landfill Bridgeton, Missouri. May 2013.

Asian or Hispanic. The number of housing units is 536, most of which are to the east on the landfill complex and near O'Connor Park or southwest in the area known as Spanish Village. Individuals aged 65 or older comprise 44% of the population and about 10% of the populations is composed of women of childbearing age.

Expanding the area to a five mile buffer (the approximate straight-line distance to Latty Avenue) increases the population to 148,566 individuals of which 78% are white, 13% black, 5% Hispanic, and 4% Asian. Individuals over the age of 65 comprise about 14% of the population, women of childbearing age comprise 21% of the population, and children 6 or younger comprise about 8% of the population. The number of housing units in this area number 67,814. These numbers are based on the 2010 Census and additional information is shown in Figure 3.

Public drinking water is supplied by the City of St. Louis Water Department or the Missouri American Water Company. In 1989, the USEPA estimated 60 people obtained drinking water from private wells within 3 miles of the site. Seven domestic wells were in use as of April 2014. Of these wells, six were located in the city of St. Charles with the remaining well in Bridgeton.

Climatic and Meteorological Conditions

The St. Louis area climate varies with four distinct seasons. During the typical winter months, temperatures are below 32°F less than 30 days. Conversely, the summers are hot and humid with temperatures above 90°F for 35 to 40 days per season. The annual rainfall in the area averages about 3 feet per year with winter being the driest season and springs the wettest. As with much of the Great Plains states, thunderstorms are common in the area with occasional tornadoes.

The potential impacts of air emissions on the public will vary with wind direction and windspeed. Typically, wind patterns are collected at airports or other locations where meteorological towers are found. For the West Lake Landfill area, the closest airport is Lambert Field at the St. Louis International Airport about 4 miles east of the landfill complex.

Wind directions and speed are measured on an hourly basis and a historical record is maintained. These collected data are graphically represented by a figure called a wind rose. The wind rose shows the directions from where the wind is blowing, and the percent of the time the wind is at from that direction. The wind rose for the St. Louis Airport as obtained from the University of Missouri Extension Service, is shown in Figure 4 and covers a 15-year time period. The majority of the time (13%) the winds are from the south at 5 to 15 miles per hour. About 7% of the time, the winds are toward the landfill and about 10% of the time, the wind is toward the airport. What is not shown on the wind rose is how the winds change with seasons or time of day.

In the winter, the winds as measured at the airport are mostly from the northwesterly direction. Application of the airport meteorological data to the landfill meteorological conditions should be used with caution as the landfill conditions may be different because of land, water, and structural obstructions in its vicinity.

Community Health Concerns

Health concerns related to the landfill include the potential impact of radiological materials in groundwater and potential releases of radiological materials to the air, including the potential impact of the smoldering fire in the municipal waste portion of the Bridgeton Landfill. The general community is also concerned with possible associations with the environmental radiological contamination and their findings of increased cancers and unexpected illness in the area as discussed on various social media sites.

Natural Background Environmental Radioactivity

Uranium and thorium are part of the natural radioactive background and their concentrations have been measured many times in many locations around the world. Their concentrations will vary with the geology of the underlying rock. In 1983, surface soil samples collected in Missouri showed that the concentration of uranium-238 averaged 1.1 pCi/g (picocuries per gram), the concentration of thorium-232 averaged 1.0 pCi/g, and the concentration of radium-226 (a decay product of uranium-238) averaged 1.1 pCi/g [5]. In 1988, the US Nuclear Regulatory Commission (USNRC) reported the background concentration of radium-226 collected near Earth City to be approximately 2.5 pCi/g [6].

Most uranium compounds are insoluble in water; however, this depends on the quality of the water. For example, if the water is acidic with high concentrations of organic matter, the uranium will be an organic complex. If the water is basic, the uranium may be present as a carbonate [7]. Uranium decay product solubilities vary as well. For example, thorium as a sulfate is soluble [8] but when it decays to radium and retains the sulfate, the radium sulfate is insoluble [9].

Exposure Pathways

Not every release of a site-related contaminant negatively affects the health of the off-site community. For a contaminant to pose a health problem, an exposure must first occur. That is, a person must come in contact with the contaminant by, for example, breathing, eating, drinking, or touching a substance containing it. If no one comes in contact with the contaminant, then no exposure occurs, and no health effects can occur. Still, even if the site is inaccessible to the public, contaminants can move through the environment to locations where people could come in contact with them. In the case of radiological contamination, because of the emission of radiation, which is a form of energy, exposure can occur without *direct* material contact.

ATSDR evaluates the site conditions to determine whether people are being or could be exposed to site-related contaminants using a process called pathway analysis. When evaluating exposure pathways, ATSDR identifies whether, through ingestion, dermal (skin) contact, or inhalation, exposure to contaminated media (e.g., soil, water, food, air, waste, or biota) has occurred, is occurring, or could occur. In the case of radioactive contamination, a person can be exposed to both external radiation and internal radiation. External exposure results from radiation sources

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5. Myrick, TE, Berven, BA, and Haywood, FF (1983). Determination of concentrations of selected radionuclides in surface soil in the U.S. Health Physics 45:631-642.

6. USNRC (1988). Summary Report Radioactive material in the West Lake Landfill. NUREG-1308 Revision 1. June 1988.

7 . Agency for Toxic Substances and Disease Registry (2013). Toxicological profile for Uranium. Atlanta, GA: Agency for Toxic Substances and Disease Registry. U.S. Department of Health and Human Services.

8. Agency for Toxic Substances and Disease Registry (1990). Toxicological profile for Thorium. Atlanta, GA: Agency for Toxic Substances and Disease Registry. U.S. Department of Health and Human Services.

9. Agency for Toxic Substances and Disease Registry (1990). Toxicological profile for Radium. Atlanta, GA: Agency for Toxic Substances and Disease Registry. U.S. Department of Health and Human Services.

originating outside the body, such as radiation emitted from contaminated sediments or soils. Radiation from these external sources can sometimes penetrate human skin, even if one does not come into physical contact with the material. Internal exposures result from radioactive sources taken into the body through the inhalation of radioactive particles or through the ingestion of contaminated food or water. ATSDR identifies an exposure pathway as completed or potentially complete if either internal or external exposures occur or could occur. If there are no exposure possibilities, the pathway is eliminated from further evaluation. Exposure pathways are complete if all human exposure pathway elements are present. A potential pathway is one that ATSDR cannot rule out because one or more of the pathway elements cannot be definitely proved or disproved. If one or more of the elements is definitely absent, a pathway is eliminated.

The five elements of an exposure pathway are 1) a source of contamination, 2) an environmental medium, 3) a point of exposure, 4) a route of human exposure, and 5) a receptor population. The source of contamination is where the chemical or radioactive material was released. The environmental medium (e.g., groundwater, soil, surface water, air) transports the contaminants. The point of exposure is where people come in contact with contaminated media. The route of exposure (e.g., ingestion, inhalation, dermal contact) is how the contaminant enters the body. The people actually exposed comprise the receptor population.

Exposure does not always result in harmful health effects. The type and severity of health effects that a person might experience depend on the dose, which is based on the person's age at exposure**,** the exposure rate (how much), the frequency (how often) or duration (how long) of exposure, the route or pathway of exposure (breathing, eating, drinking, or skin contact), and the multiplicity of exposure (combination of contaminants). Once a person is exposed, characteristics such as age, sex, nutritional status, genetic factors, lifestyle, and health status influence how the contaminant is absorbed, distributed, metabolized, and excreted. An environmental concentration alone will not cause an adverse health outcome—the likelihood that adverse health outcomes will actually occur depends on site-specific conditions, individual lifestyle, and genetic factors that affect the route, magnitude, and duration of actual exposure.

As a first step in evaluating exposures, ATSDR health assessors screen the contaminant concentrations against comparison values (CVs). ATSDR develops comparison values from available scientific literature concerning exposure, dose, and health effects. Comparison values represent concentrations that are lower than levels at which, in experimental animals or in human epidemiological studies, no effects were observed. CVs are not thresholds for harmful health effects; rather, they reflect an estimated concentration that is not expected to cause harmful health effects. Concentrations at or below the comparison values can reasonably be considered safe. Concentrations above comparison values, however, will not necessarily produce adverse health effects. This screening process enables ATSDR to safely eliminate from further consideration contaminants not of health concern and to further evaluate potentially harmful contaminants.

ATSDR uses comparison values to identify those site-related hazardous substances that are not considered health threats.

ATSDR evaluates radiation exposures and radiation doses differently from chemical exposures. Radiation exposure and radiation dose by definition are different. In order to have a radiation dose, radiation has to be absorbed but not all the radiation to which you are exposed is absorbed. The health effects are determined by the dose not the exposure. One does not have to come in direct contact to radioactive substances before exposures or doses occur.

Additionally, information about the ATSDR evaluation process can be found in ATSDR's Public Health Assessment Guidance Manual at http://www.atsdr.cdc.gov/HAC/PHAManual/index.html or by contacting ATSDR at 1-800-CDC-INFO. An interactive program that provides an overview of the process ATSDR uses to evaluate whether people will be harmed by hazardous materials is available at http://www.atsdr.cdc.gov/training/public-health-assessment-overview/html/.

For the West Lake Landfill, the pathways evaluated include groundwater, soils, and air. The results of these evaluations are summarized in Table 1.

Sample Quality Assessment and Quality Control

The sampling of environmental media must follow a data quality objectives plan that defines the study, its outcome, and the quality of the data that ultimately form the sample analysis plan (SAP). The SAP provides detailed objectives geared toward a specific site and defines the quality assurances and quality controls that assist in the production of quality data. The quality assessment relates to the intended data use and must have a frame of reference whereby the data can be used. This is part of a quality control process to which laboratory samples are subjected. If the data do not pass this quality assurance (QA) and quality control (QC), those data points are indicated or flagged as failing the control process [10]. Using this procedure, a minimum detectable activity (MDA) can be defined. If the amount of radioactivity in the sample does not exceed this MDA, then the sample is flagged as a non-detect (U) or an estimated concentration (J). Sample results flagged with a U or a J were not used by ATSDR in this evaluation.

The USEPA or its contractors processed over 5,700 analyses, including laboratory duplicates, laboratory quality control/assurance, and multiple field samples. Of these, about 800 samples contained radioactivity above the MDA.

Off-site Soils

Roads linking the SLAPS location to the West Lake area landfills collectively have been called the haul roads. Many investigations by the Department of Energy and the state of Missouri have shown varying results when searching for radioactive materials than may have fallen from transport vehicles. In 1985, USDOE, Oak Ridge National Laboratory (ORNL) reported anomalies on the roads near SLAPS but no elevated readings around the West Lake area [11]. In a 1991 study, ORNL reported elevated areas less than 1 square meter in size along the route between 9200 Latty Avenue and the West Lake Landfill complex. One area's elevated reading was determined to be related to the road base gravel used in construction; whereas, the other

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10. US Environmental Protection Agency. Data Quality Objectives Process for Hazardous Waste Site Investigations. EPA/600/R-00/007. January 2000.

11. Oak Ridge National Laboratory (1985). Results of the mobile gamma scanning activities in Berkeley, Bridgeton, and Hazelwood, Missouri. ORNL/RASA-85/7.

areas were related to a fertilizer facility [12]. These reports did not include sufficient information for further evaluation.

In 2005, the Missouri Department of Natural Resources collected soil samples along St. Charles Rock Road, Taussig Road, and Boenker Lane. These roads are along the perimeter of the West Lake Landfill (Figure 5). The soils were analyzed for isotopic uranium, thorium, and radium 226. The results, shown in Table 2, indicate that the average soil concentrations of uranium isotopes, thorium 232, and radium 226 along the landfill external perimeter were at or within the typical soil background values found in the state of Missouri.

Groundwater Level, Flow and Conductivity

As part of the new groundwater monitoring program started in 2012, water levels were monitored in three general types of wells of differing depths on the landfill property. These types are called shallow, intermediate, and deep well systems. The wells are typically sampled on a quarterly schedule resulting in four data sets. The height of the water levels is used to determine the seasonal variations and the direction of flow. The water collected during these events can also be used to determine the presence of contaminants and how fast the water flows below ground.

These studies showed that the groundwater under the site flows in a northwesterly direction toward the Missouri River that at St. Charles, is about 415 feet above the average sea level [13]. The groundwater elevation was highest on the southeastern border of the landfill, ranging from 440 to 475 feet above sea level. The lowest groundwater elevation was in the northern portion at about 430 feet above sea level [14,16]. During measurements obtained between 2012 and October 2013, the groundwater flow rate was estimated between 1.2 and 3.7 feet per year during periods of low flow to a range of 12 to 137 feet per year during high flow periods. Any contaminants in the groundwater could move toward the Missouri River, potentially reaching the river in 57 years at the highest flow rates.

The USEPA and its contractors, the USGS, and various parties responsible for waste placement have collected groundwater samples from monitoring wells within the landfill complex [15]. During the RI process, 30 wells initially were associated with the West Lake Landfill. Additional wells were on those portions of the landfill complex that did not receive radioactive wastes. Prior to the resampling of the groundwater wells in 2012, 78 monitoring wells were located in the landfill complex [12]. The landfill operator installed additional monitoring wells in 2013 [16]. The new sampling protocol required that all wells be sampled for radioactive materials, volatile

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12. Oak Ridge National Laboratory (1991). Results of the mobile gamma scanning activities in St. Louis, Missouri. ORNL/RASA-90/7.

13. http://mvs-wc.mvs.usace.army.mil/archive/mo.html (last accessed on March 5, 2014).

14. Engineering Management Support, Inc. (2012). Groundwater Monitoring Report. 2012 Additional groundwater sampling event. West Lake Landfill Operable Unit-1. December 14, 2012

15. USGS (2014). Background groundwater quality review of 2012-15 groundwater data, and potential origin of radium at the West Lake Landfill Site, St. Louis County, Missouri. December 17, 2014.

16. Engineering Management Support, Inc. (2014). Groundwater Monitoring Report. October 2013 Additional groundwater sampling event. West Lake Landfill Operable Unit-1. February 21, 2014.

organic compounds (VOC) and other organic and inorganic components. This health consultation only evaluates the radiological components.

Groundwater Pathway

The evaluation of the groundwater flow indicates that there is no completed pathway of exposure to groundwater that passes under the site. Without a completed exposure pathway, people cannot come into contact with contaminants**.**

The USEPA has established regulatory Maximum Contaminant Levels (MCL) for contaminants, including radionuclides, in drinking water. In the case of radionuclides, the MCL is a radiation dose-based concentration. Unless specifically listed in the regulations, the MCL is equivalent to an estimated dose of 4 millirems per year (mrem/y). The MCL only pertains to the intake of drinking water (water ingestion pathway). ATSDR has no health comparison values for radioactive materials in any environmental medium.

As part of an ongoing study, the USEPA and USGS groundwater well study showed very little thorium in the groundwater. This is consistent with its limited solubility. There is no equivalent MCL for thorium in groundwater. However, a value of 15 pCi/L can be used [17] since thorium is an alpha radiation emitter and the MCL for gross alpha radiation is 15 pCi/L. Radiological testing of groundwater samples collected on-site in the recent past (2007-2012) showed that radioactive substances, especially radium, are present in the landfill.

Background wells are in the same geographical area and the same groundwater flow system as the landfill but are up-gradient or outside the zone of contaminant influence. When compared to background radium concentrations, the landfill wells are elevated above the background levels and also exceeded the regulatory 5 pCi/L combined radium MCL for public drinking water sources. Other radionuclides detected are not significantly different from background values (See Table 3) collected from those wells sampled by the USGS. These wells are located west of the Missouri River or south of Interstate 70 and west of Interstate 270. Locations of the on- and off-site wells are shown in Figure 6 Figure 7, respectively.

Evaluation of On-site Wells

Groundwater samples were collected from several types of wells on the landfill (most recently between 2007 and 2012) and surrounding property. Radiological contaminants for which samples were tested included: uranium-238 and several of its decay chain products (Figure 8), uranium-235, and thorium-232 and several of its decay products (Figure 9). The samples also included QA samples including field blanks and duplicate samples. Wells designated S-80 and MW-107 are considered site background wells as they are located about 0.75 miles from the radiological waste areas and are considered hydraulically up-gradient from OU 1 Area 1 and Area 2. The water collected from most wells included unfiltered (total) and filtered (dissolved) samples.

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17 . USEPA (2008). Radiological laboratory sample analysis guide for incidents of national significance – Radionuclides in water. USEPA 402-R-07-007. January 2008.

In the filtered groundwater samples, the average dissolved radium-226 was 2.67 pCi/L; whereas, the average radium-228 was present at 2.71 pCi/L. Uranium-238 was detected at an average concentration of 1.47 pCi/L but the precursor to the radium-228, thorium-232 was not reported. When the total amount of these radionuclides was counted on filters which contain the particulate fraction, the concentration for radium-226 averaged 2.57 pCi/L and for radium-228, the average total particulate concentration was measured at 2.97 pCi/L. These data are shown in Table 4.

The data, when evaluated by the depth of the sampling point shows a somewhat different trend. In shallow wells, the total radium-226 concentration averaged 1.64 pCi/L and radium-228 concentrations averaged 2.11 pCi/L. Uranium-238 concentrations averaged 1.29 pCi/L and the thorium-232 concentration averaged 0.71 pCi/L. The average concentration of radium-226 in any type of well construction was 3.23 pCi/L; whereas, the radium-228 concentration averaged 3.28 pCi/L. These data and other results are given in Table 5.

Evaluation of Off-site Wells

During the resampling events of 2013, the USEPA and the USGS collected data from wells that potentially could serve as background monitoring locations. These wells were sampled for several radioactive materials, volatile organic compounds, and metals. During this activity, the USEPA sampled six domestic use wells two to three miles north of the landfill area (Figure 7) [18]. The samples were collected and analyzed for total radioactivity filtered to separate out the particulate sediment from the materials dissolved in the water. In no cases were dissolved radiological contaminants detected in the water. As one would expect, radiological materials were associated with the particulates (total) samples. The results of the radiological sampling in these wells are shown in Table 6.

The USGS also sampled five wells that could be representative of background. In this sampling, the wells, also shown in Figure 7 were located to the southwest of the facility. Three of the USGS wells were sampled in bedrock with the remaining wells considered alluvial wells. These results are given in Table 7.

Similarly the off-site groundwater concentrations of uranium were quite low. The USEPA established a 30 micrograms per liter (µg/L) MCL for uranium in public water supplies. Converting this mass concentration to an activity concentration gives an activity equivalent MCL of approximately 20 pCi/L. No off-site wells approached this concentration level. The MCL for combined radium-226 + radium-228 is 5 pCi/L and none of the monitored off-site well determinations exceeded this regulatory limit.

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18. USEPA (2012). Site addendum for the generic QAPP for Superfund Site Assessment Activities. October 2012.

Air Releases of Radioactive Substances

Radon

In 1988, the USNRC released NUREG-1308, which summarized the wastes in the landfill and the results of surveys conducted from August 1980 through the summer of 1981. The original report was released in May 1982.

The USNRC measured the radon release or flux from 32 locations and collected 111 samples. The release or flux is the amount of radon released per second over a specified area and is expressed as picocuries per square meter per second (pCi-m^{-2}-s^{-1}). For radon 222, the maximum reported value was 865 pCi-m^{-2}-s^{-1} in Area 2 on May 27, 1981. The concentration of radon 219 was inferred from the presence of its decay products to be on the order of 0.06 pCi/L to 0.9 pCi/L [6].

During the RI phase, contractors re-evaluated radon levels, volatile organic contaminants and trace metals in dusts from Area 1 and Area 2. The highest flux in Area 1 was 245.9 pCi-m^{-2}-s^{-1} with an average of 13 pCi-m^{-2}-s^{-1}; whereas, in Area 2 the maximum flux was 513.1 pCi-m^{-2}-s^{-1} with an average of 28 pCi-m^{-2}-s^{-1}.

The radon in air monitoring reported during 2000 RI has not been updated with any new information. At uranium mill tailings sites, mostly in the western United States, by regulation, the radon 222 flux is limited to 20 pCi-m^{-2}-s^{-1} to protect human health as stated in 40 CFR 192 [19]. The maximum radon 222 flux measured during the RI phase in both Area 1 and Area 2 exceeded this regulatory limit. In Area 1, the maximum was 245.9 pCi-m^{-2}-s^{-1}; whereas, in Area 2 the maximum flux was 513.1 pCi-m^{-2}-s^{-1}. These values are similar to those values reported at several uranium mill tailings piles [19]. The typical ambient exterior concentration of radon 222 varies with the geology and the concentrations of radium in the soils. The concentrations could range from less than 0.1 pCi/L to 2.7 pCi/L [20] and these concentrations will vary seasonally, by time of day, and by environmental conditions [21]. The ambient flux of radon in the United States is reported to be 0.45 pCi-m^{-2}-s^{-1} in soils [22].

Radon will migrate in soils; however, the migration rates are dependent on numerous factors. In a study by Shweikani and coworkers [23], the radon movement through soils was highly dependent on the porosity of the soils as well as the moisture content of the soils. They showed that the greater the porosity or soil granular size, the faster radon would migrate because the soil void spaces do not impede the gas migration. If those voids are filled with water, the gas

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19. USEPA (1983). Final environmental impact statement for standards for the control of byproduct materials from uranium ore processing (40 CFR 192). USEPA 520/1-83-008-1. September 1983.

20. United Nations (2006). Effects of Ionizing Radiation. Appendix E. United Nations Scientific Committee on the Effects of Atomic Radiation. UNSCEAR 2006. New York.

21. Borak, TB and Baynes, SA (1999). Continuous measurements of outdoor ^{222}Rn concentrations for three years at one location in Colorado. Health Physics 76:418-420.

22. Phillips, DM, Eldredge, C., and Klein, W. (2002). Above normal outdoor radon levels in central Florida: A preliminary report of sampling results. 2002 International Radon Symposium Proceedings.

23. Shweikani, R., Giaddui, TG, and Surrani, SA (1995). The effect of soil parameters on the radon concentration values in the environment. Radiation Measurements 25: 581-584.

diffusion is drastically reduced. Although the discussion is beyond the scope of this document, these physical parameters limit radon migration to a few meters from the source as discussed by Malmqvist and coworkers in 1989 [24]. Based on this, **ATSDR believes that radon migration through the soils on the landfill will not extend past the landfill property**.

Based on this evaluation and comparison to uranium mine and/or mill tailings release parameters, the soils at the West Lake Landfill may contain radium at concentrations approaching or even exceeding levels of public health hazard as the maximum measured radon flux is 12 to 25 times the regulatory limit. This release could potentially expose any on-site worker to radon gas if protective measures are not taken.

Particulates in On-site Air

The concentration of radioactive materials in air is regulated, depending on the situation, by either the USNRC or the USEPA. The USEPA, through the Clean Air Act, typically regulates phosphogypsum processors, uranium mining and milling activities, and some aspects of Department of Energy facilities. The USNRC regulates holders of their operational licenses.

In December 2013 and March 2014, air samplers were operating on the landfill property to collect dust particles generated on the landfill during operations. The samplers function by drawing air through special filters which are then collected, sent to a laboratory and then processed to determine the radioisotopes deposited on the filter. The samplers operate at various velocities and volumes per minute. Once the time of operation is known, the laboratory can determine the concentrations of contaminants in the total volume of air filtered.

The air sampler filters were analyzed for gross alpha and gross beta radiation and the specific radionuclides thorium-228, thorium-230, and thorium-232. Thorium-232, though a series of radiological decays, will produce thorium-228; whereas, thorium-230 is one of many decay products produced when uranium-238 decays. It must also be mentioned that thorium-228 decays directly to radium-228 and thorium-230 decays directly to radium-226.

Table 8 gives the results from the on-site air sampling in December 2013 and March 2014. Two sampling efforts were reported for March as the sampling occurred in different areas of the site. For comparison to regulatory limits from the USNRC, the table also shows the occupational concentration limits in air as well as the concentration in air allowed for the public as codified at 10CFR20. Occupational limits are higher than public limits because the occupational dose limit is higher for workers than the public and workers have different breathing patterns because of exertion during occupational activities. During the three sampling events, the occupational standard was not exceeded.

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24. Malmqvist, L., Isaksson, M, and Kristiansson, K. (1989). Radon migration through soil and bedrock. Geoexploration 23: 135-144.

Off-site Air Monitoring

The USEPA established several off-site air sampling stations around the landfill to determine the concentration of radioactive materials from the landfill. Five stations were set up in the locations listed in Table 9 and Figure 10. Samples were collected from May 8 through August 14, 2014. For these analyses, air was filtered and the particulates collected. The samples were analyzed for uranium, thorium, radium, alpha and beta radioactivity. Sizing of the particulates was not reported. Radon measurements were also made at these locations from May 2 through September 9, 2014. The radon measurements were averaged over 7 days to give a weekly average.

The particulate sampling results, shown in Table 10, indicates that all results were over 100 times lower that the regulatory values of the USNRC. The concentration used by the USNRC is an air concentration to ensure the radiological dose to members of the public does not exceed an annual dose of 50 millirem (this value is 50% of the ATSDR Minimum Risk Level for ionizing radiation). Short term off-site radon measurements with results shown in Table 11 suggest the off-site radon levels appear to be higher than the estimated US background for out-door radon and about 2 times the limit established by the USNRC for use by their licensees. These measurements are taken using electret ion chamber technology and may be subject to environmental conditions that artificially affect their functioning properly. Although elevated, these out-door levels are not expected to cause harm to people as the levels are below the levels associated with increased lung cancer. Moreover, ATSDR believes the radon associated with the landfill contaminants will not migrate beyond the site boundaries.

Possible Health Issues Related to Particulates and Radon

Particulates in air can be of various sizes and are measured in micrometers (25,400 micrometers = 1 inch). The larger particles quickly settle to the ground; however, smaller particles will remain suspended in the air settling slowing. Estimates of settling rates suggest that dust particles smaller than 10 micrometers settle out about 30 millimeters per second (http://www.goes-r.gov/ last accessed on August 28, 2014). Particles less than 10 micrometers (μm) can be easily inhaled and 2.5 μm particles of are especially hazardous as classified by the USEPA. Most dust particles are between 2.5 and 10 μm.

Long-term exposures to particulates have been associated with reduced lung function and chronic bronchitis. Short term exposures can aggravate pre-existing lung disease, asthma, and lead to lung infections. For more information on particulate related health effects, see the following information at http://www.epa.gov/pm/pdfs/pm-color.pdf (last accessed on August 28, 2014).

Radon is a naturally occurring radioactive gas that is ubiquitous in nature. Formed from the radioactive decay of uranium, radon is found in soils and in the air at various concentrations. Typically the outdoor concentration ranges from about 0.1 to 0.5 pCi/L with the average outdoor concentration in the United States being 0.4 pCi/L. In Missouri, the USEPA in 1991 estimated the radon concentration at 0.59 ± 0.12 pCi/L [25]. In outdoor situations, radon is not a health issue; however, when it accumulates indoors or concentrates in areas frequented by workers, the gas will become a health issue. Currently, there are no national or internationally accepted

25. Hopper, RD, RA Levy, RC Rankin, and MA Boyd (1991). National Ambient Radon Study presented at the American Association of Radon Scientists and Technologists Annual Meeting, Rockville, MD 1991.

radiation dose coefficients for radon; however, as radon decays, its decay products can deposit into the lungs and may result in lung cancer.

In 2005, the Surgeon General of the United States issued a statement warning of the health risks from radon in indoor air. In 2012, the USEPA and the US Department of Health and Human Services, Centers for Disease Control and Prevention (CDC) released an updated guide to protect individuals from radon. This guide is available at http://www.epa.gov/radon/pubs/citguide.html#risk%20charts (last accessed on August 28, 2014). For indoor exposures, the guide recommends that concentration of radon should not exceed 4 pCi/L. At this concentration, the USEPA and CDC estimate that 0.07% of an exposed population of non-smokers could develop lung cancer. If you smoke, this increases 6.2%. Reducing the indoor concentration by 50% reduces your risk accordingly.

For workers in outdoor environments, radon accumulation is normally not a health issue except in the case of workers in trenches or excavations. In those situations, radon gas can accumulate as it is emitted from the bottom of the trench as well as the sides. Worker exposures are regulated by the Occupational Safety and Health Administration (OSHA). Their regulations (29CFR1910) require employers to limit exposures to the levels set by the US Nuclear Regulatory Commission. The current USNRC regulations limit workers to 30 pCi/L per hour over the course of a year (10CFR20, Table 1).

Particulates and radon pose a special hazard. When radon, an inert, electrically neutral gas decays, those decay products are not gaseous and are electrically charged atoms. The charged atoms will be attracted and attach to the dust particles in the air. When inhaled, these dust particles with the attached radioactive particles can deposit in the lungs similarly to non-radioactive dusts and particulates. In fact, these radioactive dusts and particulates deliver the radiation dose to the lung, not the radon itself. Whereas, dust and particulates are a lung irritant, with the addition of the radioactive component, the radioactive particulates become a potential lung carcinogen. This is the basis for the Surgeon General report previously mentioned in this document. For more information on radon and its health effects, ATSDR has developed a toxicological profile on radon. This profile can be accessed on the ATSDR web site at http://www.atsdr.cdc.gov/ToxProfiles/tp.asp?id=407&tid=71 (last accessed on August 28, 2014).

Child Health Considerations

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

Recently, the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) reviewed nuclear medicine studies, nuclear accidents, and areas of high background radiation. Although the radiation interactions in children are complex, the data did indicate that children were at higher risk for leukemia and tumors such as breast, thyroid, skin, and brain cancers. The risk in children vs. adults did not differ for other types such as bladder and colon. Children appear to be at less risk for lung cancer than adults. In general, the tumor incidence was more variable in children than adults, dependent on tumor type, age, and gender [26].

Conclusions

ATSDR has reviewed the radiological environmental sampling data for the West Lake Landfill in Bridgeton, Missouri. As part of past practices, this landfill received radioactive wastes mixed with soils to serve as a cover over materials during its operational period which ended in 1988. The data reviewed included groundwater wells located off-site and on-site, off-site and on-site air monitoring results, as well as off-site soil sampling results.

ATSDR reached several conclusions in this public health consultation that are based on the pathway analysis shown in Table 1.

1. ATSDR concludes that radiation in the groundwater will not harm people's health as there is no indication that contamination is migrating off the site. In addition, the groundwater flows toward the northwest, which is away from residential areas. All concentrations of radioactive substances in the off-site wells are below the regulatory limits for drinking water. No information was found to indicate if water from any on-site well was ever used as a drinking water source for past employees of the landfill and its operator.
2. A review of the off-site soil data collected along the haul roads leading to the landfill indicates there is no evidence of contamination. However, the concentration of thorium isotopes appears to be elevated, probably related to roadbed materials.
3. ATSDR is concerned with the health impacts of radon gas to any past, current, and future on-site workers of the landfill. Radon gas could harm people's health. If any landfill surface disturbances occur, dust particles containing uranium and thorium decay products that include radium-226, radon 222, and radium-228 may be released to the atmosphere. Workers then could potentially inhale these materials if proper protective measures aren't in place. Inhalation of particulates and particulates containing radioactive substances including radon may harm workers' health and lead to lung cancer if proper protective measures aren't in place. Previous soil sampling in the West Lake Landfill has shown the presence of radioactive materials near the surface as well as various depths within the landfill in excess of regulatory limits. These materials may be re-suspended during any soil disturbances. Individual radon flux (release of radon) from the landfill exceeded the regulatory limits by as much as 10 to 25 times but area averages were within regulatory limits when uncertainties are evaluated. The radon flux describes the rate of radon release over a specified area. The USEPA classifies radon gas as a leading cause of lung cancer.

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26. United Nations (2013). UNSCEAR 2013 Report. Volume II. Scientific Annex B: Effects of radiation exposure of children. New York: United Nations

4. Off-site radon air monitors indicate that the radon concentrations are elevated above typical US background concentrations; however these were short-term measurements and may be subject to short-term environmental conditions. Release of site-related radon will not extend beyond the site boundaries
5. Although out-door radon may be greater than typical background levels, the equipment readings may have been affected by environmental conditions. ATSDR does not believe these levels are sufficient to harm people's health. Although unrelated to the landfill, ATSDR recommends that all residents should be informed to have their house interiors tested for radon as recommended by the US Surgeon General.

Recommendations

ATSDR makes the following recommendations to the USEPA and State of Missouri agencies to ensure the public is protected from contaminants in the West Lake Landfill:

Site Related Recommendations

1. Continue monitoring the groundwater, including those wells previously sampled, both on-site and off-site;
2. Although there is no evidence of soil contamination along the haul roads, due diligence is warranted to ensure that there is no off-site migration of contaminants;
3. Continue monitoring for radon both on the landfill and in the 1-mile radius surrounding areas. Off-site radon monitoring should use long term monitoring devices.
4. Ensure adequate dust control measures are in place during landfill operations to prevent off-site migration of potentially contaminated materials;

Non-site related radon recommendation

There is no evidence that radon produced in the landfill will migrate to residential areas However, the average indoor radon levels from naturally occurring radon in St. Louis County are known to be higher than national levels (http://county-radon.info/MO/Saint_Louis.html). As a general practice, the US Surgeon General, the US Centers for Disease Control and Prevention, and USEPA recommend that all homes be tested for radon as discussed on the following internet locations: (http://www.cdc.gov/nceh/radiation/brochure/profile_radon.htm and (http://www.epa.gov/radon/healthrisks.html).

Public Health Action Plan

The public health action plan for the site contains a description of actions that have been or will be taken by ATSDR and other government agencies at the site. The purpose of the public health action plan is to ensure that this public health consultation both identifies public health hazards and provides a plan of action designed to mitigate and prevent harmful human health effects resulting from breathing, drinking, or touching hazardous substances in the environment. Included is a commitment on the part of ATSDR to follow up on this plan to ensure that it is implemented.

Thus far, the public health actions that have been taken by ATSDR include:

- Meeting with federal and state partners to discuss ATSDR's proposed public involvement;
- Attending regularly scheduled public meetings with federal, state, and local agencies and concerned public interest groups;
- Meeting with public interest groups to learn more about their concerns and their efforts to identify illnesses in the community;

In consultation with the State of Missouri and other government agencies, ATSDR will:

- Continue its review of environmental sampling data as requested and as it becomes available;
- Participate and present its findings at public meetings hosted by state or federal partners;
- Meet with health professionals to discuss future plans for any studies in the area; and
- In cooperation with ATSDR, MDHSS is currently completing a health consultation on inhalation exposure to nonradioactive emissions from Bridgeton Landfill, which is adjacent to West Lake Landfill Operable Unit 1

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Appendix I

Historic
Information

West Lake Landfill
and
Radioactive Wastes

Historically, the area around the landfill complex was agricultural. In 1939, a limestone quarry and related operations began. These activities continued until 1988. The quarry operations produced two quarry pits which, beginning in the 1950s, started to receive municipal solid wastes, industrial solid wastes, and construction related debris. No permits were required as these operations began prior to the formation of either state or federal environmental regulatory agencies. In 1979, the landfill received a permit for solid trash and was then known as the Bridgeton Landfill. The permitted Bridgeton Landfill stopped accepting trash and closed in 2005. The property continues to operate as a trash transfer station where household trash from neighborhood trash trucks is consolidated into bigger loads and transported to other landfills in the St. Louis metropolitan area.

In the West Lake Landfill (the site), wastes were mixed with soils from materials obtained from the St. Louis Airport Site (SLAPS), the Hazelwood Interim Storage Site (HISS), and the Latty Avenue sites. The waste at these sites originated as part of the Manhattan Project at the Mallinckrodt Chemical Works plant in downtown St. Louis. From 1947 to the mid-1960s, the Atomic Energy Commission (AEC) stored Manhattan project waste, including leached barium sulfate cake residue, at the aforementioned SLAPS in North St. Louis County. In the 1960s, the AEC moved these materials a half mile northeast, from the airport to AEC's HISS and later to a disposal area on Latty Avenue [27]. In 1975, the AEC was split into two agencies, the U.S. Nuclear Regulatory Commission (USNRC) and the Energy Research and Development Administration (ERDA), which later renamed to the US Department of Energy (USDOE).

In April 1962, a private company bought the ore residues and the uranium and radium process wastes being stored at SLAPS from the AEC. In 1966, the company transported approximately 117,000 tons of these materials from SLAPS to 9200 Latty Avenue in north St. Louis County. These radioactive materials consisted of 74,000 tons of Belgium Congo pitchblende raffinate, 32,500 tons of Colorado raffinate, 8,700 tons of leached barium sulfate cake residue, 1,500 tons of unleached barium sulfate cake, and 350 tons of miscellaneous residues. Raffinates are materials from which other materials have been extracted. These raffinates were a waste product produced during either uranium or thorium processing.

In 1967, a company specializing in recovering distressed company assets seized the assets of the private company which owned the radiological wastes stored at Latty Avenue. Most of these assets were sold to the Cotter Corporation who shipped 70,000 tons of these radioactive materials to their Cañon City, Colorado operation. By December of 1970, the only materials still stored at Latty Avenue were an estimated 10,000 tons of Colorado raffinate and 8,700 tons of leached barium sulfate.

In 1973, the 10,000 tons of Colorado raffinate at Latty Avenue were shipped to Colorado. Cotter then mixed the remaining 8,700 tons of leached barium sulfate cake residue, the lowest radioactivity-level material stored at the Latty Avenue location, with 39,000 tons of soil and the resulting 47,700 tons of material was taken to the West Lake Landfill site in St. Louis County. There, the leached barium sulfate cake residue waste was then mixed with soils to cover incoming refuse and solid waste. The radiologically-contaminated materials now consist of

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27. ATSDR (1994). Public Health Assessment for the St. Louis Airport Site. Atlanta, GA: Agency for Toxic Substances and Disease Registry. U.S. Department of Health and Human Services.

approximately 146,000 cubic yards of commingled refuse, debris, fill materials and soil, distributed in various quantities and concentrations across and under approximately 28 acres of the site.

In 1974, the AEC notified the Cotter Corporation who managed the Cañon City, Colorado operation that Cotter had disposed of radioactive materials in the landfill improperly. The method of disposal did not appear to meet the requirements of a volumetric reduction in the amount of radioactive materials [28]. Changing the volume of the waste by blending wastes is an approved method for changing the regulatory classification of the waste as long as those wastes are not released to the environment; however, Cotter Corporation did not adequately meet the requirement.

In 1976, the USNRC also became aware of this disposal practice and began investigations in 1978. Since that time, the USNRC as well as the USEPA have tested, monitored and sampled the site. The radioactive materials are found mostly at two areas of the West Lake Landfill. These areas are known as Areas 1 and 2. A smaller area, a narrow strip of adjacent property called the "Ford Property" or the "Buffer Zone/Crossroads Property" also is contaminated. The radiological materials are mixed with landfilled refuse, debris, soil, and fill, and appear in both surface (the upper six inches of ground) and subsurface (7 to 12 feet or deeper) areas of the Site. Following additional evaluations by the USEPA, the agency placed the entire landfill complex on its National Priorities List (NPL) in 1990 [29]. The USEPA initially selected a remedy in 2008; however, as a result of community involvement, comments and concerns, the remedy was delayed and is currently being re-evaluated.

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28. Letter from John G. Davis, Atomic Energy Commission to David P. Marcott, Cotter Corporation, dated November 1, 1974.

29. www.westlakelandfill.com (last accessed on March 3, 2014).

Appendix II

Radioactivity and Naturally Occurring Radioactive Materials

The issue of radiation exposure is a matter of interest to the general public; radiation exposure is inevitable as it is a natural part of the environment. Indeed, radioactive materials have always existed around and even within all living things. While the risk of exposure to radiation from man-made sources exists, the average individual dose received from man-made radiation is small compared to that received from natural sources. When assessing the risks associated with radiation exposure, one must weigh the potential benefits (e.g., gain in quality of life related to medical diagnoses and treatments) against the potential detriments (acute radiation sickness, cancer risk) associated with the exposure. Conversely, in situations presenting minimal risks of exposure to radiation and radioactive materials, one may also compare the potential risks associated with the use of alternatives. For example, in the case of nuclear power versus power from fossil fuels, one may want to weigh the risk of exposure to coal dust, radioactive materials, combustion products and waste materials associated with coal power versus the risk of radiation exposure from nuclear power production and waste disposal. The regulations concerning radiation exposure limitations are based upon the studies and recommendations of numerous scientific organizations to ensure the health of occupational workers and the public.

Atoms are the basic building blocks of all matter. An atom consists of one nucleus, made of protons and neutrons, and many smaller particles called electrons that orbit the nucleus. The number of protons in the atom's nucleus determines which element it is. For example, an atom with one proton is hydrogen and an atom with 27 protons is cobalt. Each proton has a positive charge, and positive charges try to push away from one another. The presence of neutrons may act as a kind of glue that holds the nucleus together. The number of protons in an atom of a particular element is always the same, but the number of neutrons may vary. Neutrons add to the weight of the atom, so an atom of cobalt that has 27 protons and 32 neutrons is called cobalt-59 because 27 plus 32 equals 59. If one more neutron were added to this atom, it would be called cobalt-60. Cobalt-59 and cobalt-60 are isotopes of cobalt. Isotopes are forms of the same element, but differ in the number of neutrons within the nucleus. Since cobalt-60 is radioactive, it is called a radionuclide. All isotopes of an element, even those that are radioactive, react chemically in the same way. Atoms tend to combine with other atoms to form molecules (for example, hydrogen and oxygen combine to form water). Radioactive atoms that become part of a molecule do not affect the chemical reactions inside your body until the radioactive atom decays.

Ionizing radiation is energy that is carried by several types of particles and rays given off by radioactive material, X-ray machines, and fuel elements in nuclear reactors. Ionizing radiation includes alpha particles, beta particles, X-rays, and gamma rays. Alpha and beta particles are essentially small fast moving pieces of atoms. X-rays and gamma rays are types of electromagnetic radiation. These radiation particles and rays carry enough energy that they can knock out electrons from molecules, such as water, protein, and DNA, with which they interact. This process is called ionization, which is why it is named "ionizing radiation." Humans cannot sense ionizing radiation, so we must use special instruments to learn whether we are being exposed to it and to measure the level of radiation exposure. The other types of electromagnetic radiation include radiowaves, microwaves, infrared radiation, visible light, and ultraviolet light.

These types of radiation do not carry enough energy to cause ionization and are called non-ionizing radiation. This profile will only discuss ionizing radiation.

Ionizing radiation is not a substance like salt, air, water, or a hazardous chemical that we can eat, breathe, or drink or that can soak through our skin. However, many substances can become contaminated with radioactive material, and people can be exposed to ionizing radiation from these radioactive contaminants. Practically, however, after 10 half-lives, less than 0.1% of the original radioactivity will be left and the radioactive material will give off infinitesimally small amounts of ionizing radiation. The half-life is the time it takes one-half of the radioactive atoms to transform into another element, which may or may not also be radioactive. After one half-life, ½ of the radioactive atoms remain; after two half-lives, half of a half or 1/4 remain, then 1/8, 1/16, 1/32, 1/64, etc. The half-life can be as short as a fraction of a second or as long as many billions of years. Each type of radioactive atom, or radionuclide, has its own unique half-life.

The majority of exposure to radiation comes from natural sources. With the exception of indoor radon exposure (and to some extent exposure from terrestrial sources), exposure to natural radiation is only moderately controllable. Controllability in relation to radon refers to mitigation of radon concentrations in buildings and homes.

Cosmic radiation contributes approximately the same amount of background radiation as terrestrial radiation (8%), which is emitted by naturally occurring radioactive materials found in the earth's crust, such as potassium 40, uranium and its progeny, and thorium and its progeny. Uranium, for example, is found in all types of soil and rock at concentrations ranging from 0.003 parts per million (ppm) in meteorites to 120 ppm in phosphate rock from Florida. Exposure to radioactive materials in the soil and earthen products occurs continuously since we are surrounded by these sources. The radiation dose varies tremendously and is affected by such factors as geographic location, concentration of natural radioactive materials in the soil and building materials, and the types of materials used in building structures.

Radioactive substances decay into either other radioactive substances or into stable, non-radioactive substances. In the case of uranium and thorium, both naturally occurring, they decay through multistep processes ultimately producing stable lead. Uranium is composed of three separate radioactive components (isotopes) of different masses. Uranium-238 decays into uranium-234, which through a series of transformations, produces thorium-230, radium-226, and other radioactive substances. The third isotope of uranium, uranium-235 forms similar products, differing only by their mass numbers. thorium-232 also decays through several steps producing both radium-228 and thorium-228 in the process.

Naturally occurring uranium and thorium have extremely long half-lives but their decay products have half-lives that can be relatively short. Because of this relationship, the short lived decay products will be present in the environment until the uranium and thorium completely decay. This also means that the decay products can be calculated using a relationship between their half-lives. The term secular equilibrium, used to describe this relationship, means that the radioactivity concentration of the decay product will equal the radioactivity concentration of the uranium-238 or thorium-232 in an undisturbed environment. The following simplified equation defines this relationship:

$$A_b = A_a\,(1 - e^{-\lambda_b t})$$

A_b is the activity of the decay product, A_a is the activity of the parent, λ_b is a relationship of the half-life of the decay product and e is a constant (approximate value of 2.718) used with natural logarithms.

Most uranium compounds are insoluble in water; however, this will depend on the quality of the water. For example, if the water is acidic with high concentrations of organic matter, the uranium will be an organic complex. If the water is basic, the uranium may be present as a carbonate. Thorium and radium solubility will vary as well with thorium sulfate being soluble in water but radium sulfate being insoluble.

Tables

Table 1. Review and summary of completed or potential pathways of concern for the West Lake Landfill, Bridgeton, Missouri.

Pathway	Location	Time Frame	Pathway Evaluation
Groundwater	On-site	past	Potential; Unknown if groundwater was used for drinking by employees
		current	Eliminated; groundwater is not used for a drinking water source
		future	
	Off-site	past	Eliminated; radioactive substances in groundwater wells are below regulatory limits; the groundwater wells are not used as public water.
		current	
		future	
Air	On-site	past	Completed; radon 222 released from radium-226 will continue to be released exposing on-site employees
		current	
		future	
	Off-site	past	Potential; equipment issues need to be resolved
		current	
		future	
Soil	On-site	past	Potential; unknown if human exposures routes, times and frequencies of exposure occurred at hazardous levels.
		current	
		future	
	Off-site	past	
		current	Eliminated as contamination, if present is within ranges typical of background concentrations.
		future	

Table 2. Off-site soil sampling results on adjacent haul roads.*

	St. Charles Rock Road	*Boenker Road*	*Taussig Road*	*Typical Missouri Background†*
Ra 226	1.19	1.32	1.45	0.31-1.04
Th 228	0.73	0.89	0.99	
Th 230	2.51	1.71	1.67	
Th 232	0.83	0.93	1.05	0.32-1.3
U 234	0.91	0.92	0.98	
U 235	0.12	0.07	0.52	
U 238	0.86	0.96	0.95	0.33-1.7

*The values are the average of the sampling points along the specified road and are given in picocuries per gram of soil.

†Background values from Reference 5

Table 3. Comparison of On-site vs Off-site Average Groundwater Concentrations, West Lake Landfill, Bridgeton, Missouri

	On-site soluble*	**On-site particulate***	**Off-site USEPA (Total)***	**Off-site USGS soluble***	**MCL†**
Radium-226	2.67	2.57	0.43	1.01	
Radium-228	2.71	2.97	0.71	0.64	
Total Radium	5.32	5.54	1.14	1.65	5
Uranium-234	2.22	2.01	1.52	0.71	
Uranium-238	1.47	1.77	1.32	0.43	
Total Uranium	3.69	3.78	2.84	1.14	20
Thorium-228	NA	1.23	0.19	0.07	
Thorium-232	NA	1.32	0.08	0	15

*Average concentrations are expressed as picocuries per liter (pCi/L). The USEPA did not separate the soluble from the particulates in the water.

†MCL – Maximum Contaminant Level in pCi/L. For uranium, the MCL is 30 micrograms per liter but the activity concentration is 20 pCi/L. ATSDR has not established a health based comparison value for uranium in water.

Data from Groundwater Monitoring reports for 2012 and 2013.

Table 4. Concentrations of radionuclides in groundwater soluble and particulate fractions found in West Lake Landfill, Bridgeton, Missouri, monitoring well samples

Analyte	Soluble fraction*	Particulate fraction*	Average for both fractions combined*
Radium-226	2.67	2.57	2.62
Thorium-230	0.45	1.47	1.24
Uranium-234	2.22	2.01	2.12
Uranium-238	1.47	1.77	1.62
Radium-228	2.71	2.97	2.85
Thorium-228	NA	1.23	---
Thorium-232	NA	1.32	---
Total Radium†	5.38	5.54	5.47

*Average values are expressed as picocuries per liter (pCi/L) and were determined from data obtained the groundwater sampling between 2007 and 2012. The data used for this table only includes those samples which passed the quality control and quality assurance standards previously determined.

†The total radium concentration is a regulatory requirement in which the combined concentration should not exceed 5 pCi/L. ATSDR has not established a health based comparison value for radium in water.

Data from Groundwater Monitoring reports for 2012 and 2013.

Table 5. Radionuclide groundwater concentrations found at various depths within West Lake Landfill, Bridgeton, Missouri monitoring wells

Analyte	Deep*	Intermediate*	Shallow*	Monitoring Wells*	Piezometer Wells*	Average*
Radium-226	2.58	1.24	1.64	7.75	3.24	3.23
Thorium-230	3.14	2.98	2.75	1.37	0.81	2.21
Uranium-234	0.76	1.22	1	3.93	2.61	1.9
Uranium-238	1.41	0.88	1.29	3.2	1.54	1.67
Radium-228	3.39	2.88	2.11	5.7	2.31	3.28
Thorium-228	1.5	1.72	0.82	1.65	1.06	1.35
Thorium-232	1.76	0.98	0.71	1.51	1.17	1.23
Total Radium†	5.97	4.13	3.75	13.2	5.55	6.51

* Average values are expressed as picocuries per liter (pCi/L) and were determined from data obtained the groundwater sampling between 2007 and 2012. The data used for this table only includes those samples which passed the quality control and quality assurance standards previously determined.

†The total radium concentration is a regulatory requirement in which the combined concentration should not exceed 5 pCi/L. ATSDR has not established a health based comparison value for radionuclides in water.

Data from Groundwater Monitoring reports for 2012 and 2013.

Table 6. Results of radiological groundwater samples taken from domestic wells near the West Lake Landfill performed by the US Environmental Protection Agency during 2013, West Lake Landfill, Bridgeton, Missouri

Sampling Points*							
Isotopic analysis		Well C-1	Well C-2	Well C-3	Well C-4	Well C-5	Well C-7
A†	Radium-226	0.51	0.74	0.20	0.38	0.35	0.39
	Thorium-230	0.18	0.12	<0.115	0.16	0.67	0.18
	Uranium-234	0.30	1.64	1.38	0.19	2.66	2.97
	Uranium-238	<0.137	0.91	0.89	<0.109	1.57	1.9
B	Radium-228	0.73	1.3	<0.0724	0.67	0.35	0.49
	Thorium-228	<-0.0542	<-0.026	0.19	<0.0102	<0	<0.0137
	Thorium-232	<0	<0.0461	<0.0156	<0.0272	0.08	<0.035
C	Uranium-235	0.09	<0.0773	<0	<0.02	<0.107	0.28

*The results are expressed as picocuries per liter (pCi/L). The sampling point well identification refers to those points in Figure 7.

†Letters refer to decay series. The isotopes listed in Group A are produced by the radioactive decay of uranium-238. Those in Group B are produced by the decay of thorium-232. Group C decay products from uranium-235 were not reported. ATSDR has not established a health based comparison value for radionuclides in water.

Data supplied to ATSDR by USEPA.

Table 7. Results of off-site domestic well sampling performed by the US Geological Survey in 2013, West Lake Landfill, Bridgeton, Missouri

Sampling Points*						
Isotopic analysis		Well E-1	Well A-5	Well D-1	Well B-4-S	Well B-3
A†	Radium-226	0.31/<0.02‡	3.29/2.92	0.58/0.38	0.28/0.33	0.56/0.54
	Thorium-230	0.03/0.08	<0.003/<0.016	0.01/0.04	0.05/<0.014	<0.010/0.045
	Uranium-234	0.79/0.79	0.24/0.3	1.35/1.66	0.52/0.476	0.67/0.87
	Uranium-238	0.43/0.46	0.08/0.07	0.96/0.91	0.33/0.322	0.36/0.51
B	Radium-228	<0.23/<0.21	0.3/0.42	0.43/0.8	1.22/0.96	1.42/2.69
	Thorium-228	<0.019/0.19	0.06/0.14	0.08/0.16	0.10/0.22	0.10/0.28
	Thorium-232	<0/<0	<0.005/<0.006	<0/<0.016	<0/<0.003	<0.003/<0.006
C	Uranium-235	<0.020/<0.021	0.03/<0.012	<0/<0.002	0.03/<0.003	<0.014/<0.007

*The results are averages expressed as picocuries per liter (pCi/L). The sampling point well identification refers to those points in Figure 7. ATSDR has not established a health-based comparison value for radionuclides in water.

†Letters refer to decay series. The isotopes listed in Group A are produced by the radioactive decay of uranium-238. Those in Group B are produced by the decay of thorium-232. Group C decay products from uranium-235 were not reported.

‡The values listed are the dissolved value/total value.

Data supplied to ATSDR by USEPA

Table 8. Results of radiological particulates air sampling conducted on the West Lake Landfill, Bridgeton, Missouri

	Thorium-228	*Thorium-230*	*Thorium-232*
December 2013	9.2E-16	2.00E-15	4.47E-16
March 2014 (in administrative areas)	1.18E-13	2.76E-13	1.10E-13
March 2014 (on landfill areas)	2.04E-13	5.02E-13	1.85E-13
High volume air samplers (as reported in March 2014)	1.09E-14	2.26E-14	7.88E-15
USNRC occupational limit	4.00E-12	6.00E-12	5.00E-13
USNRC public limit	2.00E-14	2.00E-14	4.00E-15

The results are averages expressed as microcuries per milliliter. Data from air sampling reports prepared by Feezor Engineering for December 2013, March 7, 8, and 9, 2014.

Table 9. Off-site air monitoring locations

Station Number	Station Name	Alternate Name	Approximate Location
1	Robertson St. 2	USEPA trailer	Taussig Rd and Enterprise Way
2	Pattonville Adm	Fire District Station 3	St. Charles Rock Rd and Earth City Parkway
3	Pattonville St. 2	Fire District Station 2	McKelvey Road at I-70
4	Spanish Village	Spanish Village Park	San Sevilla Court and Spanish Village Drive
5	St. Charles St. 2	St. Charles Fire Department	South River Rd and S. Main Street

Air samples were collected between May 8 and August 14, 2014. Samples were analyzed for, alpha and beta radiation, uranium, thorium, and radium. Seven-day radon averages, measured by electret ion chambers, were collected from May 2 through September 9, 2014.

Table 10. Particulate radioactivity in air at off-site locations.

	Station 1	Station 2	Station 3	Station 4	Station 5	USNRC limit
U 238	1.30E-04	1.82E-04	1.23E-04	1.31E-04	9.63E-05	6.00E-02
Th 230	8.98E-04	5.64E-04	5.68E-04	5.55E-04	5.21E-04	2.00E-02
Total radium	4.80E-04	7.94E-04	5.11E-04	6.80E-04	4.50E-04	9.00E-01
alpha	6.63E-04	6.61E-04	5.74E-04	6.21E-04	6.33E-04	No USNRC regulatory value
beta	1.96E-02	2.00E-02	1.98E-02	1.99E-02	1.90E-02	
Data are averages expressed as picocuries per cubic meter of air. The averages also include those values that did not exceed the minimum reporting limit or were less than the sample detection limit. The USNRC limit is promulgated at 10 CFR 20.						

Table 11. Radon levels in air measured at off-site locations.

	Station 1	Station 2	Station 3	Station 4	Station 5	USNRC limit	USEPA
Average concentration	0.31	0.32	0.25	.027	0.26	0.1	4.0
Minimum value	0.20	0.15	0.17	0.09	0.13		
Maximum value	0.87	0.75	0.37	0.83	0.72		
Average background	0.14 to 0.4 (estimated world-wide) 0.2 to 0.75 (United States)						
Data are averages expressed as picocuries per liter of air. The USNRC limit is promulgated at 10 CFR 20 and is the value for radon in air with its decay products present. The USEPA limit is based on the USEPA recommended level for indoor air.							

Figures

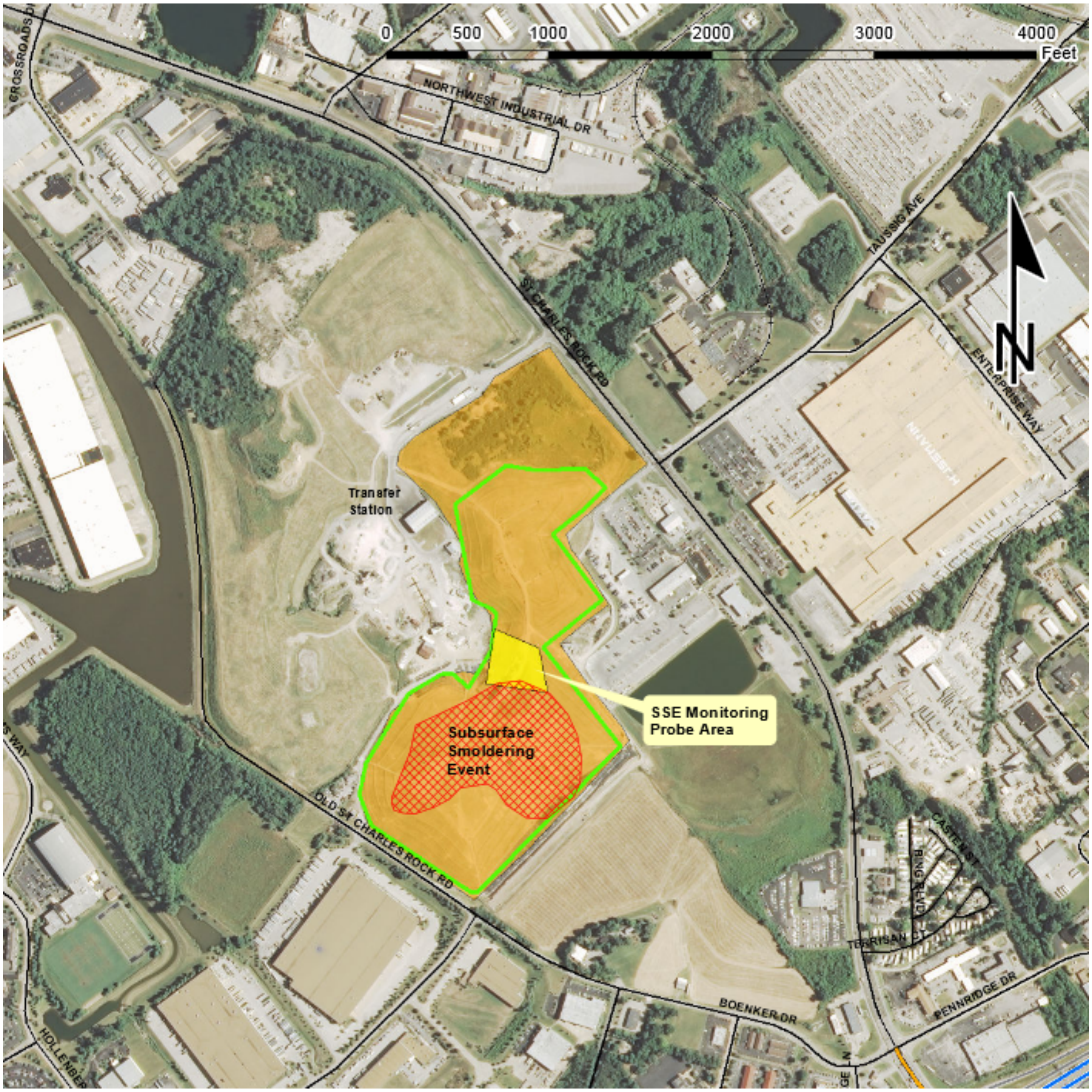

Figure 1. West Lake/Bridgeton Landfill complex, Bridgeton, Missouri. In this undated photo from the Missouri Department of Natural Resources, the highlighted area shows the North Quarry and South Quarry areas.

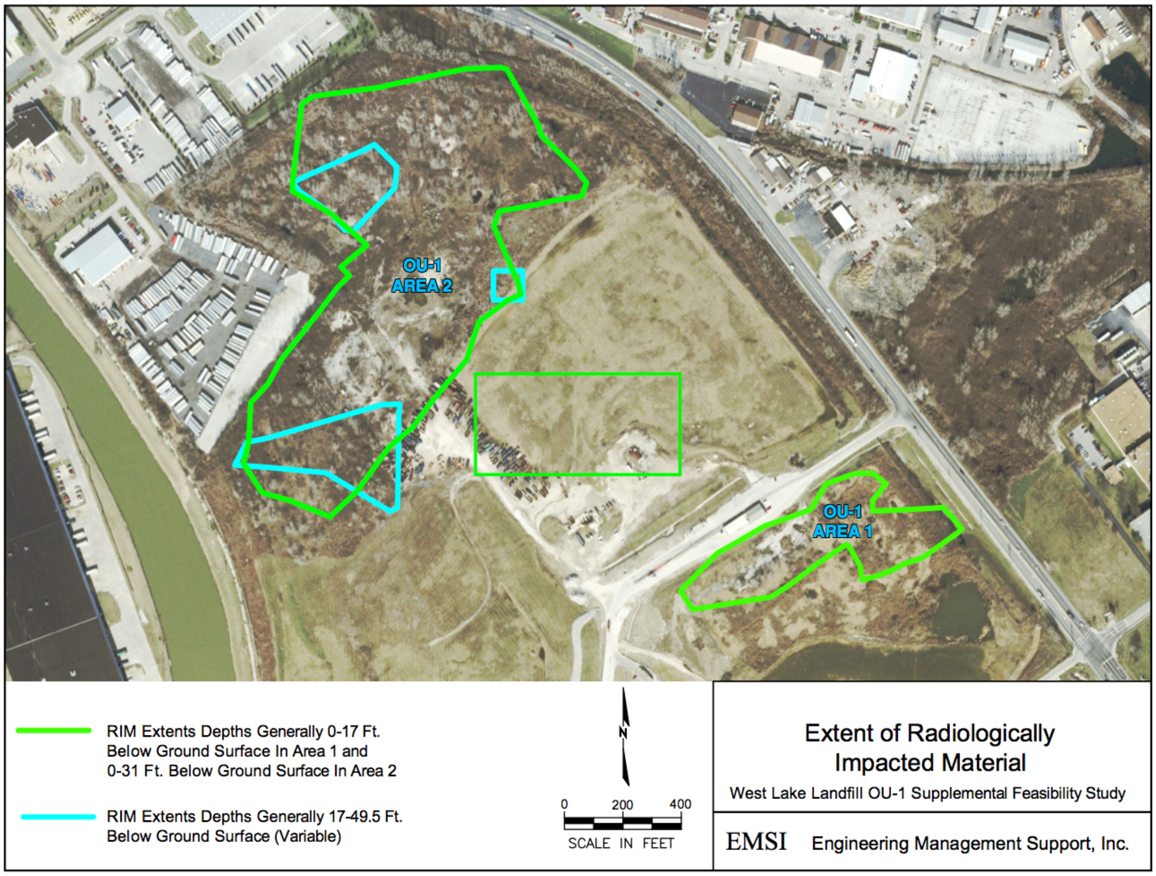

Figure 2. Extent of radioactive materials. Figure from 2011 Supplemental Feasibility Study

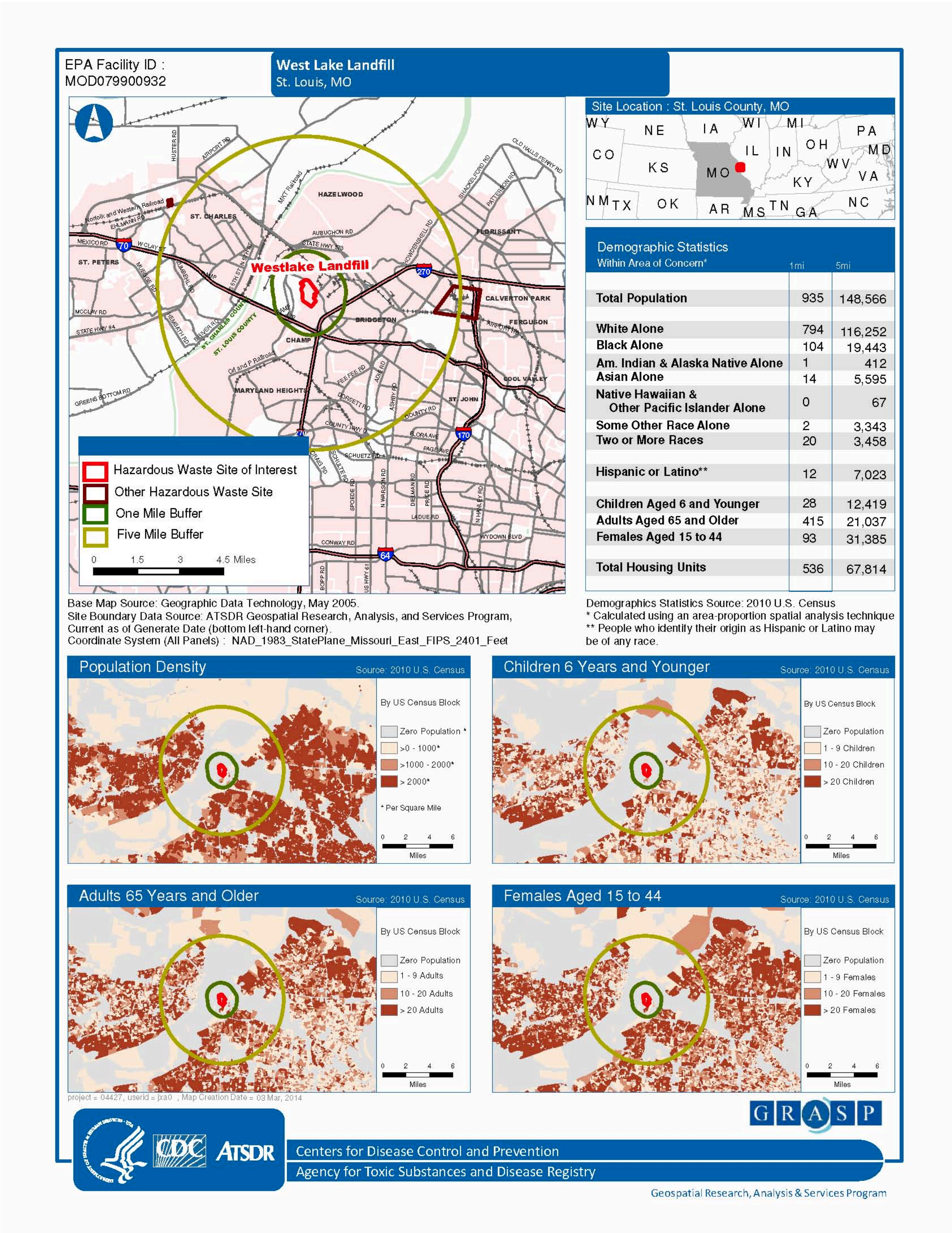

Figure 3. West Lake and Bridgeton Landfills, Bridgeton, Missouri, area demographics.

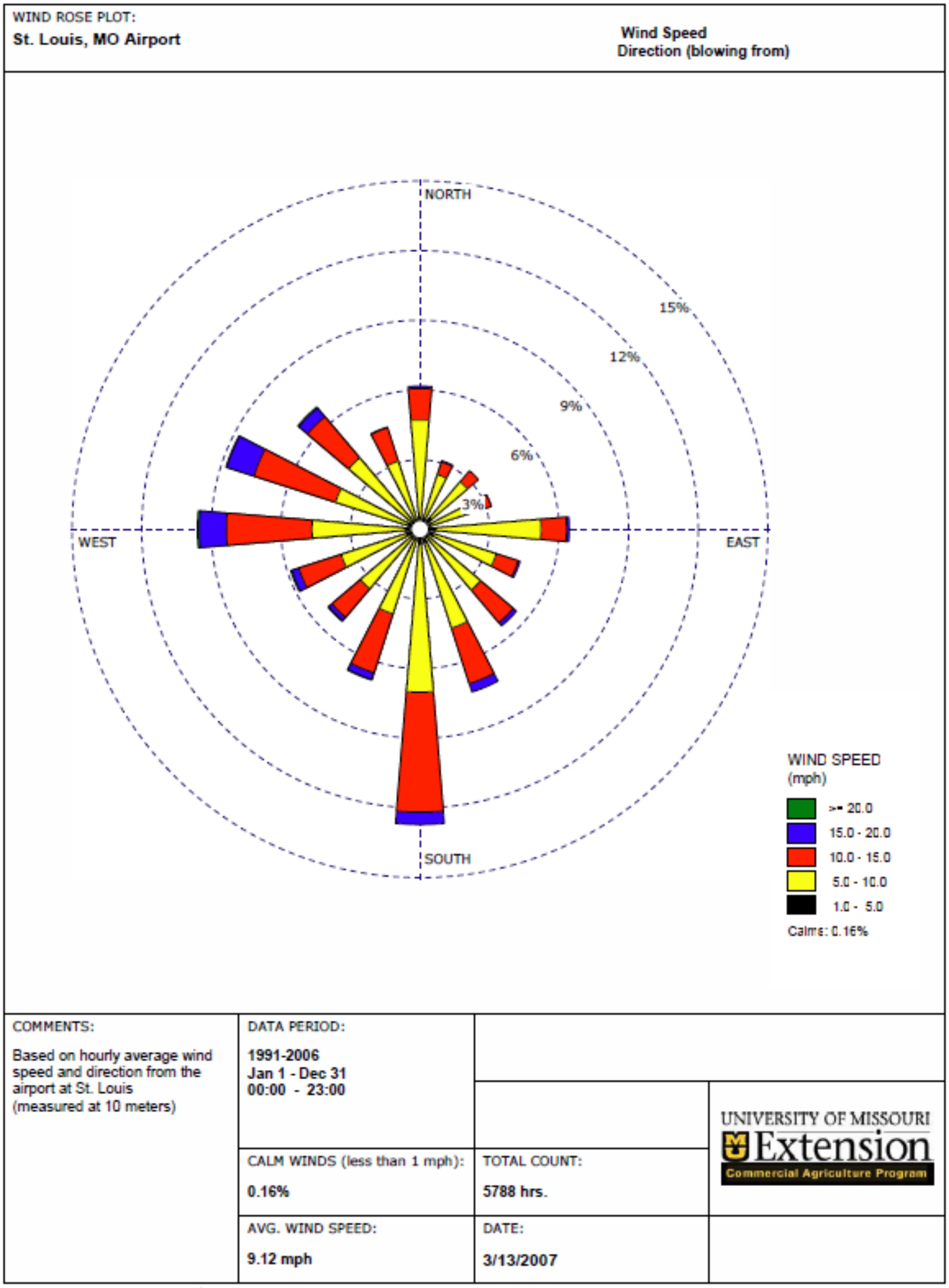

Figure 4. St. Louis International Airport, Missouri, wind speeds and directions from January 1996 to December 2006.

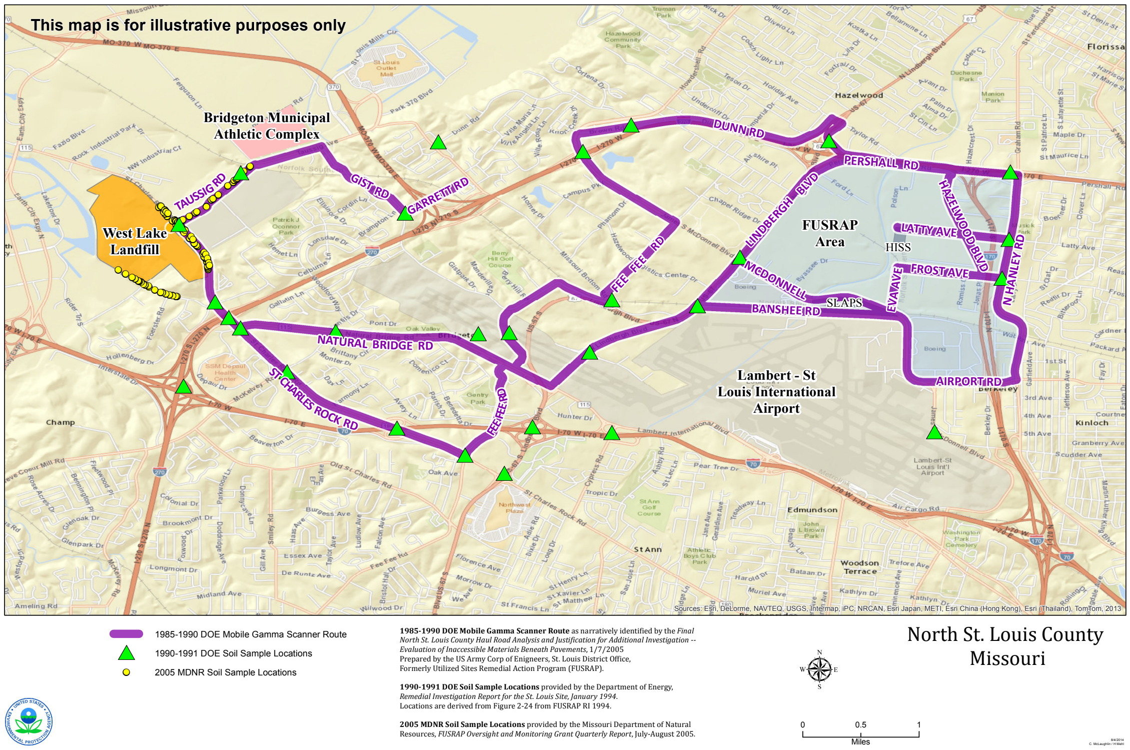

Figure 5. Soil sampling locations. Figure courtesy of USEPA.

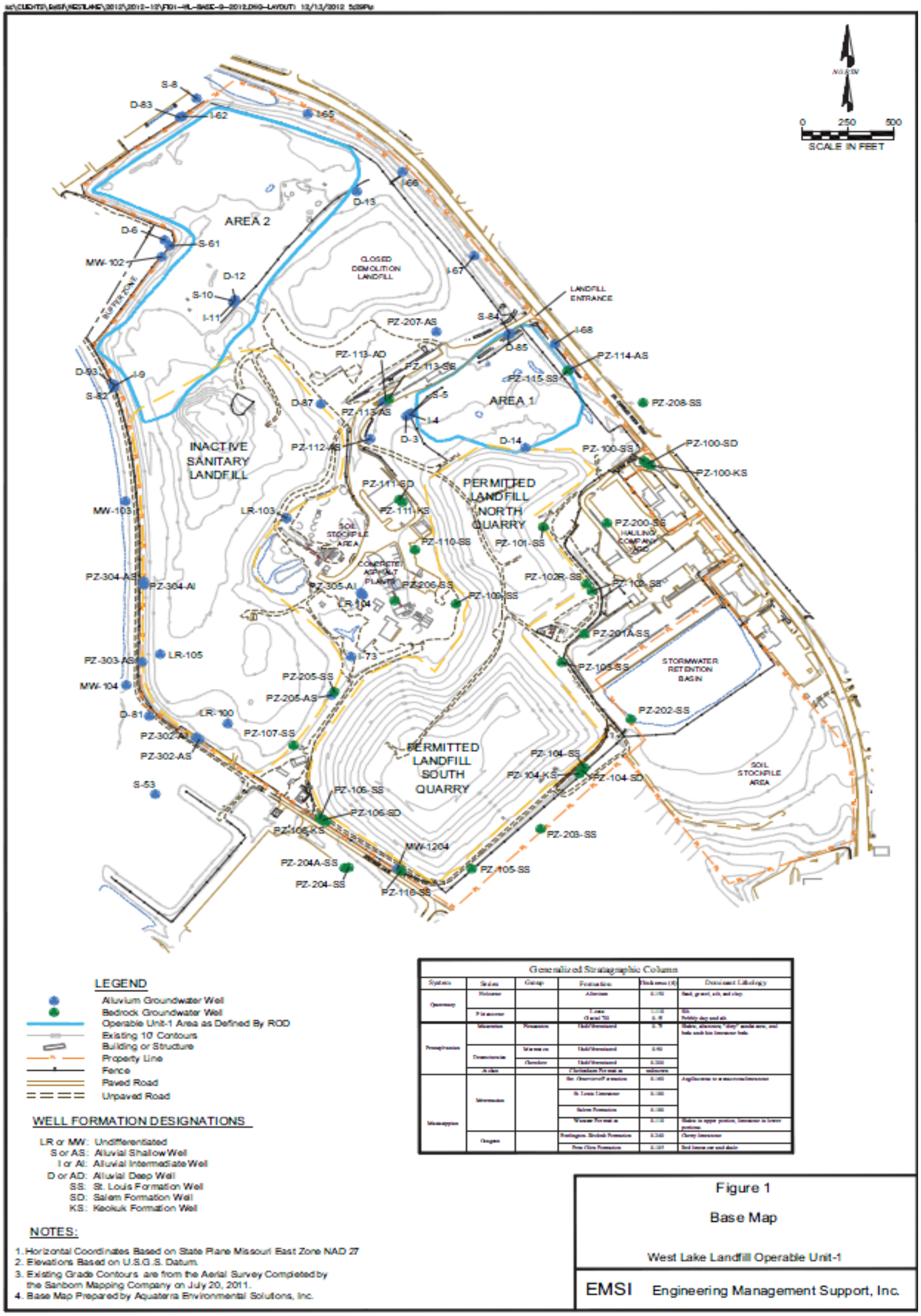

Figure 6. Base map showing location of groundwater monitoring wells within the West Lake and Bridgeton Landfills, Bridgeton, Missouri.

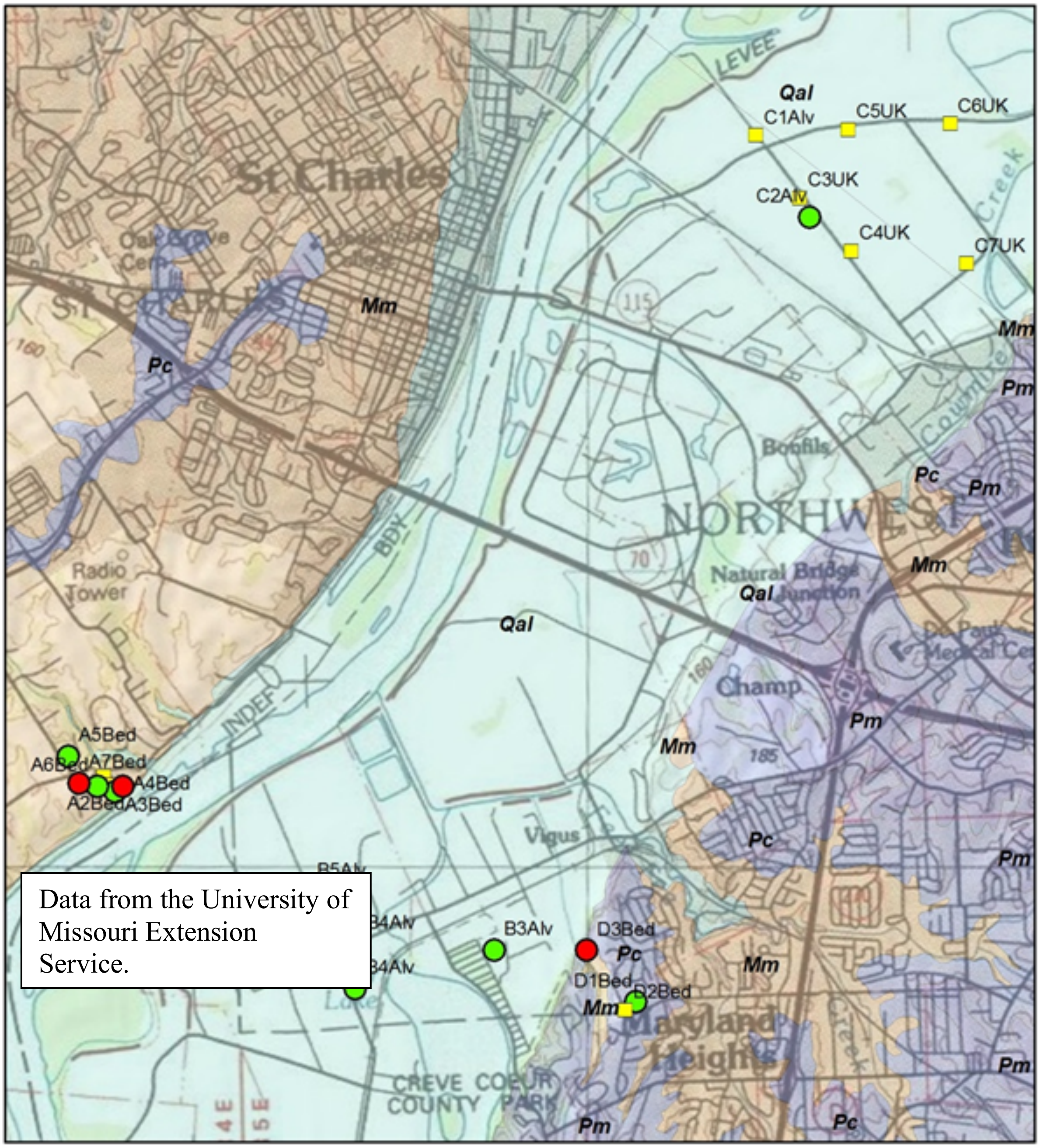

Figure 7. USGS background domestic well sampling locations near the West Lake and Bridgeton Landfills, Bridgeton, Missouri.

The green circles are those wells in which permission was given to sample, red circles, no permission was given, and the yellow squares represent wells at which time the permission was unknown or undecided.

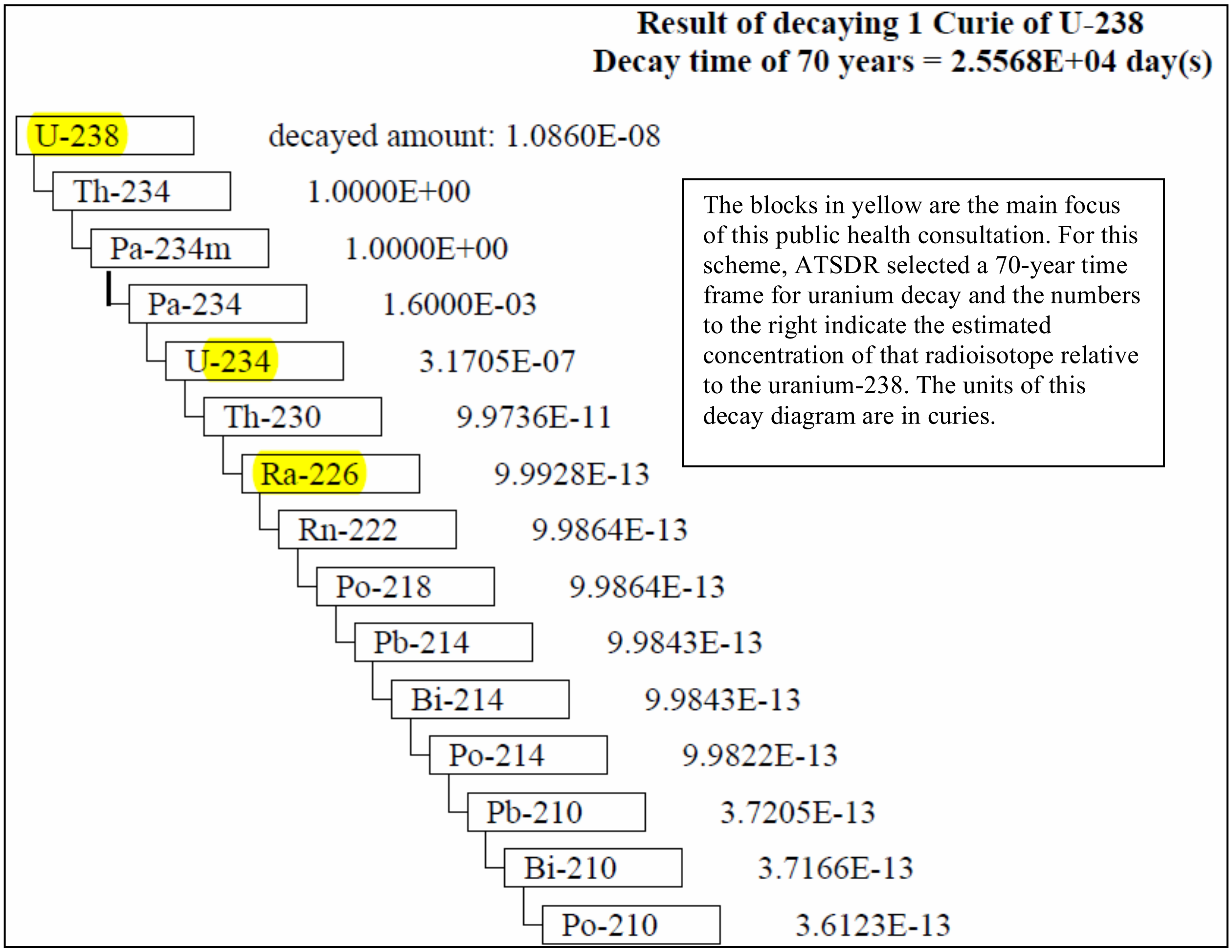

Figure 8. Diagram of how uranium-238 decays into its decay products and the activity of those decay products assuming a 70-year time lapse.

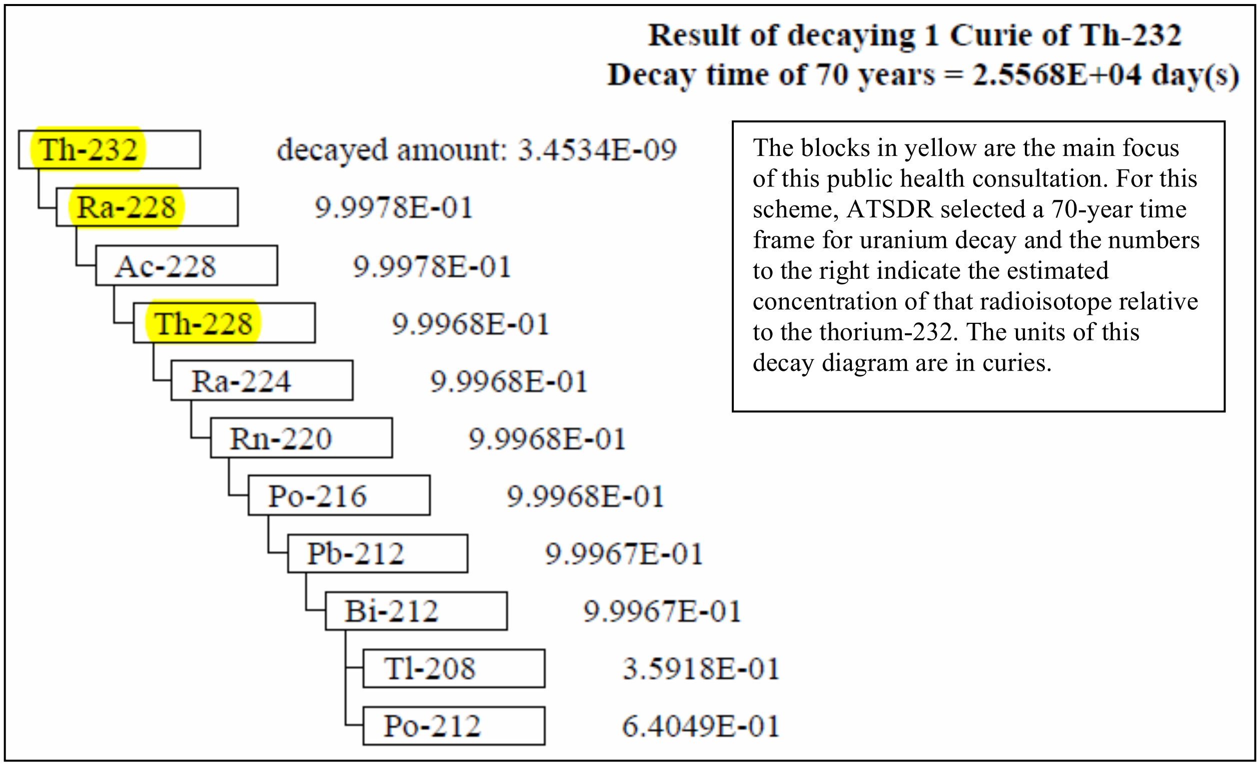

Figure 9. Diagram of how Thorium-232 decays into its decay products and the activity of those decay products assuming a 70-year time lapse.

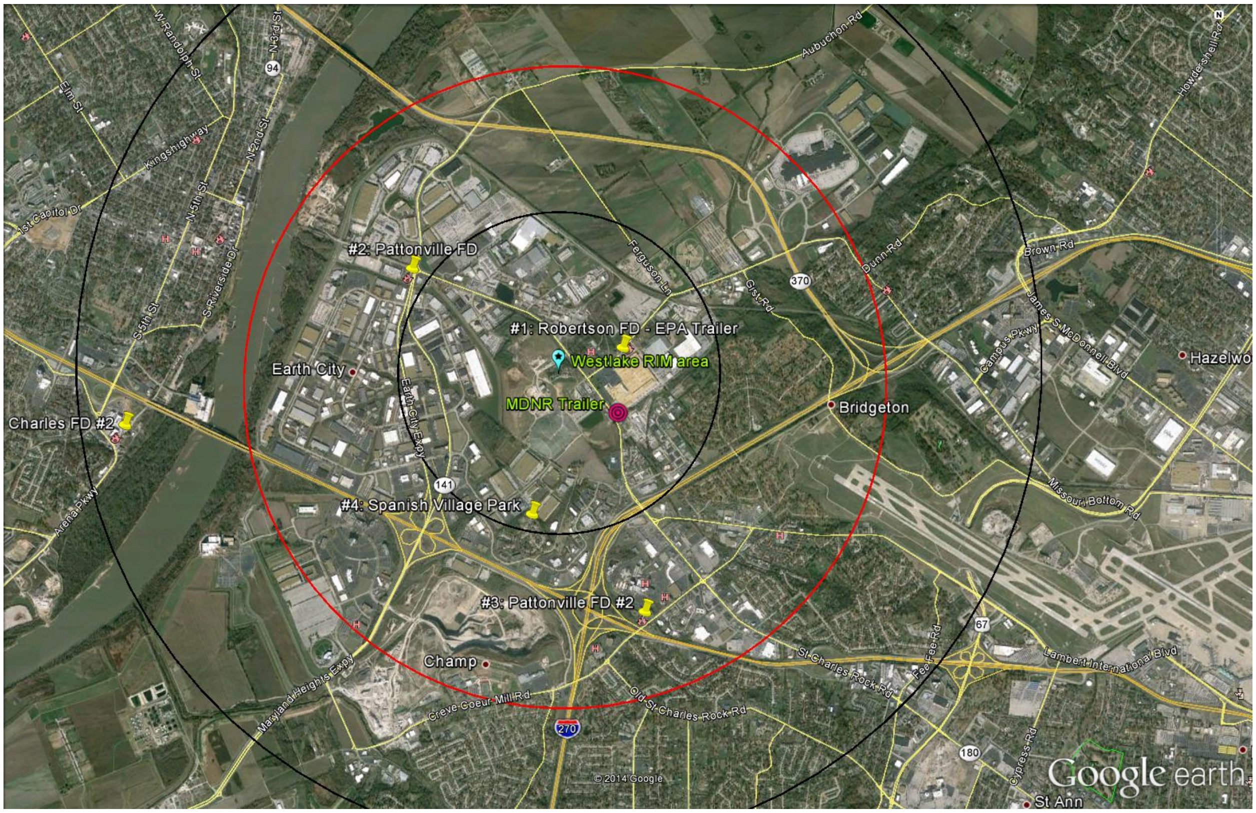

Figure 10. Imagery of off-site air monitoring locations. Image supplied by USEPA