Health Consultation

Review of Radiological Data
Measured in the
Polycythemia Vera Investigation Study Area
in Carbon, Luzerne and Schuylkill Counties, Pennsylvania

JULY 22, 2014

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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Division of Community Health Investigations
Agency for Toxic Substances and Disease Registry

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 and Statement of Issues

The Agency for Toxic Substances and Disease Registry (ATSDR) Region III office in Philadelphia, Pennsylvania requested a public health consultation for the purposes of evaluating radiologic data collected in association with a polycythemia vera (PV) cluster investigation. The purpose of this health consultation is to provide a public health evaluation of the available radiological environmental sampling results as reported in 2011 and 2012 from the study area, and to highlight this information for relevant agencies, community members, and for future studies in the cause of PV. Environmental sampling information in the cluster area was collected as a component of the overall research investigation into this disease cluster. This sampling information included metals, organic compounds, and radioactive substances. This document only reviews the radiological environmental sampling data collected by the Pennsylvania Department of Environmental Protection (PADEP) on behalf of ATSDR.

The National Library of Medicine (NLM) states that polycythemia vera (PV) is a bone marrow disease that leads to an abnormal increase in the number of red blood cells although the numbers of white blood cells and platelets which are essential for blood to clot are also increased. A rare disease that occurs more often in men than women, PV is rare in patients under age 40[1]. Only one report possibly linking PV to radiation exposure was found. In that report, 2 cases of PV were found in over 3,200 military personnel exposed to a nuclear weapons test[2].

A cluster is an aggregation of cases of a disease or health issue that is closely associated with both time and location. In order to investigate this grouping of the health issue, an analysis of the area or the cluster is performed and this is called a cluster analysis or investigation.

This public health consultation evaluates radiologic data collected by PADEP on behalf of ATSDR in water (including drinking water), surface soils, and indoor air.

Background, Site Description, and History

In 2004, four cases of PV were found in people living on the same rural road near the Borough of Tamaqua, also in Schuylkill County. The Pennsylvania Department of Health (PADOH) reviewed the cancer cases reported in the State's Cancer Registry from the three counties (Carbon, Luzerne, and Schuylkill) surrounding the Tamaqua area. PADOH found that the overall cancer rate in the tri-county area was similar to that in other parts of the state, but there were more PV cases than expected in a population of this size. In October 2006, the state health department requested ATSDR's help in investigating a high number of PV cases reported in the three counties. ATSDR was asked to make sure that the reported cases actually had PV, and to find any other cases of PV in the tri-county area. A survey of the possible cases was conducted to collect information on work and residence histories, health status, and other factors that might be related to PV.

The localities nearby this nexus include Hometown/Rush Township, Kline Township, McAdoo Borough, and Tamaqua Borough.

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[1] National Library of Medicine, http://www.ncbi.nlm.nih.gov/pubmedhealth/PMH0001615/ last accessed February 11, 2013.

[2] Caldwell, GG, DB Kelley, Heath, CW, and Zack, M (1984). JAMA 252:662.

An expert panel convened to investigate the cluster recommended that ATSDR conduct additional research into the cluster investigation[3]. This research would be an "all-hazards" approaching evaluating identified environmental constituents or hazards identified as being present. Additional information can be found at http://www.atsdr.cdc.gov/sites/polycythemia_vera/index.html on the ATSDR web site (last accessed on February 11, 2013). This public health consult is a follow up of that recommendation and additional research.

Northeastern Pennsylvania is known for its historical coal mining activities. Mining for anthracite coal occurred from 1884 until 1969 in the vicinity of McAdoo Borough and Kline Township in Schuylkill County. A number of currently operating coal ash cogeneration facilities are in the area, as well as other active and inactive industrial sites. Coal is largely composed of organic matter, but it is also contains inorganic matter (minerals and trace elements). Some of the trace elements in coal are naturally radioactive. These radioactive elements include uranium (U), thorium (Th), and their numerous decay products, including radium (Ra) and radon (Rn)[4,5].

A range of current and past industrial operations were identified in northeastern Pennsylvania as part of this cluster investigation. Northeastern Pennsylvania is known for its historical coal mining activities. Mining for anthracite coal occurred from 1884 until 1969 in the vicinity of McAdoo Borough and Kline Township in Schuylkill County. A number of currently operating coal ash cogeneration facilities are in the area, as well as other active and inactive industrial sites. Nearby the residences of some of the original cases identified with PV is one of the more well known former industrial sites in the study area, the McAdoo Associates Superfund Site in Schuykill County. Demonstrating the complexity of past and present environmental exposures in this region, neighboring the McAdoo site is an operating coal co-generation facility and ash storage area (co-generation operations collect and reprocess culm (coal waste and refuse) to extract the additional coal attached to rock and burn it to produce electricity). One of the projects ATSDR completed to gather information to support this cancer cluster investigation was to create a "data warehouse" or inventory of environmental exposure information available for the area. ATSDR developed a database containing federal, state, and other relevant data and documents relating to possible human exposures to contaminants from hazardous waste sites and other operations, industries, or businesses that release toxic material within the cluster area. The data warehouse contains about 100,000 samples and 2.5 million records for 2,700 substances. Future reports related to ATSDR's PV investigation will be published that will include more detailed information and maps describing the data from the warehouse. ATSDR has provided this database to interested research partners and community members.

Radon is a regional indoor air quality concern in northeastern Pennsylvania. The Pennsylvania Bureau of Radiation Protection reports that the average indoor radon levels as determined by radon test results from Air Chek, Inc, of Schuylkill County, is 14.7 picocuries per liter (pCi/L) in Schuykill County, 11.2 pCi/L in

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[3] V Seaman, SM Dearwent, D Gable, B Lewis, S Metcalf, K Orloff, B Tierney, J Zhu, J Logue, D Marchetto, S Ostroff, R Hoffman, M Xu, D Carey, P Erlich, G Gerhard, P Roda, J Iannuzzo, R Lewis, J Mellow, L Mulvihill, Z Myles, M Wu, A Frank, C A Gross-Davis, J Klotz, A Lynch, J Weissfeld, R Weinberg, and H Cole (2010). A Multidisciplinary Investigation of a Polycythemia Vera Cancer Cluster of Unknown Origin Int J Environ Res Public Health. 2010 March; 7(3): 1139–1152.

[4] RA Zielinski and JR Budahn (1998). Radionuclides in fly ash and bottom ash: improved characterization based on radiography and low energy gamma-ray spectrometry. Fuel 77:259-267.

[5] C Papastefanou (2010). Escaping radioactivity from coal-fired power plants (CPPs) due to coal burning and the associated hazards: A review. J. Environ Radioactiv 101:191-200.

Carbon County, and 4.8 pCi/L in Luzerne County (http://pa-radon.info/PA_counties.html). A USGS report noted that the state of Pennsylvania has average indoor radon levels of 7.5 pCi/L, which exceeds the USEPA action limit of 4 pCi/L. Of the 2,389 homes sampled, 39% had levels that exceeded the action limit. The Appalachian Mountain section of the state, which includes the tri-county area, has been associated with high geologic radon potential due to soils with high soil-gas radon concentrations[6]. These are considerably greater than the average national indoor radon level in the U.S. of 1.3 pCi/L.

Environmental Sampling Events

The laboratory results used in the development of this document are not included in this report because the data contain personal identifiers such as names and addresses. However, Appendix B of this document contains the statistical analyses of the data used by ATSDR.

Under contract with ATSDR, PADEP initiated environmental sampling in the three county area, collecting samples of surface water, indoor air, groundwater, soils and sediments in and around the former McAdoo site as well as other industrial and residential properties[7]. The sampling events occurred in two phases with Phase I occurring from March 22 through May 10, 2010 and from June 7 through July 29, 2010. Phase II sampling ran from January 9 to January 23, 2012 with indoor air sampling running from March 21 through March 28, 2012[8].

During the Phase I sampling of 2010, residential drinking water samples were collected from 48 locations previously selected either by the PADEP or ATSDR. Residential soil samples were collected during two distinct sampling events from a total of 20 areas (two samples at ten residences). The soil samples did not include vegetation which was removed prior to sampling at depths of 3 inches below the vegetative cover. Groundwater samples were obtained from monitoring wells at coal-power generation stations previously identified by the state. Surface water and sediment samples included 40 water samples and 38 sediment samples. These samples were composed of 20 water samples and 19 sediment samples collected during each sampling event but not all were collected for radiological analyses. Samples also were collected for chemical contaminants including, but not limited to, volatile organic compounds, metals, and herbicides. The surface water samples included river tributaries, mine pool drainage, and 2 privately-owned areas. Indoor air sampling for radon 222 occurred at 40 locations where the residential drinking water samples had been collected. For the remaining 8 locations, either owner approval was not received or they were not home during the time necessary for the sampling.

In the Phase II sampling of 2012, 52 residential drinking water samples were collected and analyzed for radium isotopes and radon, of which 34 were new locations not sampled in 2010. Soil samples were collected in duplicate from 18 residential areas and 2 sediment samples were collected from an area sampled during the 2010 events. Indoor radon 222 testing was conducted in 30 residences. Some previously tested homes were re-sampled for radon in drinking water or soil.

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[6] USGS (1993). Geological radon potential of EPA Region 3. Open File Report 93-292-C. US Department of Interior, US Geological Survey prepared in cooperation with the US Environmental Protection Agency.

[7] AECOM (2011). Final Summary Report. McAdoo Polycythemia Vera Area Site Luzerne, Schuylkill, and Carbon Counties, Pennsylvania. Volume 1. AECOM Technical Services Mechanicsburg, PA.

[8] AECOM (2012). Final Summary Report Round III Sampling. McAdoo Polycythemia Vera Area Site Luzerne, Schuylkill, and Carbon Counties, Pennsylvania. Volume 1. AECOM Technical Services Mechanicsburg, PA.

The Phase 1 and Phase 2 environmental samples were analyzed for both radiological and non-radiological analytes. This document focuses only on the radiological results. The water samples were evaluated for gross alpha radiation and gross beta radiation, radium 226 and its decay product radon 222, and radium 228. Soil and sediment samples were evaluated for radium 226 and radium 228, and as previously mentioned, air samples were evaluated for radon 222.

Radiological Survey Results

Laboratory results were subjected to a quality control (QC) process. Samples not meeting data standards[9] are noted in the data reports by the presence of a qualifier or flag. Sample results flagged with a U (not detected), J (estimated concentration), K (biased high value), or L (biased low value) were not used by ATSDR in this evaluation.

Residential Private Drinking Water

Drinking water samples were collected during the two collection activities. In total, 71 samples of drinking water were tested for the levels of gross alpha radiation and gross beta radiation. Of the samples collected, only 38 of the samples collected for gross alpha radiation were acceptable passing the quality control evaluations established by the sampling protocols. Samples below the detection limit are flagged as non-detects. The maximum concentration reported was 2.17 picocuries per liter (pCi/L)[10]. The USEPA established a 15 pCi/L Maximum Contaminant Level[11] (MCL) for gross alpha radiation in public drinking water systems.

Many of the residential water sources (private wells) were tested for radium 226 and radium 228. These radioactive elements are associated with the decay of uranium 238 and thorium 232, respectively. The concentrations of both radium species were within the 5 pCi/L limits established by the USEPA for total radium in drinking water. The maximum concentration of radium 226 detected was 4.4 pCi/L and the maximum concentration of radium 228 detected was1.4 pCi/L, albeit, in a different well. Thus, the total radium MCL for public drinking water was not exceeded in the private wells sampled for this investigation.

For the analysis of the radioactive gas radon 222 in residential drinking water, 52 samples were collected and analyzed. The maximum concentration found in these drinking water samples was approximately 8,900 pCi/L with an average concentration of about 4,200 pCi/L. The lowest reported concentration was 54 pCi/L.

Conversion Table

To convert from	To	Multiply by
Liters	Quarts	1.057
Quarts	Liters	0.946
Ounces	Grams	28.35
Grams	Ounces	0.0353
Pounds	Grams	453.59

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

[10] A picocurie is an amount of radioactive material equal to 2.22 nuclear disintegrations per minute regardless of the type of radioactive material. A liter is a volume measurement. A liter of water is approximately one quart.

[11] The highest level of a contaminant that EPA allows in public drinking water. The MCL does not apply to private water wells. MCLs are enforceable standards that ensure that drinking water does not pose either a short-term or long-term health risk. EPA sets MCLs at levels that are economically and technologically feasible. Some states set MCLs that are more strict than EPA's.

Currently, the USEPA has not established a regulatory limit for radon in drinking water.

The locations for drinking water samples are shown in Figure 1. Personal identifying information on these figures has been removed.

During the analysis for gross beta radiation, all water samples passed the quality control process. Although not a drinking water source, the maximum gross beta radiation was reported at 219 pCi/L from a monitoring well on the Westwood property (MW 4-WW); all other samples had a reported concentration of less than 15 pCi/L. The average concentration for all residences was about 4.6 pCi/L. The USEPA gross beta radiation MCL for public drinking water is a screening level set at 50 pCi/L. If the screening level is exceeded, additional steps are necessary to determine what radioactive materials contribute to the detected concentration.

Residential soils

ATSDR reviewed approximately 40 soil samples that were analyzed for the radium isotopes radium 226 and radium 228. These materials are part of the natural decay of uranium and thorium. The concentration of radium 226 averaged about 1.5 picocuries per gram (pCi/g) with a 2.4 pCi/g maximum concentration. The radium 228 concentration averaged 12 pCi/g, with a minimum value of 4.3 pCi/g and a maximum of 19.3 pCi/g. The method used for the detection of Ra 228 was a standard procedure which could also be used to back calculate the estimated amount of Th 232 in the environment (radium 228 is a decay product of thorium 232, normally present at concentrations less than 5 pCi/g). This is important as historically the area was mined for anthracite coal. The radium content of coals varies especially with the type of coal. Typical concentrations of both uranium and radium 228 in anthracite coal are less than 1 pCi/g and the corresponding concentration in ash is less than 5 pCi/g[12].

The data reviewed by ATSDR as supplied by PADEP indicates that the soil concentrations of Ra 228 are indicative of naturally occurring concentrations and not associated with any residual radioactivity associated with coal mining activities.

Radon in indoor air

Radon detectors were placed in residential homes in Andreas, Ashland, Barnesville, Hazelton, Jim Thorpe, Lansford, McAdoo, Tamaqua, and Weatherly. The placement of the detection units varied with the basement being the most common location. Three homes had radon mitigation installed; the radon levels were all less than 2 pCi/L.

In the residences without radon mitigation, the indoor radon concentrations ranged from about 2 pCi/L to over 100 pCi/L. In some of these locations, however, only one test was performed. The USEPA recommends that indoor radon in air not exceed 4 pCi/L. In those locations where the measured radon exceeded 3.5 pCi/L, the average radon level was measured at 21.2 pCi/L and ranged from 3.5 pCi/L to 109 pCi/L. Figure 2 shows the locations of the residences sampled for radon and the range of measured values.

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[12] Zielinski, RA and JR Budahn (1998). Radionuclides in fly ash and bottom ash: improved characterization based on radiography and low energy gammy-ray spectrometry. Fuel 77:259
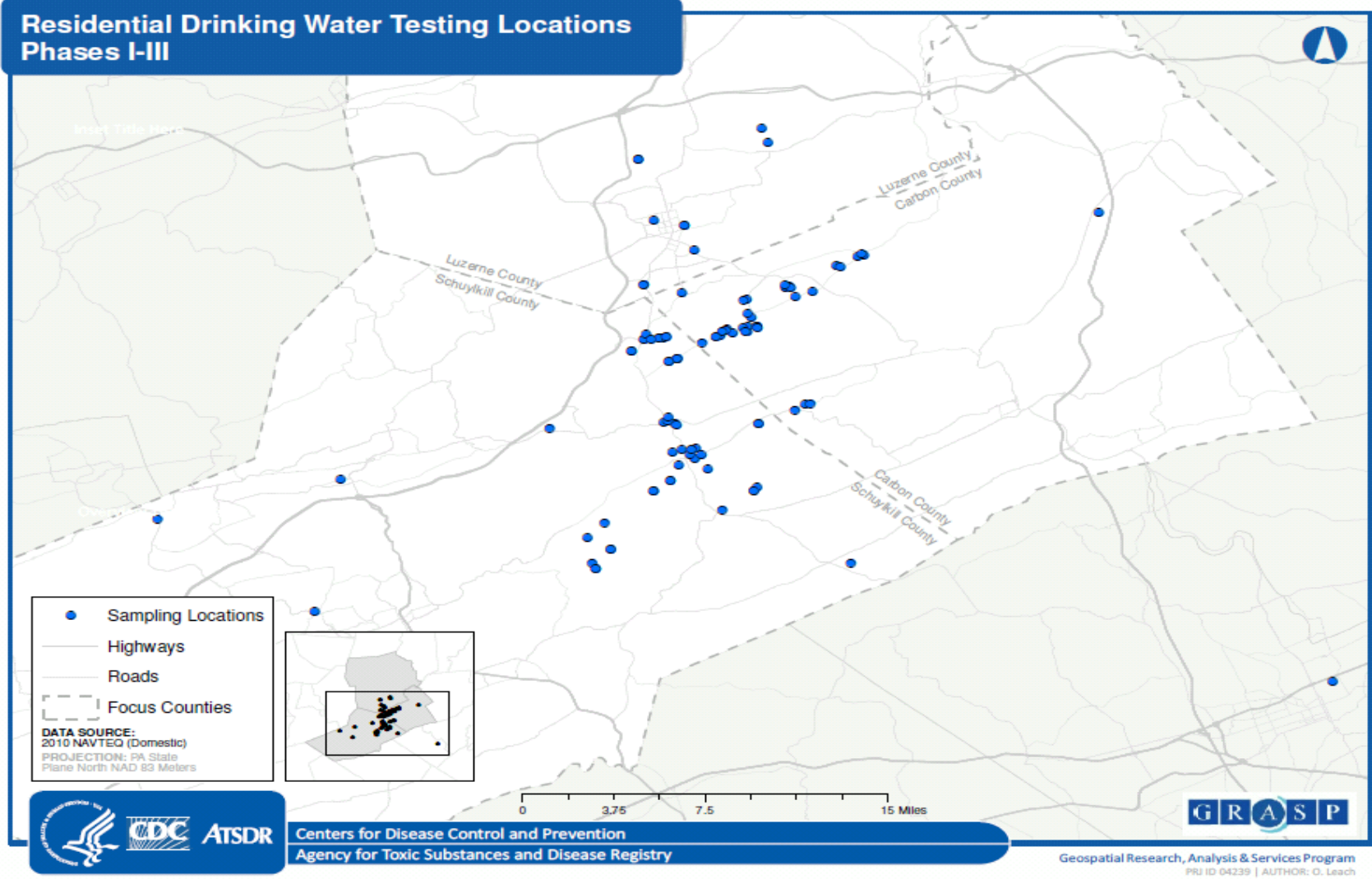
Figure 1. Residential groundwater well sampling locations in the broad study area in PADEP's environmental sampling event.
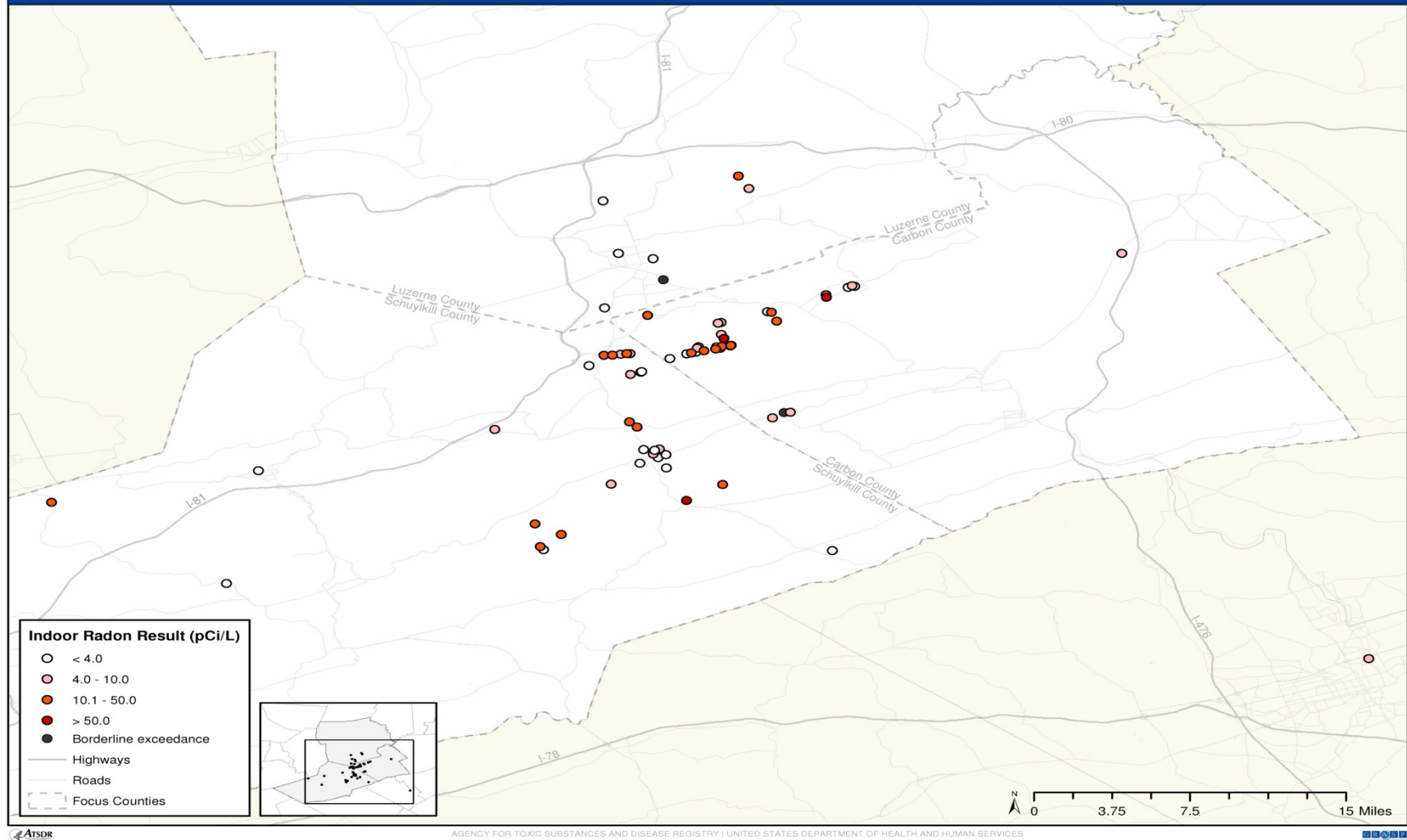
Figure 2. Spatial location of radon sampling in the study area.

Pathway analyses

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 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. 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.

Completed Exposure Pathways

ATSDR has reviewed radiologic data collected from homes in the PV investigation study area. Based on these data from soils, surface waters, groundwater, and indoor air, the completed exposure pathways of public health concern are those where residents will come in contact with radon gas released from groundwater and/or indoor air containing radon[13] and those pathways associated with residential soils and sediments.

The air pathway was selected for additional evaluation because a number of the radon in air concentrations exceeded a health-based screening level of concern (i.e., the USEPA recommended indoor air concentration of 4 pCi/L). ATSDR selected the groundwater pathway because of the possible contribution of radon in water to radon in air (albeit, this contribution is small), and because of the potential chance for the induction of stomach cancer via the ingestion of drinking water contaminated with radon[14].

ATSDR also is concerned about the apparently elevated levels of radium 228 present in both residential soils and sediments. Soils and sediments were selected for additional evaluation because the radium 228 concentrations in residential soils were as high as 19.3 pCi/g. In sediments, the average concentration of radium 228 was 12 pCi/g, based on two samples. In screening these values, ATSDR used values from the National Council on Radiation Protection and Measurement, which states that a background screening concentration for radium 228 in residential soils is less than 2 pCi/g of soil for residential lawns and less than 1 pCi/g for those areas where food is produced[15]. When ATSDR finds values greater than these

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[13] There are several forms of radon, all of which are radioactive. In this document, the term radon refers to the specific form or isotope know as radon 222 (Rn 222).

[14] National Research Council (1999). Risk Assessment of Radon in Drinking Water. National Academy Press, Washington, DC.

[15] NCRP (1999). Recommended screening limits for contaminated surface soils and review of factors relevant to site-specific studies. NCRP Report 129. Bethesda MD.

screening concentrations, additional evaluation is necessary prior to the determination of potential health effects.

ATSDR eliminated the other pathways of exposure in which radiologic data were supplied because the reported levels were within the expected range of background in the Pennsylvania area[16]. The background levels of naturally radioactive substances are not considered a public health hazard.

Assessing Health Effects

Exposure to radiation does not always result in harmful health effects. The type and severity of health effects that a person might experience depends on the dose, which is based on the person's age at exposure, the exposure rate (how fast), the frequency (how often) or duration (how long), 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 radiation levels and doses found in a particular media (i.e., soil, air, or drinking water) against health-based comparison values (CVs). ATSDR develops CVs from available scientific literature concerning exposure, dose, and health effects. CVs represent radiation doses or chemical 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 radiation dose or chemical media concentration that is not expected to cause harmful health effects. Radiation doses and chemical media concentrations at or below the CVs can reasonably be considered safe. When a CV is exceeded, exposures will not necessarily produce undesirable health effects. This screening process enables ATSDR to eliminate safely from further consideration contaminants not of health concern and to further evaluate potentially harmful contaminants. During the development of CVs for chemicals in the environment, ATSDR develops environmental media guidelines for exposure. In the case of radioactive materials in the environment, ATSDR approaches the exposures using a radiation dose-based methodology using internationally accepted radiation dose coefficients where appropriate. In addition, ATSDR uses radiological screening values developed through a peer-reviewed process.

One example of CVs is called the Minimal Risk Level (MRL). Because the MRL is an estimate of human exposure to a hazardous substance that is unlikely to have an appreciable risk of adverse non-cancer health effects over a specified route and duration of exposure, a dose exceeding the MRL does not mean that an adverse health effect will occur. The ATSDR MRL for ionizing radiation is 100 millirem per year (mrem/y) above ambient background levels[17]. The ATSDR MRL is not a regulatory level. However, for ionizing radiation, the MRL is the same value used by both the US Department of Energy (DOE) and the

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[16] Myrick, T. E., Berven, B.A., and Haywood, F.F. (1983). Determination of Concentrations of Selected Radionuclides in Surface Soil in the U.S. Health Physics **45**: 631-642.

[17] Agency for Toxic Substances and Disease Registry (1999). Toxicological Profile for Ionizing Radiation. Atlanta: US Department of Health and Human Services.

US Nuclear Regulatory Commission (NRC) to protect members of the public from general exposures produced by their licensees.

ATSDR has not developed any MRLs specifically for radon. The only end point for radon exposure via inhalation is cancer, which is not an appropriate end point to derive an MRL (MRLs are by definition specific to non cancer health outcomes). Furthermore, ATSDR has not derived an MRL for oral exposure to radon, because there is a lack of suitable human or animal data and there are no studies indicating that radon is absorbed through the skin[18].

If the estimated radiation doses or chemical media concentrations at a site are above selected health-based comparison values, ATSDR proceeds with a more in-depth health effects evaluation. ATSDR radiation safety scientists then determine whether the doses are large enough to trigger public health action to limit, eliminate, or study further any potentially harmful exposures. These specialists conduct a health effects evaluation by 1) examining site-specific exposure conditions for actual or likely exposures, 2) conducting a critical review of radiological, toxicological, medical, and epidemiological information in the scientific literature to ascertain the levels of significant human exposure, and 3) comparing an estimate of possible radiation doses or chemical doses to situations that have been associated with disease and injury. This health effects evaluation involves a balanced review and integration of site-related environmental data, site-specific exposure factors, and toxicological, radiological, epidemiological, medical, and health outcome data to help determine whether exposure to contaminant levels might result in harmful, observable health effects.

Radon dose assessment

Uranium is a naturally occurring radioactive element that undergoes multiple transformations producing radium, other radioactive elements, and ultimately non-radioactive lead. Radon is a ubiquitous radioactive gas that is produced from the decay of naturally occurring radium[19] (Figure 3). The resulting radon is non-reactive or inert and will not combine to form any compounds in the natural environment. Because it is inert, the radon will migrate through materials such as soils and concrete. In 1989, the National Council on Radiation Protection and Measurements (NCRP) estimated that radon infiltration into homes could be as high as 246 pCi per second on average[20]. People are exposed to various levels of radon depending on the local water, soil and rock characteristics, the type of building materials, how well the building is sealed/ventilated, and even how and where residents spend their time within the building[21].

Radon is inert and will therefore not interact with materials in the lung or the body. However, its decay products will impart a radiological dose to the lung or other organs. The International Commission on Radiological Protection (ICRP) released a 2009 statement in which they reviewed newer studies and

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[18] ATSDR (2012). Toxicological Profile for Radon. Agency for Toxic Substances and Disease Registry. Atlanta, Georgia

[19] The naturally occurring radioactive element radium occurs in several forms or isotopes. In this discussion, the term radium refers to radium 226 (Ra 226) which is the parent of radon. That is, when radium decays, it is transformed into radon.

[20] NCRP (1989). Control of radon in houses. NCRP Report 103. Bethesda, MD.

[21] ICRP (2010). Lung cancer risks from radon and progeny and Statement on radon. International Commission on Radiological Protection. ICRP Publication 115.

developed a nominal cancer risk coefficient which could be applied to a population of all ages for radon in air. This coefficient, 2.6×10^{-4} per pCi/L per year was also consistent with international estimates.

Previously, the National Research Council of the National Academies of Sciences received a contract from the USEPA to review radon risks from ingestion of water containing radon and the release to indoor air from radon in water. The tasks developed included but were not limited to modifying existing risk models if appropriate and develop cancer risk coefficients for radon in air and radon in water ingestion[14]. This study estimated a radon ingestion (water pathway) risk estimate between 1.4 and 16.3×10^{-8} per pCi/L with a central value (approximate average) of 7.04×10^{-8}. The majority of the risk was associated with the stomach and stomach cancer with an estimated risk of 5.9×10^{-8} per pCi/L. The risk estimates for radon in air were more difficult to determine; however, a population estimate of 5.9×10^{-3} lifetime risk in the home to 1 pCi/L was selected. This value is about 22 times higher than the 2009 risk coefficient cited by the ICRP. The risk from radon in water with the radon being transferred to the air was calculated to be 5.9×10^{-7}. This coefficient was based on the estimate that there is a very small release of radon from water, on the order of 1 pCi per 10,000 pCi in water.

In humans, radon is inhaled and exhaled; however, the radon will decay producing other radioactive elements. These elements will react with other compounds in the lung and also dissolve in lung fluids. The radioactive short-lived elements (see Figure 3) are the most hazardous to the lungs as they deliver substantially more radiation dose to the lungs than to the systemic organs and the gastrointestinal tract. Nevertheless, calculations indicate that small doses may be received by the red bone marrow and other systemic organs. Recent studies noted specific excesses or trends with radon exposure for non-Hodgkin's lymphoma; multiple myeloma; and kidney, liver, and stomach cancers. However, such observations have not been confirmed by other studies. Epidemiological studies have been conducted on the possible association between leukemia and indoor radon concentrations. In conclusion, the review of the available epidemiological evidence shows no consistent evidence for an association between radon concentration and cancer, other than lung cancer. Most available studies are for adult populations[21].

The USEPA classifies radon as a known human carcinogen producing lung cancer. This finding is mostly derived from underground mining operations and the prevalence of lung cancer in these workers. The ICRP states that comparing underground mining studies to residential studies is not necessarily easy, regardless; the ICRP believes that current studies on the risk estimates for lung cancer in miners and residences show a consistency with regards to lung cancer[21].
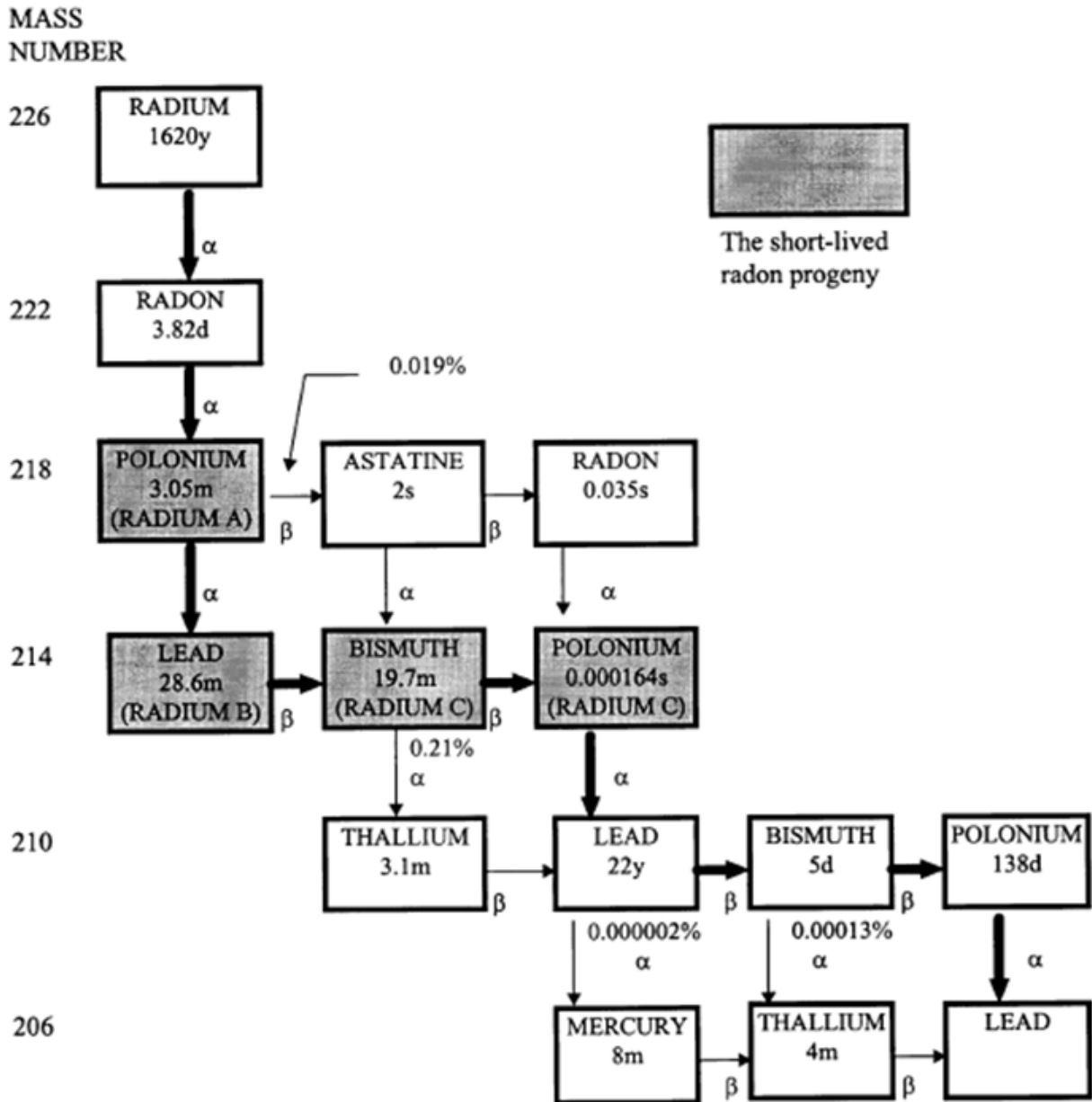
MASS
NUMBER

Figure 3. Radium and radon decay scheme (From the National Research Council[22])

[22] National Research Council (1999). Health effects of exposure to radon. BEIR VI. National Academy Press. Washington, DC.

Evaluation of risks from radon exposure

To estimate the risks arising from the potential exposure to radon inside houses, ATSDR used the maximum reported concentration of radon in air and radon in water. For the risk coefficients, the values used were those as reported by the National Research Council. Following the calculation of the individual pathway risks, the risks were then summed across all pathways to estimate the total risks. The risks were calculated for both average concentrations in each medium as well as the maximum reported concentration using the following equations:

$$Risk = Concentration \; x \; risk \; coefficient$$

$$total \; risk = \; \Sigma \; risk$$

Using indoor air as an example, to calculate the average risk:

$$Risk = 21.2 \frac{pCi}{L} \times \frac{5.9 \times 10^{-3}}{\frac{pCi}{L}} = 0.125$$

Once this is performed for each medium, the resulting risks are added together to estimate the total average risk or the total maximum risk.

Table 1. Estimated possibilities of lung cancer from radon*.

Medium	Concentration (pCi/L) Average	Maximum	Risk Coefficient for annual exposures	Average risk	Maximum risk
Indoor air	21.2	109	5.9×10^{-3}	0.125	0.643
Groundwater ingestion	4,184	8,899	7.04×10^{-8}	0.000295	0.000626
Stomach via groundwater	4,184	8,899	5.9×10^{-8}	0.000247	0.000525
Radon from water to air	4,184	8,899	5.9×10^{-7}	0.00247	0.00525
*The risks shown in this table are based on a population and are not meant to be used for any individual assessment. The total risk is based on an exposed population of 10,000 individuals. These individuals include smokers and non-smokers [21]. The USEPA estimates the lifetime risk of fatal lung cancer from 1 pCi/L of indoor radon is 0.58%.			Total risk	0.128 (1280 per ten thousand)	0.65 (6500 per ten thousand)

Evaluation of radium 228 soil concentrations

Radium 228 is a naturally occurring decay product of thorium 232. Radium 228 decays with the emission of a beta particle which is a possible external exposure hazard to the skin as well as when taken into the body either through inhalation or ingestion. ATSDR used the RESRAD computer code[23] for residual radioactivity to estimate the radiation dose an individual might receive from radium 228. The parameters used for this computer model included setting the radium 228 and one of its decay products, thorium 228, to 15 pCi/g and a contaminated area covering 5000 square meters, equivalent to 1.23 acres. The maximum calculated dose was 141 (mrem/y) with the majority of the dose arising from external exposure (76 mrem/y) and food intake from plants grown and irrigated with contaminated water (61 mrem/y). All other parameters of the model remained at their default settings. Additional information on the complexity of this model can be found on the Argonne National Laboratory website at http://web.ead.anl.gov/resrad/documents/ (last accessed on February 11, 2013).

The radiological dose from exposure to radium 228 was then calculated. The dose also included thorium 232, thorium 228 as these are the parent radionuclide and the decay product of the radium respectively, with radioactive half-lives greater than 1 year. The results of this dose assessment are shown in Figure 4. Additional discussion of this figure can be found in Appendix C

The RESRAD output also generated an estimate of the excess cancer risk from the exposures to radium 228 and its decay products. The initial risk calculated was on the order of 1.35×10^{-3} which also exceeds the USEPA upper risk range of 1×10^{-4} by a factor of 13.5. Although the graph in Figure 5 shows the risks decreasing over time, the risk will remain elevated as the radium 228 is being constantly produced from the decay of thorium 232 if it is present in the soil at elevated levels indicated by the radium 228. Additional, detailed information is given in Appendix C.

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[23] USDOE (2001). User's Manual for RESRAD Version 6. Argonne National Laboratory. ANL/EAD-4. US Department of Energy.
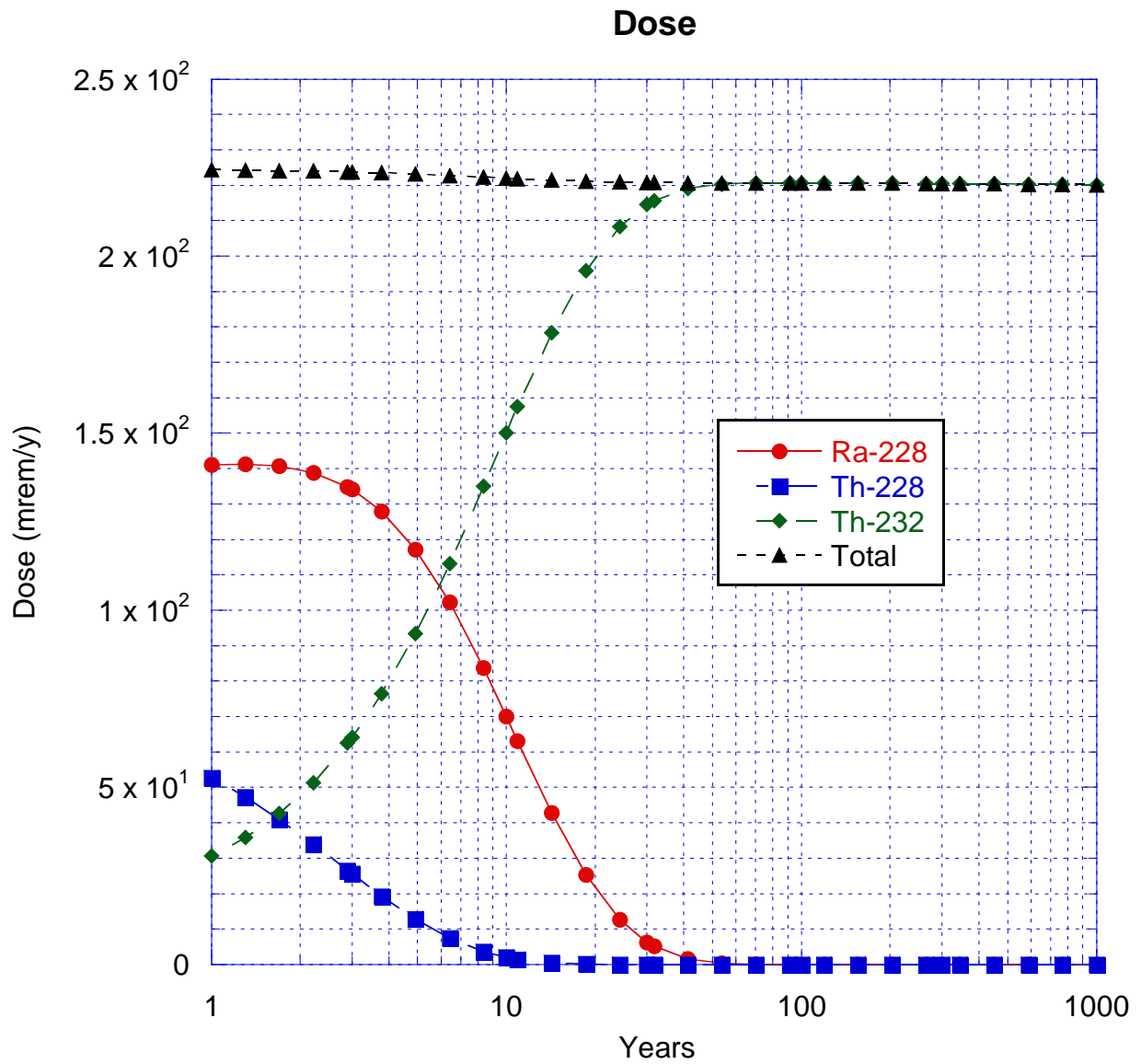
Dose

Figure 4. Radiological dose from the radium 228 family and combining all pathways of exposure. Additional, detailed information is given in Appendix C.
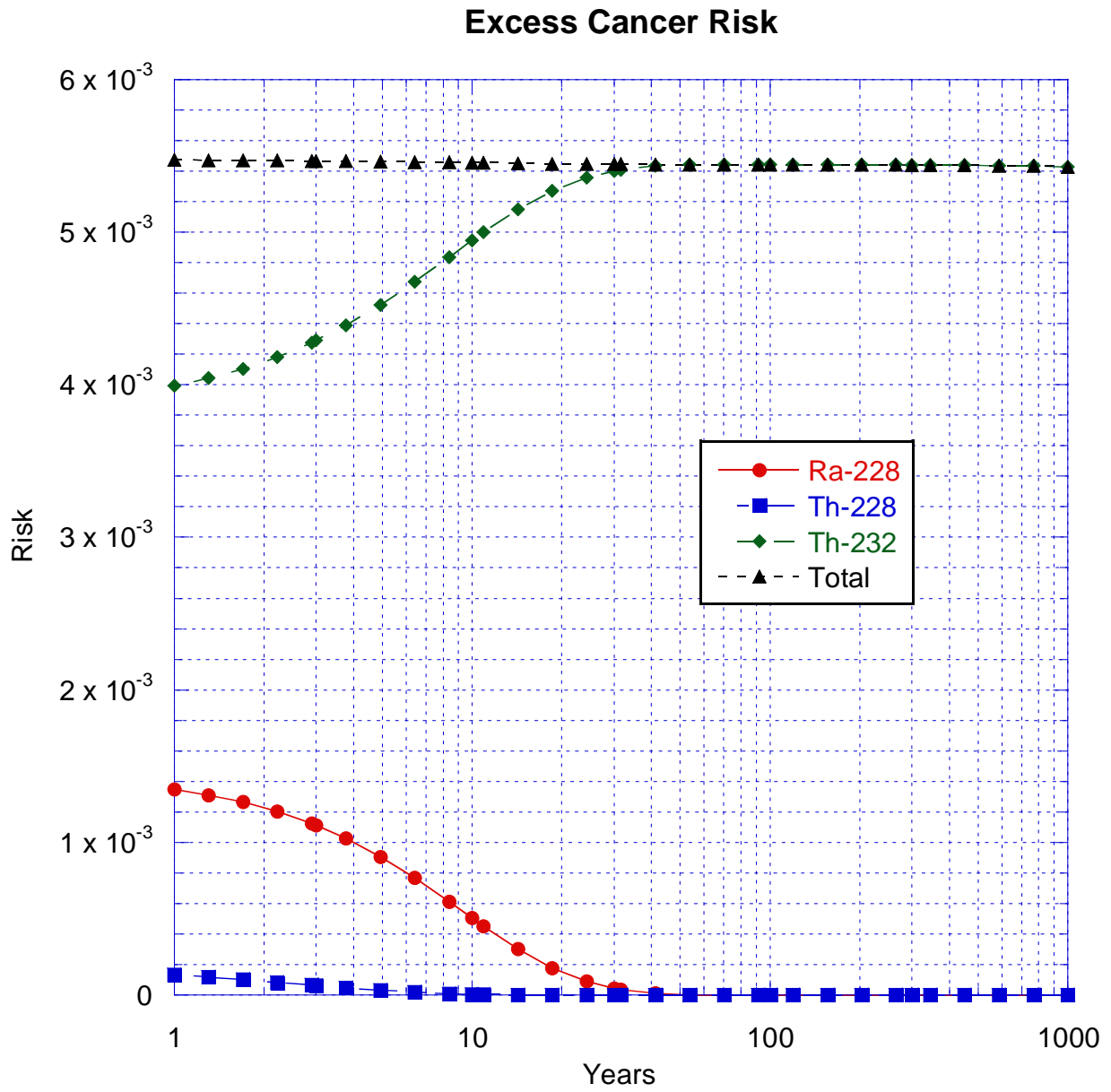
Excess Cancer Risk

Figure 5. Excess cancer risk from radionuclides in the radium 228 family. The risk estimate is based on an initial concentration of 15 pCi/g of soil. Additional, detailed information is given in Appendix C.

Conclusions

ATSDR reached four important conclusions in this health consultation. Each conclusion is discussed separately with the major finding in **bold type**.

Radiological exposures and doses

1. The inhalation of radon gas has been determined to be a major contributor to lung cancer. The USEPA estimates that at least 20,000 lung cancer deaths[24] occur each year in the U.S. as a result of exposure to this radioactive gas. Furthermore, the USEPA states that two studies showed definitive evidence of an association between residential radon exposure and lung cancer. These studies, a North American study and a European study, both combined data from several previous residential studies. Moreover, the World Health Organization (WHO)[25] and the USEPA[26] say radon causes up to 15% of lung cancers worldwide.

   The USEPA has adopted a target risk range for exposure to hazardous substances. This risk ranges from 1 in a million to 1 in ten thousand (1×10^{-6} to 1×10^{-4}); any risk exceeding the upper range of 1×10^{-4} is considered elevated. Using the maximum reported concentrations of radon in air and water in the Phase 1 and Phase 2 environmental sampling information, **the estimated risk from the radon exposure to inhalation of indoor air ($1,280 \times 10^{-4}$) exceeds the upper range for the average radon concentrations in the homes measured in this survey. Therefore, ATSDR considers this a public health hazard.**

2. With respect to the risk of stomach cancer associated with the ingestion of radon-contaminated water, this exceeds the upper risk range as well. The estimated risk from this pathway of exposure was about 2.5 per ten thousand (2.5×10^{-4}).

   ATSDR concludes that consuming water with dissolved radon is not expected to harm health. Although the risk value is slightly elevated over the upper range of the CERCLA requirements, the estimated numbers of radon induced stomach cancers is thought to be less than 0.5% of all the stomach cancers in the United States.

3. In addition, exposures to radium 228 in soils appears to be elevated. The estimated radiological dose from external exposures did not exceed the ATSDR MRL for ionizing radiation nor did the ingestion of locally grown crops when evaluated as separate pathways. However, when the resulting doses were added as a combined exposure and dose pathway, the resulting total dose did exceed the ATSDR MRL of 100 millirem per year[17] above background. The background levels of radiation, excluding those doses from medical and dental exams are estimated to be 311 millirem/y by the NCRP[27]. They further estimated that of this 311 millirem/y, an estimated 22 millirem/y arose from terrestrial sources in soils. The estimated sources in the **study area soils result in radiological doses that are about 3.5 times the estimated average radiological dose**

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[24] http://www.epa.gov/radon/ (last accessed on November 6, 2012).

[25] World Health Organization (2009). WHO Handbood on Indoor Radon. A Public Health Perspective

[26] http://www.epa.gov/radon/healthrisks.html (last accessed on November 6, 2012).

[27] NCRP (2009). Ionizing radiation exposure of the population of the United States. NCRP Report 160. National Council on Radiation Protection and Measurements: Bethesda, MD.

(78 millirem vs 22 millirem per year). However, ATSDR does not consider this a public health hazard as this does not exceed the ATSDR Minimal Risk Level (MRL).

4. *Radiological exposures and doses related to Polycythemia Vera*

Polycythemia vera is a bone marrow disease that leads to an abnormal increase in the number of blood cells, primarily red blood cells. ATSDR reviewed the medical literature, and found one peer-reviewed scientific article relating radiation exposure as a risk factor for PV. Specifically, Caldwell et al (1984)[28] noted two cases of polycythemia vera and two cases of suspected polycythemia vera among 3,217 nuclear test participants present during the detonation of a nuclear test device in 1957. The test participants were followed through 1981. The observed occurrence of four cases of polycythemia vera in a group this size significantly exceeded what was expected. However, the researchers felt that the small individual whole-body doses of radiation reported for these four participants made the association with ionizing radiation tenuous, although they noted that ionizing radiation was the only identified unusual risk factor for this population. Previous reports from the National Academy of Sciences have only linked radon exposure to lung cancers[22] and radium 228 exposure has only been linked to bone cancers. In the family of blood cancers, Bauchinger et al (1996)[29] noted that radon exposure could induce chromosome aberrations in hematopoietic components in the bone marrow, and Utteridge (1997)[30] and Harley and Robbins (2009)[31] have noted that radon exposure is associated with induction of leukemia. **Without any additional radiobiology and medical interaction research information, ATSDR cannot determine if the disease cluster is related to these radiological exposures and resulting radiological doses.**

Recommendations

ATSDR is making the following recommendations to protect the public health from the radiological exposure in the environment.

1. In those residences where the radon in air is 3.5 pCi/L or higher, retest the air in multiple locations within the house. If the house has an occupied basement, also test the basement air.

2. In houses where the retest indicates elevated radon levels, the residents should contact the state of Pennsylvania radon program hotline at 1-800-237-2366 and request additional information on how to reduce the radon levels in the home.

3. In houses where well water analysis indicates elevated levels of radon, contact the state radon program for assistance; if the residential wells have holding tanks, aeration of the water will help reduce the radon in the water; and

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[28] Caldwell G.G., Kelley D.B., Heath C.W. Jr, Zack M. (1984) Polycythemia vera among participants of a nuclear weapons test. JAMA Aug 3;252(5):662-4.

[29] Bauchinger, M, Braselmann, H, Kulka, U, Huber, R, and V. Georgiadou-Schumacher (1996). Quantification of FISH-painted chromosome aberrations after domestic radon exposure. International Journal of Radiation Biology 70(6), 657-663.

[30] Utteridge, T.D. (1997). Radon decay in bone marrow fat cells and the possible induction of leukaemia. Medical Physics 24 (7), 1181.

[31] Harley, N.H., and E.S. Robbins (2009). Radon and leukemia in the Danish Study: Another source of dose. Health Phys 97(4), 343-347.

4. In those areas where the radium 228 in soils appear elevated, additional characterization of those soils should be performed unless sufficient data from other sources currently exists to adequately evaluate the reported levels. The laboratory results and all quality control and quality assurance should be submitted to the appropriate state offices and ATSDR for re-evaluation.

Public Health Action Plan

When the results from all of the ongoing research projects under this investigation are available, ATSDR will review this information and will plan a public forum to share and discuss the results with interested stakeholders.

ATSDR will continue to discuss the potential for a future collaboration with USGS to further evaluate levels of radiological contaminants in environmental media in the study area.

ATSDR will work with other private and public entities to support existing health promotion work related to radon awareness and mitigation in the study area.

Author

Paul A. Charp, Ph.D.

Appendix A

A Brief Discussion of Radioactivity and Naturally Occurring Radioactive Materials

Derived from the ATSDR Toxicological Profile for Ionizing Radiation[17]

The issue of radiation exposure is a matter of interest to the general public; however, 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, with the exception of locally high exposures, the average individual dose received from man-made radiation is small compared to that received from natural sources. When assessing the risks associated with a 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 elements. We have models of an atom that are supported by measurements. An atom consists of one nucleus, made of protons and neutrons, and many smaller particles called electrons. The electrons normally circle the nucleus much like the planets or comets circle the sun. 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 neutrons neutralize this action and act as a kind of glue that holds the protons together in the nucleus. 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 way the molecule behaves in chemical reactions or inside your body.

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, ultrasound, 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.

Theoretically, many of these contaminants give off ionizing radiation forever. 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 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.

Appendix B

Statistical Tables related to Radiological Sampling
Collected in 2011 and 2012
Associated with the Polycythemia Vera Investigation
in the Carbon, Luzerne and Schuylkill Counties

Table 2. Statistical evaluation of radium and radon radioisotopes in the Polycythemia Vera study area of Carbon, Luzerne, and Schuykill Counties

Statistical Parameter	Radium in Residential Soil		Radium in Residential Drinking Water (private wells)				Radon in households		
	Ra 226	*Ra 228*	*Gross Alpha*	*Gross Beta*	*Ra 228*	*Ra 226*	*Radon in Drinking Water*	Radon in air All Samples	*Radon in homes with greater than 3.5 pCi/L*
Mean	1.514	12.085	-0.398	4.591	0.147	0.480	4183.752	16.359	21.201
Standard Error	0.046	0.569	0.155	3.082	0.042	0.194	256.217	2.931	3.618
Median	1.525	11.648	-0.332	0.800	0.130	0.230	3879.244	7.900	14.450
Standard Deviation	0.281	3.509	0.956	25.973	0.275	0.932	2017.456	20.932	22.300
Range	1.490	14.977	4.262	220.440	1.820	4.400	8844.353	108.400	105.500
Minimum value	0.920	4.279	-2.095	-1.110	-0.390	0.000	54.404	0.600	3.500
Maximum value	2.410	19.256	2.167	219.330	1.430	4.400	8898.757	109.000	109.000
Number of samples	38.000	38.000	38.000	71.000	43.000	23.000	62.000	51.000	38.000
Confidence Level (95.0%)	0.092	1.153	0.314	6.148	0.085	0.403	512.338	5.887	7.330

Mean – the arithmetic mean or central tendency of the data, sometimes called the average. When used with other statistical finding, the mean can be an informative.

Standard error – represents how much fluctuation occurs in a data set. Typically, when one has a large number of samples, this value is small.

Median – when ranked low to high, the value in the middle is the median. This indicates that 50% the numbers are less than the median and 50% are greater. If the median value is close to the mean value, the distribution of the samples may represent a bell shaped curve. This curve is also called a normal distribution.

Standard Deviation – indicates how variable the samples vary; the larger the standard deviation, the more spread out the sample results.

Range – the difference between the highest value and the lowest value. This also indicates the spread of the data but is sensitive to extremes.

Confidence Level (95%) – indicates how certain (95%) one is that the measured values are possibly valid. For example, if a mean is 10 and the confidence level (95%) is 2, any number between is 8 and 12 is possibly valid. Any number less than 8 or greater than 12 is probably not a valid measurement.

Appendix C

Discussion of Figures 4 and Figure 5
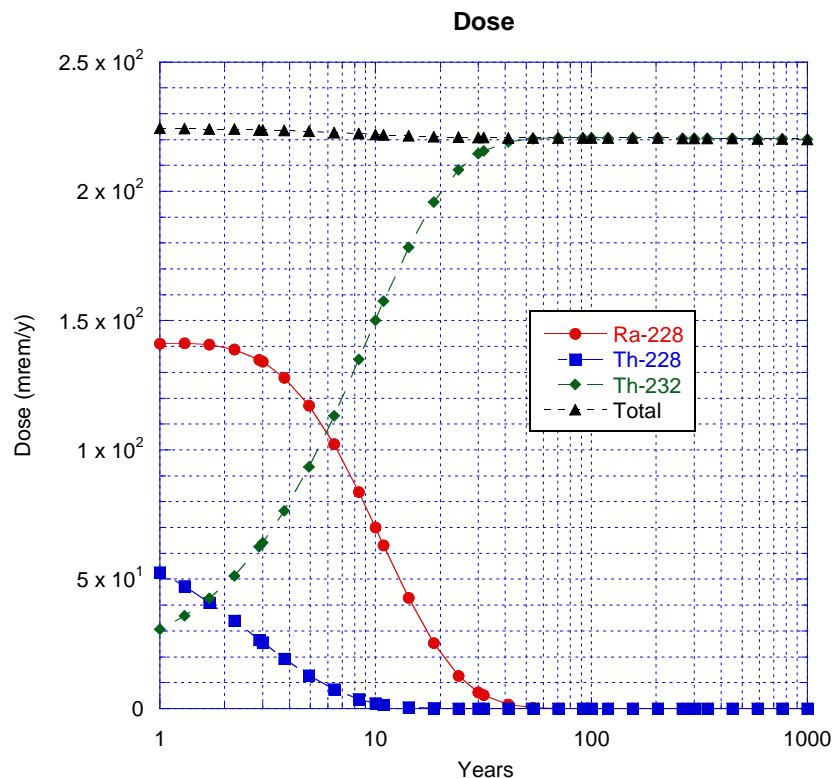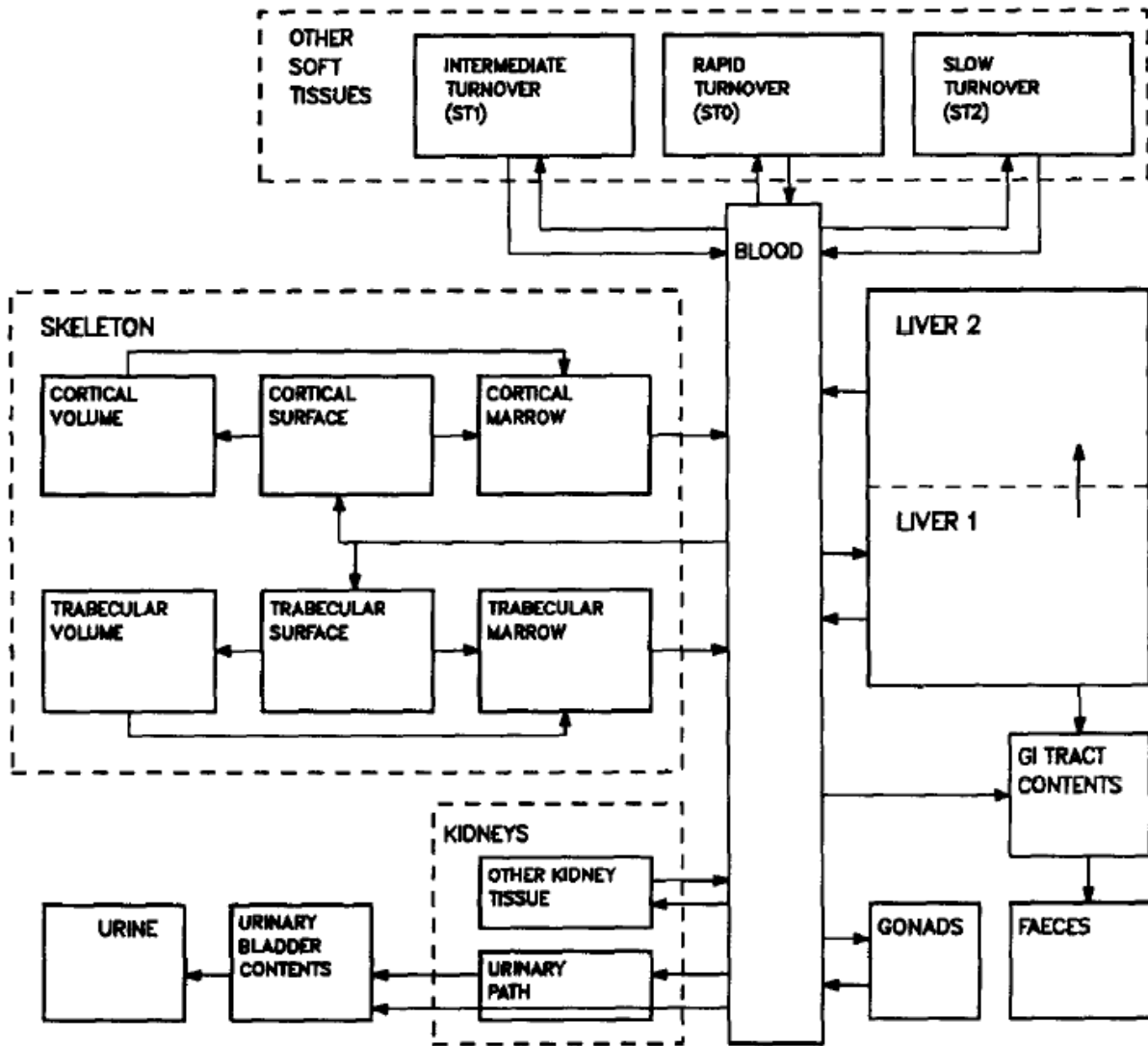
Figure 4

Dose

Figure 4. Radiological dose from the radium 228 family and combining all pathways of exposure. Additional, detailed information is given in Appendix C.

Radiological dose estimates, similar to chemical dose estimates, entail estimating the environmental concentrations, how those concentrations may be taken into the human body, and how the body processes those contaminants. For radioactive substances, however, historical human and animal studies as well as laboratory research has led to the compilation of dose coefficients including organ specific doses. Unlike chemical doses, radiological doses are dependent on the amount of energy absorbed by the body and the mass of the absorbing material such as an organ. Each route of exposure to radioactive materials, the chemical composition, and the organ in which the material is deposited will result in a different dose coefficient. Furthermore, since the radioactive material is constantly undergoing decay and forming other elements, the rate of decay of the parent as well as any radioactive materials produced in the body have to be incorporated into these dose coefficients. The radiation dose of the decay product is also included in the internal dose, if the decay occurs within the body. To determine how the materials are distributed throughout the body, biokinetic models have been developed to assist in the determination of the dose coefficients. An example of the biokinetic model for thorium is shown below.

The RESRAD model incorporates these factors and other temporal (time) and spatial (location) parameters then calculates the resultant doses for each radionuclide specified in the model parameters. One of the assumptions in the model is that the intake occurs once and there is no additional intake of material. In this

modeling scenario, the results show that about 50% of the early radiological dose arises from the intake of Th 232 with Ra 228 contributing a significant portion of the remaining dose. As the Ra 228 decays within the body, the resulting dose from Th 228 is significant for a relatively short period of time. Since the uptake of materials at this site probably has continuously occurred for several years, the early doses have remained steady. That is, the dose from Ra 228 has exceeded 100 millirem per year (the ATSDR minimum risk level, MRL) and the total continuous exposure has resulted in a continual dose in excess of 200 millirem per year.

Biokinetic model for thorium as published in the International Commission on Radiological Protection's Report 69, Age-dependent doses to members of the public from intake of radionuclides: Part 3 Ingestion dose coefficients.
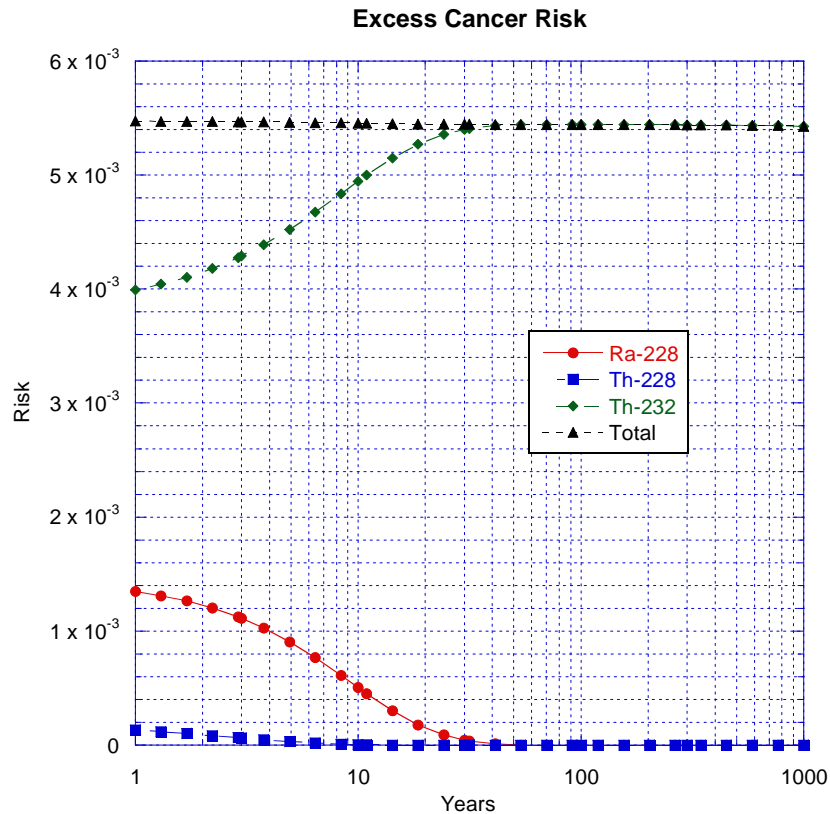
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Figure 5

Excess Cancer Risk

Figure 5. Excess cancer risk from radionuclides in the radium 228 family. The risk estimate is based on an initial concentration of 15 pCi/g of soil. Additional, detailed information is given in Appendix C.

The determination of excess cancer risk from the exposure to radioactive materials has been studied for perhaps 100 years or more. Of particular note, two groups of exposed individuals have been extensively studied with respect to the induction of cancer by radiation. These groups are the radium dial painters of the early 20th century and the survivors of the atomic bombings that lead to the cessation of World War II in 1945. Recent reports from the International Commission on Radiologic Protection (ICRP) and the USEPA have evaluated the risk of cancer and developed risk coefficients for exposure. In the case of the ICRP, their risk coefficient associated low dose radiation (ICRP Report 99) is 5.7% at 100 millirad with an upper uncertainty of 17%.

The USEPA approached the issue differently from the ICRP in that the USEPA used US population cancer statistics and populations. Therefore, the USEPA risks are somewhat different from those risks published by the ICRP. The USEPA values for excess relative risk for a uniform, whole body exposure to low dose gamma radiation is 0.00128 per rad for cancer incidence (USEPA 402-R-11-001, Table 3-25).

The RESRAD code uses the Federal Guidance Report 13 for its excess cancer risk estimates. The values in this document are different from the USEPA and ICRP values. However, sufficient uncertainty exists in all models so that the calculated risks are within the errors associated with the values.

To calculate the risks, one takes the calculated dose and multiplies the dose by the excess risk coefficient. This gives a first approximation of the risk. The RESRAD method time integrates the risks over all intakes, times of intakes, and durations of exposures.

With regard to Figure 5, the majority of the total risk is associated with the intake of Th 232 which, as previously discussed, is the parent radionuclide for the Ra 228. The risk from Ra 228 is about 30% of the risk attributable to the Th 232. Regardless of the radionuclide, the estimated excess cancer risk is over 5×10^{-3} or 50 times higher than the USEPA upper risk range limit of 1×10^{-4} established in the CERCLA legislation.

Although this risk appears excessive, the risk of exposure to background radiation from natural sources is also quite high. Using the most recent risk estimates from the USEPA listed previously in this appendix, the most recent estimates of the average background radiation exposure, not including medical exposures, and exposure for 30 years and 70 years, the excess risk calculates to:

$$R_y = Dose \; x \; Exposure \; Duration \; x \; Risk \; Coefficient$$

$$R_{30} = 0.311 \; rad \; x \; 30 \; years \; x \; \frac{0.00128}{rad - year} = 1.2x10^{-2}$$

$$R_{70} = 0.311 \; rad \; x \; 70 \; years \; x \frac{0.00128}{rad - year} = 2.8x10^{-2}$$

When comparing the estimated risk from the model to the risks associated with typical background exposures over a 30 year period, the calculated risks are about 50% lower than background and would not be expected to cause any detectable health issues.