Auxier & Associates, Inc.
Radiological Health, Safety and Environmental Services
A USA Environment, L.P. Company

FINAL
HUMAN HEALTH RISK ASSESSMENT

PIKE COUNTY COMMUNITY
PIKETON, OHIO

May, 2023

PREPARED FOR:

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Neither the results nor the particular method described herein should be used to assess doses or risks to specific individuals.

It is important to note that the risk calculation method used in this analysis (Risk Assessment Guidance for Superfund, or RAGS) is constructed from a theoretical description of the effects of the listed radionuclides on humans. This description includes numerical descriptions of idealized receptors and their behaviors, as well as estimates of contaminant sources and environmental transport mechanisms.

Neither the results nor the methods presented in this document should be relied upon to accurately portray actual doses and risks to a particular individual. Rather, the methods and results are reserved for its intended purpose of supporting the estimation of generic risks as they are defined under the CERCLA process for selecting "the most appropriate method of achieving protection of human health and the environment at a particular site." (1990)

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LIST OF ACRONYMS

Am-	americium
Auxier	Auxier & Associates, Inc.
BPRG	Building Preliminary Remediation Goal
CCSE	Pike County Community Comprehensive Sampling Evaluation
CERCLA	*Comprehensive Environmental Response, Compensation, and Liability Act*
cm^2	square centimeter(s)
Community	Pike County Ohio Community
DOE	U.S. Department of Energy
DQO	data quality objective
EPA	U.S. Environmental Protection Agency
FTSS	fraction transferred surface to skin
g	gram(s)
Handbook	*Exposure Factors Handbook*
HHRA	*Human Health Risk Assessment*
L	liter(s)
L_c	critical value
LET	linear energy transfer
m^3	cubic meter(s)
MARLAP	*Multi-Agency Radiological Laboratory Analytical Protocols*
MARSSIM	*Multi-Agency Radiation Survey and Site Investigation Manual*
µg	microgram(s)
mg	milligram(s)
NCP	National Contingency Plan
NNSA	National Nuclear Security Administration
Np-	neptunium
Pa-	protactinium
pCi	picocurie(s)
PORTS	Portsmouth Gaseous Diffusion Plant in Piketon, Ohio
PRG	Preliminary Remediation Goal
Pu-	plutonium
REAL	Radiological and Environmental Analytical Laboratory
RME	reasonable maximum exposure
RfC	inhalation reference concentration
RfD	oral reference dose
ROCs	radionuclides of concern
SAP	*Sampling and Analysis Plan*
site	PORTS
Solutient	Solutient Technologies, LLC
SwRI	Southwest Research Institute®
Tc-	technetium
Th-	thorium
UCL	upper confidence limit
U-	uranium
ZCMS	Zahn's Corner Middle School

ES 1. EXECUTIVE SUMMARY

This Human Health Risk Assessment Report was prepared by Auxier & Associates, Inc. in response to concerns expressed by members of the Pike County Ohio Community after reports that elevated levels of radionuclides had been found at off-property locations around the former Portsmouth Gaseous Diffusion Plant in Piketon, Ohio (PORTS). This risk assessment was based on data gathered from properties located within six miles of the PORTS facility boundary during the Pike County Community Comprehensive Sampling Evaluation Project. Eleven-hundred and seventy-nine (1,179) samples were collected from four media between October 4, 2020 and February 17, 2022 (Figure ES-1). This includes 112 samples collected from interior surfaces of local schools. These samples were analyzed for an assortment of transuranics (americium-241, neptunium-237, plutonium-238, plutonium-239), technetium-99 and isotopes of uranium (uranium-233/234, uranium-235/236, and uranium- 238).

This risk assessment used EPA's CERCLA risk evaluation methodology and 9,424 analytical results from this sampling and analysis campaign to estimate excess cancer risks to local residents. Calculated risks to hypothetical local receptors from the listed radionuclides, as calculated using EPA's CERCLA risk calculators and reported in this assessment, are generally acceptable under the system EPA uses to evaluate risks within its CERCLA program. Potential subpopulations were identified by the community and the risk assessment team during the course of the investigation, including school children, residents consuming substantial quantities of local foods, life-long residents and recreational users of local streams. Risks to select subpopulations eating unusually large portions of locally grown food can reach risk levels approaching the upper end of EPA's "acceptable" risk range of 10^{-6} to 10^{-4}. The two radionuclides contributing the largest portions to the calculated risks are projected to be technetium-99 and plutonium-238. Risks to other groups, such as students attending schools in the study area and swimmers in local water bodies, were estimated to range between 1×10^{-8} and 8×10^{-7}, which are below EPA's acceptable risk range.

The aforementioned risks to the hypothetical resident were based on a community-wide exposure scenario. The possibility that larger, localized risks may exist was explored by examining the spatial distribution of the radionuclides of concern across the study area. Maps illustrating calculated risks at specific locations were produced and the location symbols on those maps were assigned different colors based on the calculated risk associated with the radionuclides of concern concentration reported at that location. The resulting maps did not indicate a well-defined pattern of distribution within the study area. Rather, the maps suggest a "mottled" distribution across the area, with localized areas of elevated concentrations separated by areas without a noticeable accumulation of radionuclides of concern. This is illustrated by Figure ES-2 which presents the distribution of the radionuclide projected to produce the highest risks (Technetium-99) within the study area.

Based on this evaluation, this study concludes that typical residents within six miles of PORTS are not currently at risk of excess cancer. However, some small areas contained radionuclides at levels that may produce risks at or above the 10^{-4} "acceptable risk range," as calculated for residents consuming large quantities of locally grown food. As these calculations incorporate various assumptions and uncertainties, it is recommended that direct measurements be made of technetium-99 in of locally grown produce and soil, as well as plutonium-238 in local fish flesh. This will reduce the considerable uncertainty imparted by the simple first-order partitioning model used by EPA's calculators to estimate this uptake.

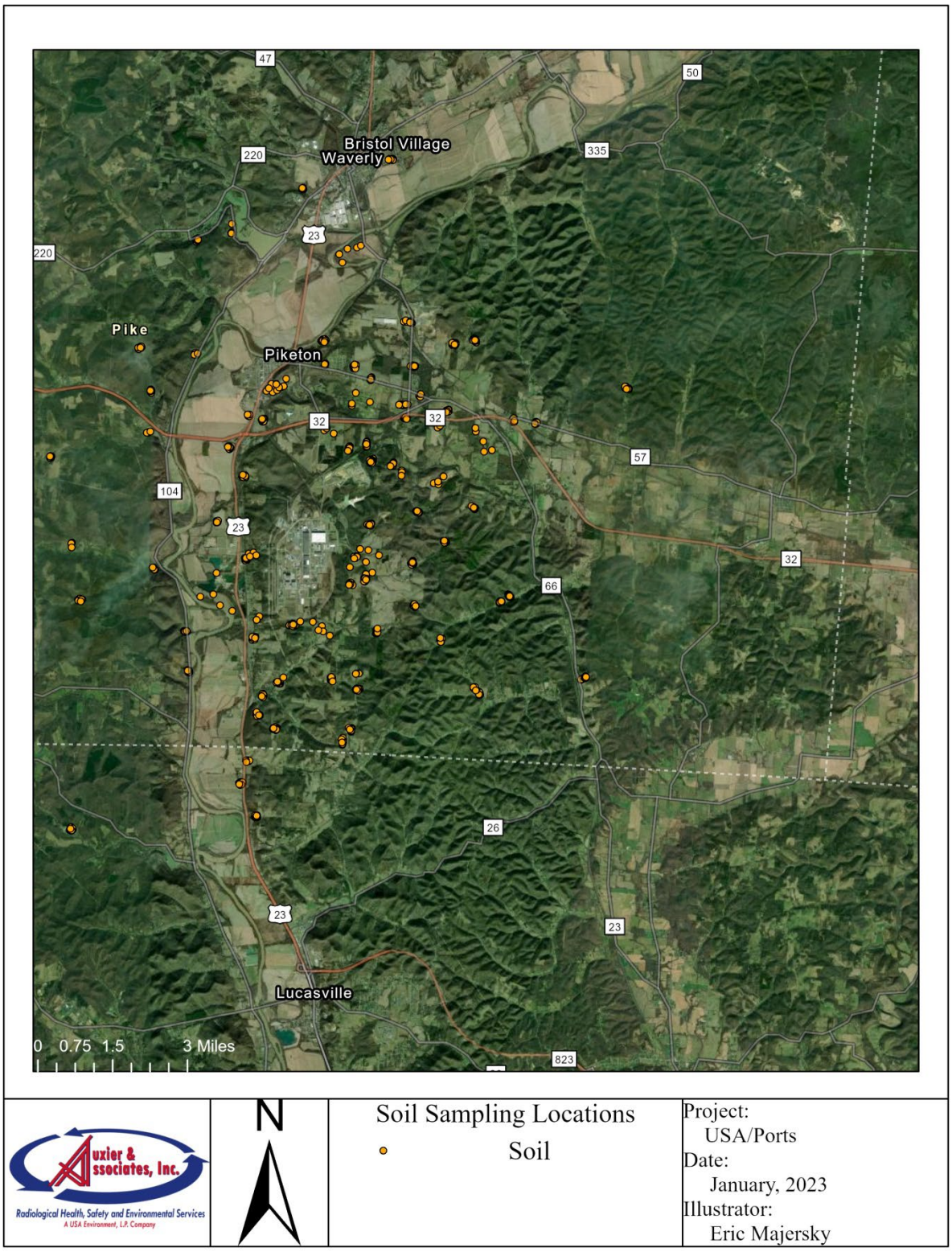

Figure ES-1 All Soil Sampling Locations in Study Area

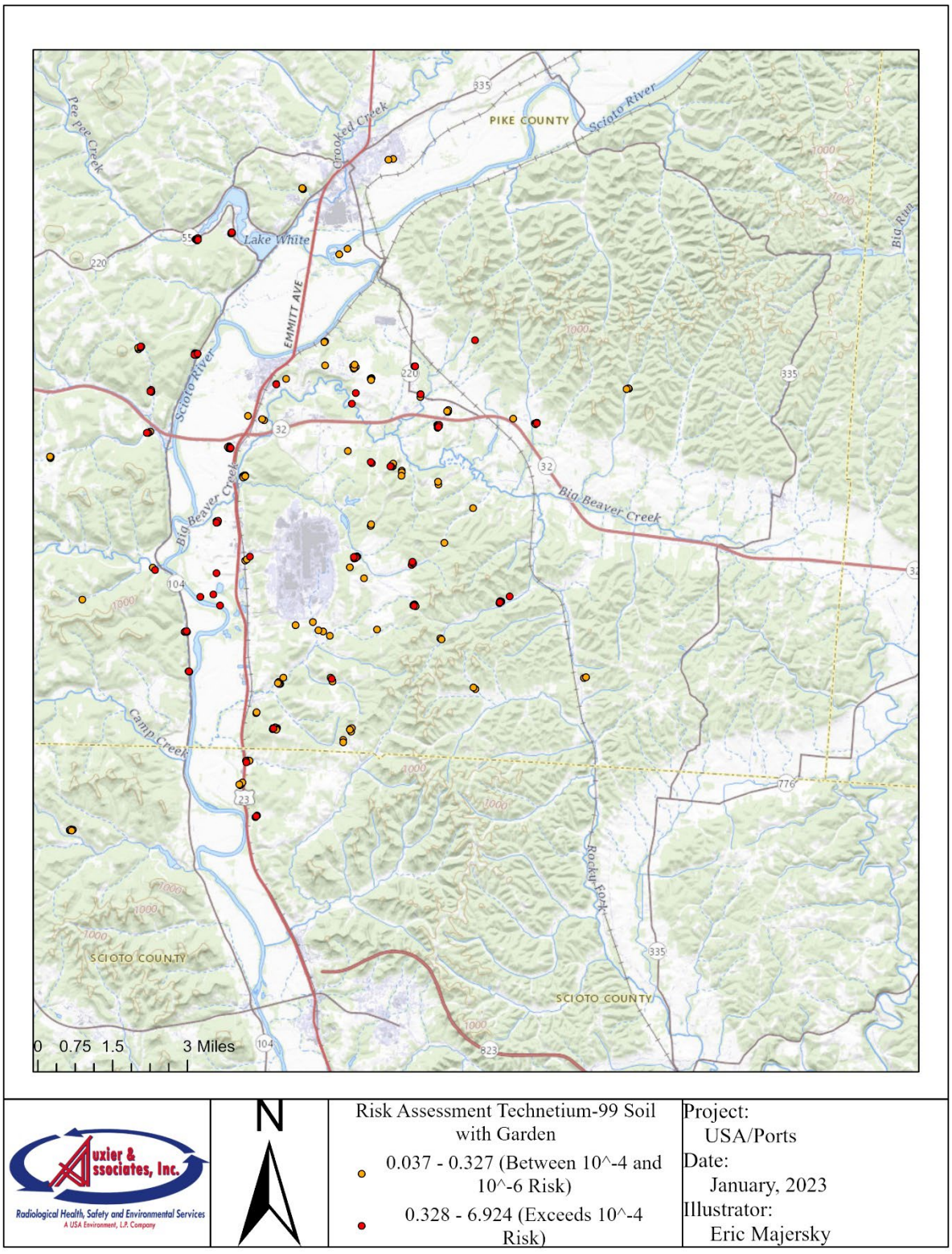

Figure ES-2 Distribution of Technetium-99 within the Study Area

1. INTRODUCTION

1.1 OVERVIEW

This Human Health Risk Assessment (HHRA) Report has been prepared by Auxier & Associates, Inc. (Auxier) and it is based on data gathered during the Pike County Community Comprehensive Sampling Evaluation (CCSE) Project. This work is being performed in response to concerns expressed by members of the Pike County Ohio Community (the "Community") regarding reports of "non-natural uranium" and transuranics[1] at off-property locations around the former Portsmouth Gaseous Diffusion Plant in Piketon, Ohio (PORTS). The study area evaluated in this HHRA is comprised of the area outside of the PORTS boundaries and within six miles of PORTS (Figure 1).

Tasks were performed as described in detail in the Solutient Technologies, LLC (Solutient) *Sampling and Analysis Plan/Quality Assurance Project Plan for the Pike County Community Comprehensive Sampling Evaluation Project* ("the SAP", Solutient 2020a) and the *Background Media Sampling and Analysis Plan for the Pike County Community Comprehensive Sampling Evaluation Project* (the "Background SAP", Solutient 2020b). These tasks included:

- Working closely with Community representatives to identify radionuclides of concern (ROCs) and select locations of interest to be sampled in the study area;
- Collecting samples of soil, sediment, surface water, and settled dust (i.e. smears) on surfaces in the study area and its associated reference area (background samples);
- Processing, tracking and analyzing samples;
- Validating analytical results and
- Collating sample results from the sampling campaign in an on-line database accessible to stakeholders.

In October 2022 Auxier submitted an HHRA Work Plan (Auxier 2022) to establish a structure for the tasks required to perform the HHRA. These tasks included:

- Reviewing the validated analytical results and comparing the reported concentrations to reference criteria such as analytical detection limits and background sample results,
- Using statistical tools and graphical representations to identify patterns and distributions that might produce environmental exposures,
- Describing previously identified ROCs and their potential concentrations at locations where higher exposures are likely to occur,
- Identifying generic receptors within the study area and quantitatively describing their behaviors in the environment,
- Identifying and describing potential exposure pathways for the generic receptors at the greatest risk of exposure,

[1] Transuranics are radionuclides with atomic numbers greater than 92 (i.e. neptunium, plutonium, americium, etc…).

- Characterizing potential risks using the methodology established by the U.S. Environmental Protection Agency (EPA), as expressed in their Preliminary Remediation Goal (PRG) and Building Preliminary Remediation Goal (BPRG) calculators (EPA 2022a and EPA 2022b, respectively), and
- Perform a multi-pathway assessment of radiological doses to the hypothetical "reasonably maximally exposed" receptor identified in the HHRA using RESRAD.[2]

1.2 HISTORY

On July 12, 2015, the Akron Beacon Journal published an article describing the approval of a U.S. Department of Energy (DOE) plan to pursue on-site disposal of some of the waste generated during decontamination and decommissioning at PORTS. In August of 2017, members of the local community approached the Pike County Commissioners "to express their strong opposition" to a waste disposal cell being constructed at PORTS.[3] Other residents have expressed concern that the cleanup of the PORTS property will spread contamination to nearby environmental media.[4]

In March of 2019, the DOE published the *Portsmouth Gaseous Diffusion Plant Annual Site Environmental Report–2017 Piketon, Ohio* (DOE 2019a). The report indicated neptunium-237 (Np-237), plutonium-239/240 (Pu-239/240), technetium-99 (Tc-99), uranium-238 (U-238), U-233/234, and U-235/236 had been detected in various media beyond the PORTS property boundaries. It was concluded in the report that "[p]otential doses to the public from radionuclides detected by the PORTS environmental monitoring program in 2017 are significantly less than the 100 mrem/year limit in DOE Order 458.1." Table 4.2 of that report presents a total dose rate of 0.038 mrem/y "to the public from radionuclides detected by DOE monitoring programs in 2017" (DOE 2019a).

Both the news media and members of the Pike County, Ohio, Community brought details of the report to the attention of the Pike County General Health District. Concerns included the finding that Np-237 was detected at a DOE off-site air monitoring station which is in close proximity to Zahn's Corner Middle School (ZCMS). The air sampler, designated as A41A, is sited approximately 1.5 miles northeast of PORTS property boundary (Figure 2).

The following month Dr. Michael Ketterer, in collaboration with Scott C. Szechenyi and a member of the local community, issued a report entitled *Investigation of Anthropogenic Uranium, Neptunium, and Plutonium in Environmental Samples near Piketon, Ohio* (Ketterer 2019). The report states it was prepared to answer questions about uranium, neptunium and plutonium in media collected from the local environment. The Ketterer report includes a

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[2] RESRAD's user's manual describes RESRAD as "… a computer model designed to estimate radiation doses from residual radioactive materials. Since its release in 1989, RESRAD has been used widely by the U.S. Department of Energy (DOE), its operations and area offices, and its contractors for deriving limits for radionuclides in soil. RESRAD was also used by the U.S. Environmental Protection Agency (EPA) in its 1994 technical support document for the development of radionuclide cleanup levels for soil. Other entities using RESRAD include the U.S. Army Corps of Engineers, the U.S. Nuclear Regulatory Commission (NRC), industrial firms, universities, and foreign government agencies and institutions." As this code was not used in the development of the EPA's PRG, DCC, BPRG, and BDCC calculators, it provides an independent assessment of the potential human health impacts of the site under investigation.

[3] https://www.newswatchman.com/news/article_3863e79b-18c9-5e60-b43d-605fc7675645.html

[4] https://www.dispatch.com/story/news/local/2020/09/01/pike-county-school-district-asks-feds-to-move-middle-school-away-from-radiation/113641168/

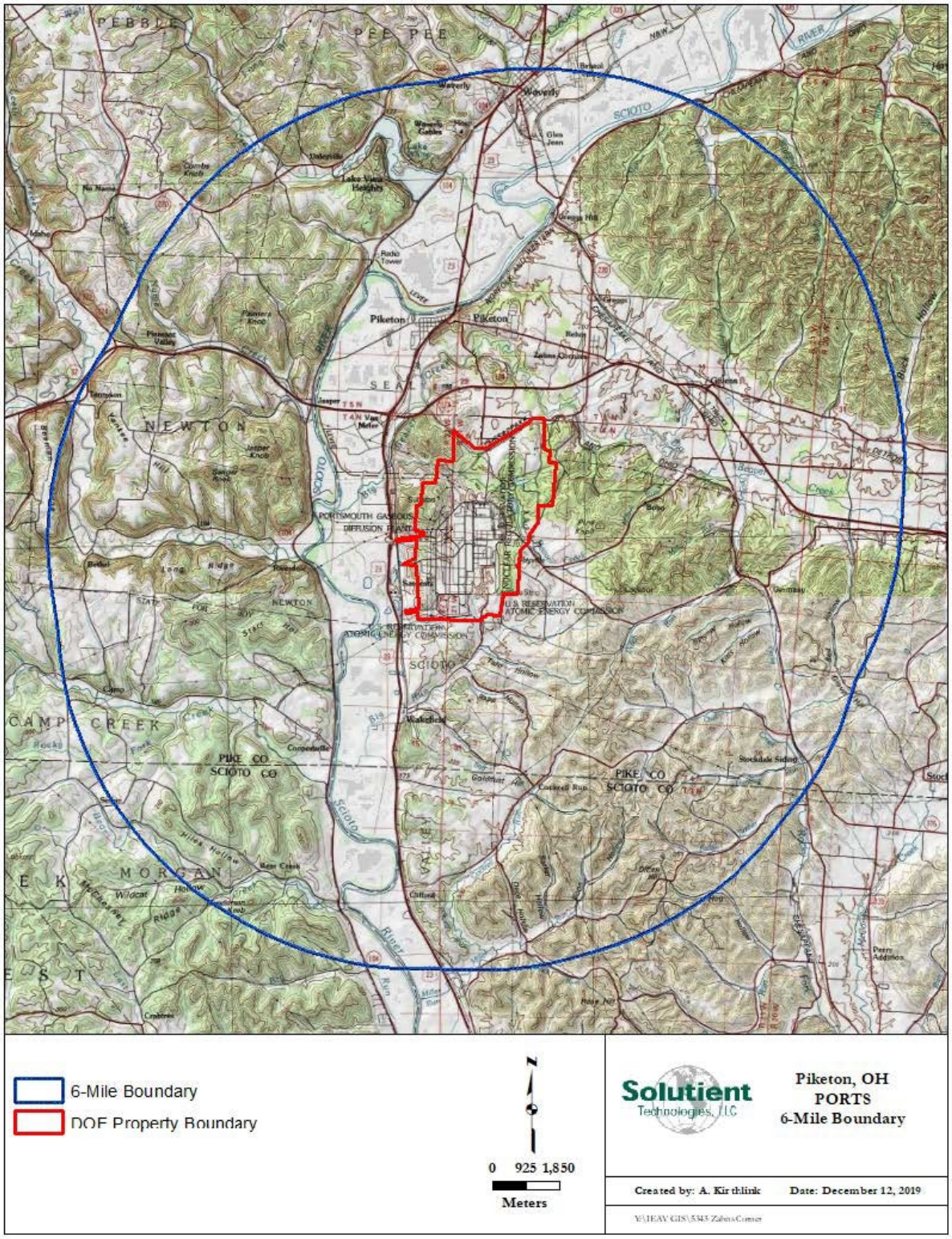

Figure 1 Study Area Surrounding the Portsmouth Gaseous Diffusion Plant

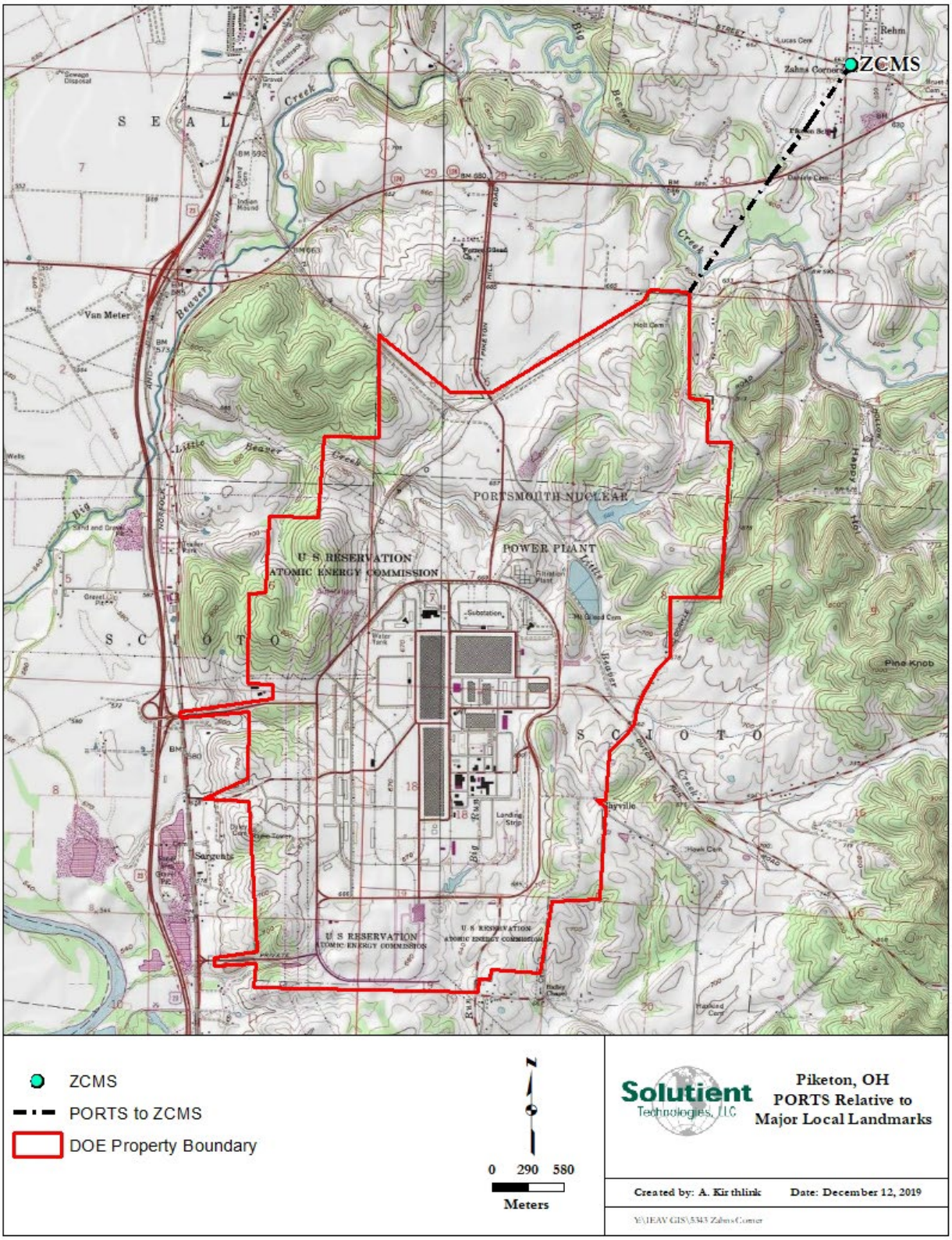

Figure 2 Location of ZCMS Relative to the PORTS Property Boundary (upper right)

description of the author's use of isotope ratios for nuclear forensics and concludes that the PORTS complex was the likely source of off-site radiological contamination.

In early May 2019, local and national media outlets (e.g., News Watchman, Cable News Network [CNN], the Weather Channel, Cincinnati Inquirer, Columbus Dispatch) began reporting on stakeholder concerns regarding off-property radiological contamination, with particular emphasis given to findings published in Dr. Ketterer's 2019 report that enriched uranium was identified inside a local school building. Community concerns led to the decision to close ZCMS for the remainder of the 2018–2019 school year and the entire 2019–2020 school year. The school did not reopen, as of the writing of this document.

In response to community concerns, DOE's national laboratories and the National Nuclear Security Administration (NNSA) sent a team to investigate radiological conditions at Zahn's Corner Middle School in 2019. The DOE published an account of this sampling event and its findings in *Sampling Analysis Report for Zahn's Corner Middle School Sampling Event* (DOE 2019b). The report listed the locations searched, the media sampled, the radionuclides the NNSA team focused on, and the concentrations in the samples collected. "Only naturally occurring radionuclides were found in any of these samples; none of the samples indicated any excess radiological risk above background to the public." (DOE 2019b)

At the request of the Community, DOE also provided funding to the Community via a financial assistance award to Ohio University for an investigation to 1) define the nature and extent of the radionuclides of concern within six miles of the PORTS site and 2) evaluate potential health impacts to members of the Community. As part of the financial assistance reward's terms and conditions, DOE only completes factual accuracy reviews of OU's products. In May 2019, Ohio University's Voinovich School of Leadership and Public Service agreed to work closely with County and Community representatives and serve as the independent coordinator for the project.

As part of that work, Ohio University is providing contract administration services to the project and will assist with the dissemination of results while the Community has retained sole authority over selecting all vendors to perform the sampling, laboratory analyses, data validation, and the HHRA. Under this arrangement, a team of third-party contractors specializing in radiological investigations and evaluations was assembled.

The Community selected Solutient in July 2019 as the third-party contractor to perform an independent sampling campaign called the CCSE project. The Community, in concert with Solutient, jointly defined the sampling area for this investigation as the area within a six-mile radius of the PORTS site (Figure 1) when they developed the Data Quality Objectives (DQO's). Solutient subsequently worked closely with Community representatives to complete the project's SAP (Solutient 2020a) and its subcontractor ORISE (Oak Ridge Institute for Science and Education) were tasked with performing the required environmental sampling within a six-mile radius of PORTS (Figure 1).

In May 2020, Auxier was selected by the Community to perform the Human Health Risk Assessment using the data gathered by Solutient. In association with Solutient, and in support of the CCSE project, Auxier developed a HHRA Work Plan (Auxier 2022) to describe the process to be used to perform the HHRA. Auxier performed the HHRA in accordance with the *Risk Assessment Guidance for Superfund, Human Health Evaluation Manual* (EPA 1989) and its accompanying body of guidance. This included using the EPA's PRG and BPRG calculators to assess potential human health risks (EPA 2022a & 2022b). This HHRA is consistent with guidance presented in that Work Plan.

1.3 ORGANIZATION OF THIS REPORT

The remainder of this report follows the four major steps of a CERCLA-style risk assessment (data collection and evaluation, exposure assessment, toxicity assessment, and risk characterization). This information is organized as follows:

- Section 2 briefly recounts the data collection and analytical phases of the project, describes data validation processes and summarizes the analytical results. It also lists the ROCs to be evaluated in the HHRA and presents the methods used to evaluate the large volume of data and focus the analysis on higher-impact results.
- Section 3 describes the human exposure assessment process (including estimating exposure point concentrations), identifies potential receptors and exposure pathways to be considered, and presents parameters used to describe those exposures by medium.
- Section 4 presents information on the properties and toxicities of the ROCs identified.
- Section 5 contains descriptions of how the EPA's risk assessment methodology was applied in this human health risk characterization and it presents the results of this HHRA.
- Section 6 presents notable sources of uncertainty/bias.
- Section 7 summarizes the findings and recommendations of this HHRA; and
- Section 8 lists the references used in completing this HHRA report.

2. DATA COLLECTION AND EVALUATION

The SAP (Solutient 2020a) developed by the Community and Solutient served as the blueprint for the sampling and analyses that provided the data used in this HHRA. This blueprint:

- Defined the study area to be the area within six miles of the PORTS perimeter;
- Listed the ROCs the Community wanted investigated as americium-241 (Am-241), Np-237, Pu-238, Pu-239, Pu-240, Tc-99, U-234, U-235, U-236, and U-238;
- Identified the media to be investigated as soil, surface water, sediment and settled dust;
- Provided guidance on how and where samples were to be collected;
- Specified the analyses to be performed and named the laboratories to be contracted to perform those analyses; and
- Required formal quality assurance and control checks of analytical results, such as verification and validation in accordance with EPA QA/G-8 and MARLAP, where applicable.

Only validated analytical results from the resulting sampling campaign formed the basis of this HHRA.

The first part of this section presents overviews of sample collection (Subsection 2.1) and analytical activities (Subsection 2.2). Subsequent subsections (Subsections 2.3 through 2.5) describe the methods used to focus the analysis on the subset of data that had the largest potential to produce quantifiable exposures. Summary statistics are presented in Subsection 2.6.

2.1 DATA COLLECTION NARRATIVE

A summary of the sampling efforts described in the *Piketon Comprehensive Community Sampling Evaluation* (Solutient 2022) is provided below. Field activities were conducted in two phases.

The first phase culminated in the June 2020 pilot study sampling event. During this sampling, various sampling and analytical techniques were compared to determine the preferred set of sample collection and analytical methods that would be used during the main sampling campaign. The primary objectives of the pilot study, conducted during the week of June 7, 2020, were to determine how many different types of soil were present in the study area and to evaluate the efficacy of the analytical techniques used. Data collected during the pilot study phase were reviewed by the risk assessment team, but were not used in determining exposure point concentrations (Section 3.2) because various analytical methodologies were being tested and refined during that phase.

The second phase of sampling began by identifying properties to sample. The "background area" is defined in the Background SAP (Solutient 2020b) as the area outside the six-mile radius from PORTS. Background area sample locations were identified between six and roughly 50 miles from PORTS in areas determined to be least likely to have been impacted by PORTS operations. These areas were primarily east and west of PORTS (predominantly upwind from PORTS, see Figure 3).

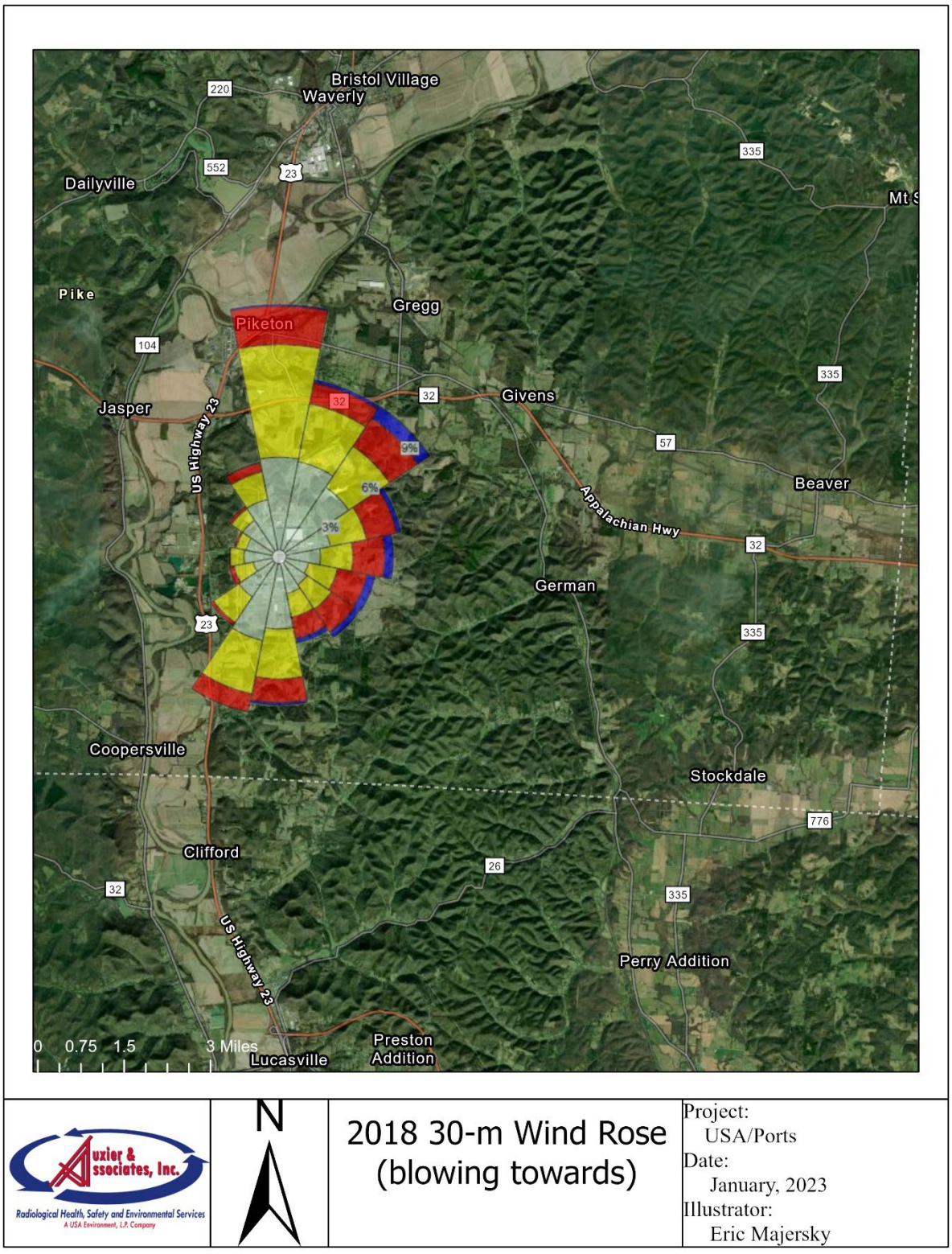

Figure 3 2018 Wind Rose Superimposed on PORTS Facility

Sampling locations used to characterize the six-mile study area around PORTS (the "study area") were identified within physical boundaries set by CCSE project stakeholders and were selected using a combination of community requests, knowledge of the terrain and demographics, meteorological data, and Gaussian plume modeling. Subsequently, access and sampling permissions were gathered from property owners prior to initiating the sampling effort.

Background area sampling efforts began the week of October 4, 2020 and ended mid-month. Sampling within the six-mile study area began in October 2020 and concluded in February 17, 2022. Ten separate field expeditions were required to complete the CCSE main study sampling. Seventeen weeks of actual time in the field collecting samples occurred between October 4, 2020, and February 17, 2022.

Table 1 lists the numbers of soil, sediment, surface water, and smear samples provided to Auxier for the background area and the study area. Figure 4 through Figure 9 depict the known locations of characterization and background area samples relied upon in the HHRA. Additional details of the sample selection process and subsequent field activities are provided in *Piketon Comprehensive Community Sampling Evaluation* (Solutient 2022).

Table 1 Number of Samples Provided to Auxier by Phase and Medium

Phase	Soil	Sediment	Water	Smear	Totals
Background Study	52	11	13	32	108
Main Study	843	20	26	182	1,071
Grand Totals	895	31	39	214	1,179

2.2 ANALYTICAL SUMMARY

Samples collected from soil, sediment, surface water, and settled dust on surfaces (i.e. smears) were sent under chain of custody to the laboratory chosen by the Community, the Radiological and Environmental Analytical Laboratory (REAL) at the Oak Ridge Institute for Science and Education in Oak Ridge, Tennessee. For all media, analyses were performed for Am-241, isotopic plutonium (Pu-238 and Pu-239/240[5]), Np-237, and isotopic uranium (U-233/234[6], U-235/236[7], U-238) by alpha spectrometry and Tc-99 by liquid scintillation counting. Analyses were completed at REAL for all 1,179 samples between June 2020 and May 2022.

Of the 1,179 samples analyzed at REAL, approximately 15% (173) were split and sent to Southwest Research Institute® (SwRI) Department of Analytical and Environmental Chemistry in San Antonio, Texas. For all media, analyses were performed for isotopic plutonium, Np-237, and isotopic uranium by inductively coupled plasma mass spectrometry. Analyses were completed at SwRI for the176 samples between January 2021 and April 2022.

Each laboratory provided analytical results to Solutient in electronic spreadsheet format. In addition, laboratory packages, including case narratives and analytical results, were provided in uneditable electronic format. The original laboratory packages are currently held by Solutient

[5] Pu-239 toxicity was used to represent the Pu-239/240 analysis.

[6] U-234 tox was used to represent the U-233/234 analysis.

[7] U-235 tox was used to represent the U-235/236 analysis.

pending direction by the Community. The data were assembled by Solutient and provided to the risk assessment team in electronic spreadsheet format.

Data from the paired analyses from the two laboratories were plotted and compared visually (Attachment A).

2.3 DATA VALIDATION AND REVIEW

Data collected during the sampling phase of this investigation were evaluated by USA Environment, LLC using a formal data validation process and quality objectives documented in the Project DQO (Solutient 2020c) and SAP (Solutient 2020a) documents, along with guidance and quality control criteria from the *Multi-Agency Radiological Laboratory Analytical Protocols Manual* (MARLAP) (MARLAP 2004). The goal of this validation was to evaluate the quality of individual analytical results and assign data validation qualifiers as necessary to assist in proper data interpretation. The following descriptions provide brief explanations of the qualifiers commonly assigned to results during the data review process.

- U — The sample was analyzed but the analyte was not detected. The reported instrument response was indistinguishable from the response of the blank sample.
- UJ — The analyte was not detected above the critical value, but the minimum detectable concentration is greater than the quantification goal, and therefore the numerical value may be approximate.
- J — The analyte was positively identified; but the minimum detectable concentration is greater than quantification goal, and therefore the numerical value may be approximate.
- Q — The total propagated uncertainty at one sigma was greater than the required measurement uncertainty.
- S — Sample result was superseded by another sample.
- R — The sample result was rejected due to serious deficiencies in the ability to analyze the sample and/or meet quality control criteria. The presence or absence of the analyte cannot be verified.

Solutient, working closely with Auxier, collated the validated data in a readily available digital database using commercially available software.

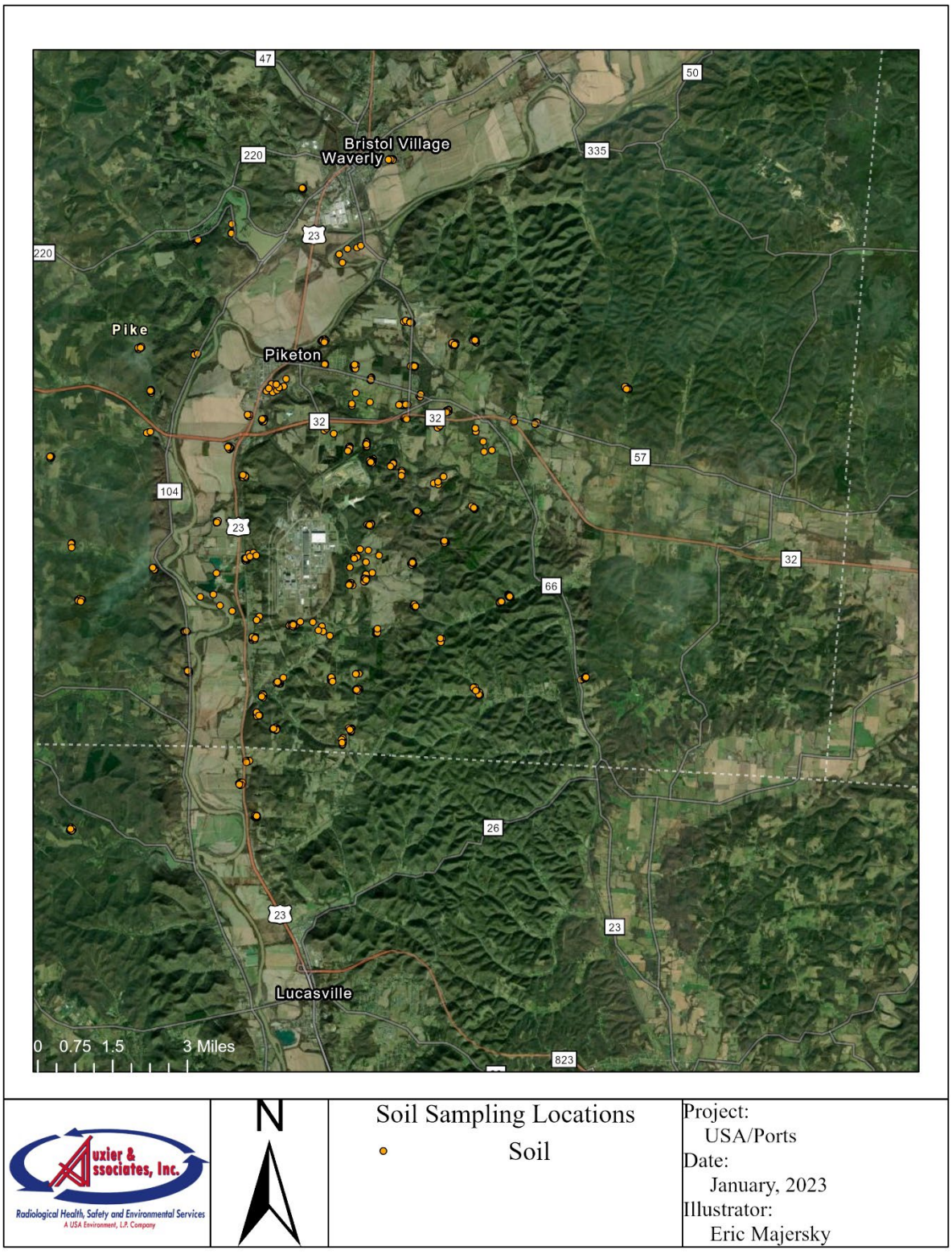

Figure 4 Study Area - Soil Sampling Locations

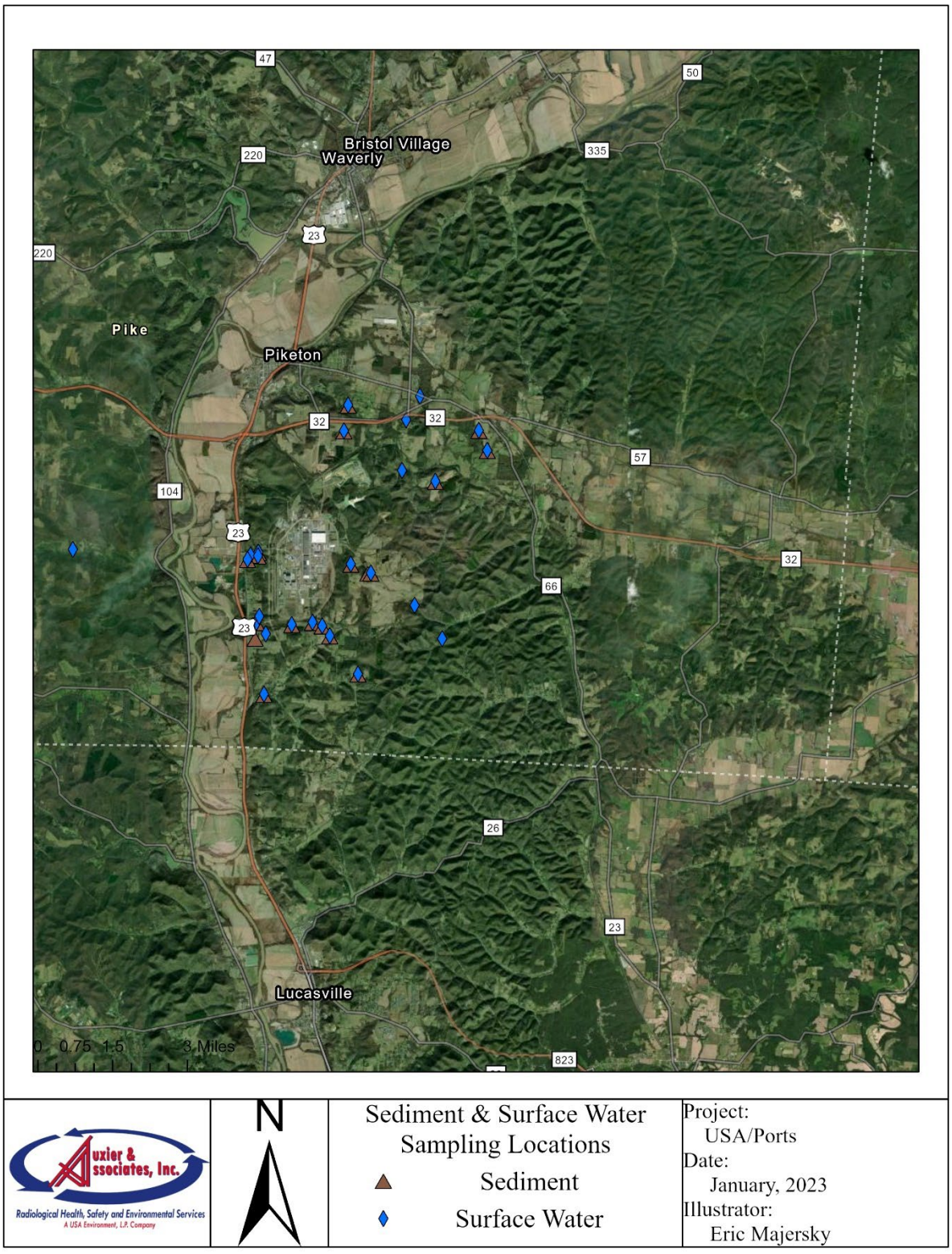

Figure 5 Study Area - Sediment & Surface Water Sampling Locations

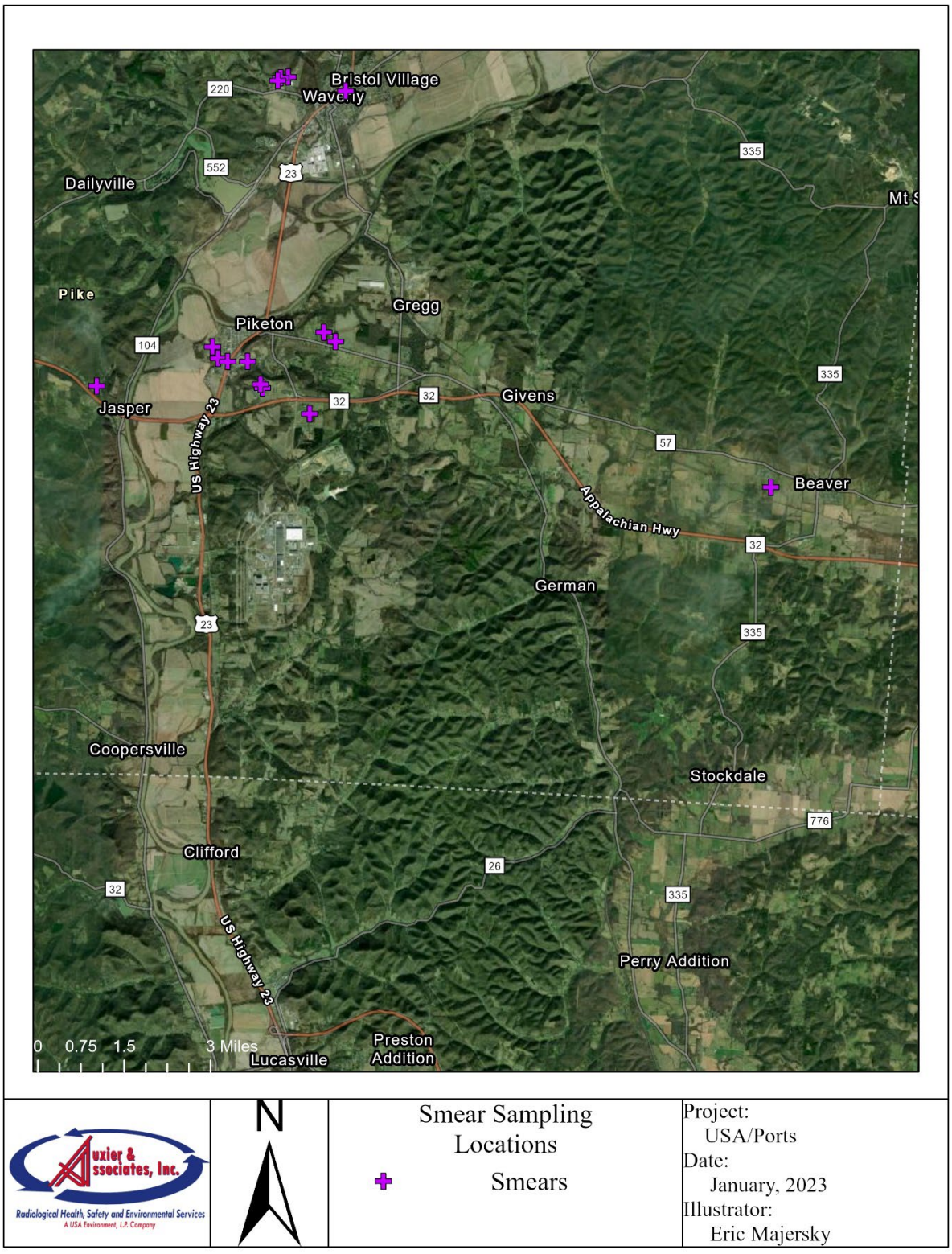

Figure 6 Study Area - Smear Sampling Locations

Figure 7 Background Area - Soil Sampling Locations

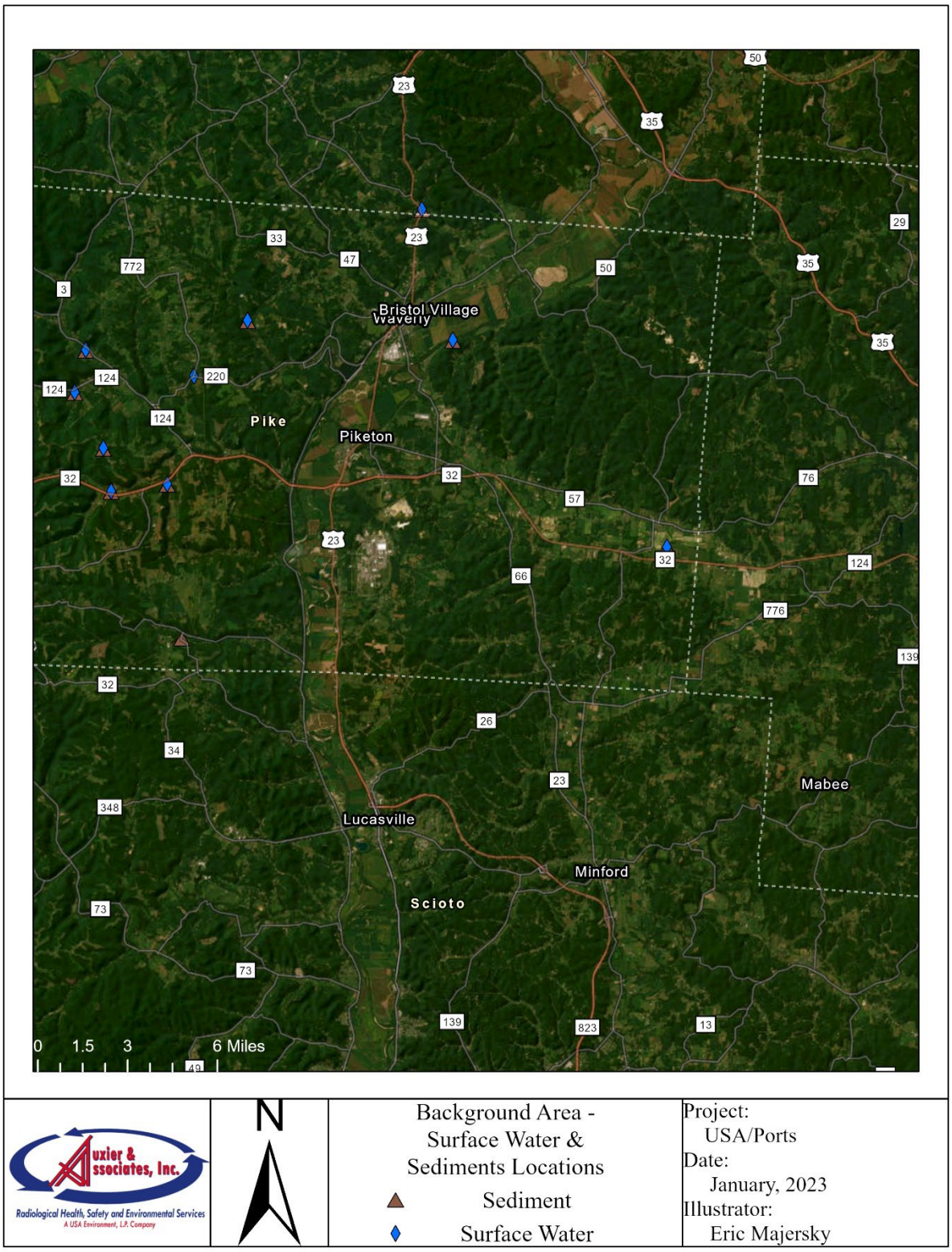

Figure 8 Background Area – Surface Water & Sediments Locations

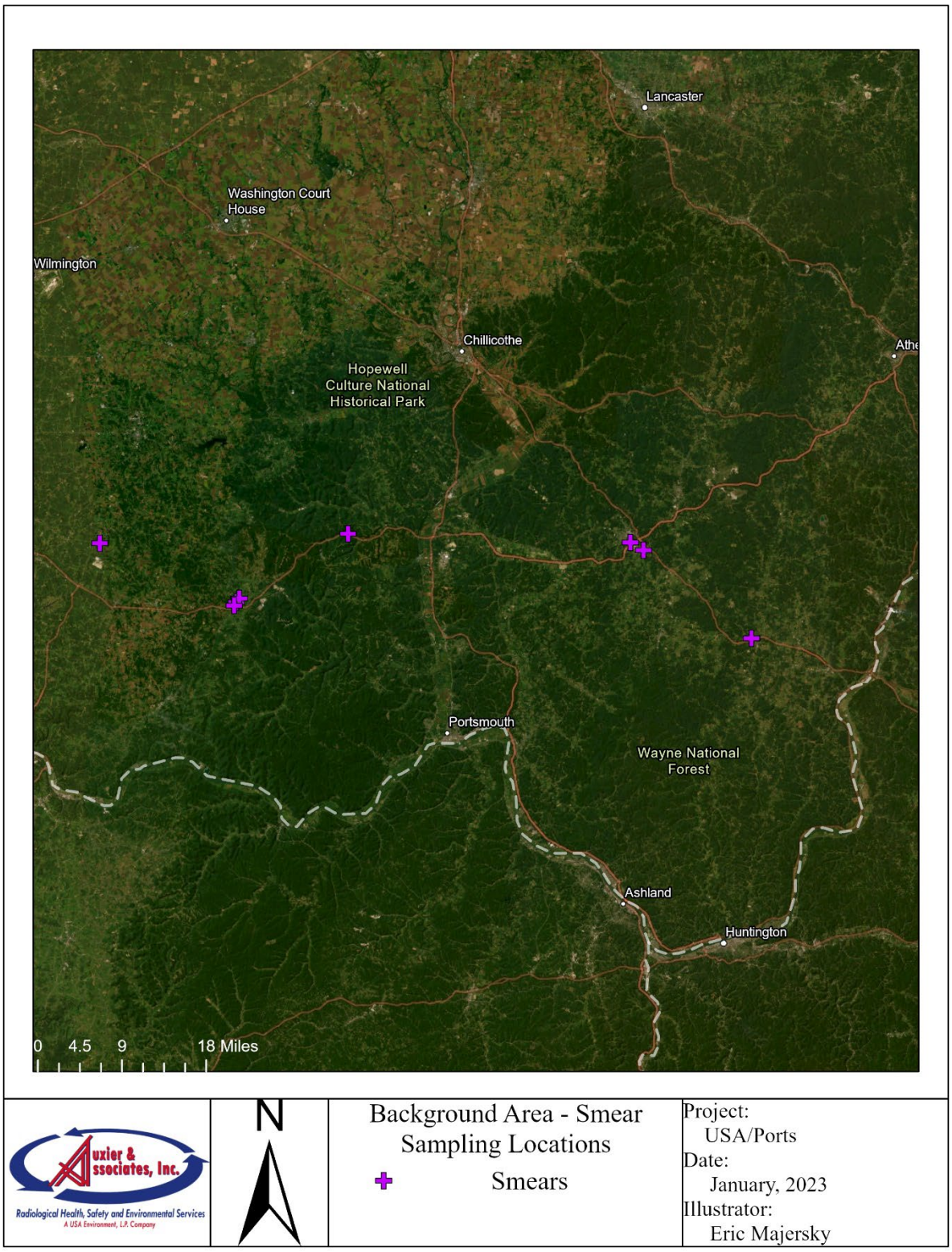

Figure 9 Background Area – Smear Sampling Locations

2.4 DATA USABILITY

Once validated data and relevant qualified records, such as completed questionnaires from the community, were compiled, an evaluation was performed to determine if the quality of the data satisfied the objectives established in the "*Overarching Data Quality Objectives for the Pike County Community Comprehensive Sampling Evaluation"* (Solutient 2020c). Methods offered in EPA guidance were selected to perform this evaluation. As stated by EPA's Office of Research and Development on page 102 of its "*Guidance for Data Usability in Risk Assessment (Part A)*," (EPA 1992a), data…

> *"…must be reviewed at a predetermined level before use in the final risk assessment."*

Thus, a "data usability evaluation" is a standard and necessary task that EPA's risk assessment guidance recommends be performed before using data to finalize risk assessments (EPA 1989).

Although the study area is not an EPA Superfund site, this step is considered appropriate and useful for evaluating the usability of environmental data collected in the study area. In this HHRA, the data usability evaluation provides a means to assess and assure that the quality of data generated during an investigation is known and that data are of sufficient quality to be used for the intended purpose(s) (EPA 1992a).

Validated results were subjected to an additional combination of qualitative examinations and tests to ascertain if specific data points were representative of conditions in the study area. If these examinations identified a result that might be anomalous, a series of additional tests were performed to determine if the anomaly could be explained as an artifact of the sampling or analytical process.

For example, histograms were prepared of isotopic data received from REAL. Visual examination of these graphics indicated some data sets contained results that were above and below the bulk of the results. A numerical test was then run on those data sets to identify individual samples producing these outliers. In other cases, isotopic ratios were used to identify samples producing anomalous results. To add context to the initial result, either the samples were flagged for additional scrutiny and reanalyzed by the laboratory or the sampling team was sent back to those locations to collect confirmatory samples around the original sample location.

Based on the outcome of this verification process, the original sample result was either accepted as representative or the initial database record was annotated with an "S" qualifier to indicate the result had been superseded by new data. This process enhanced the risk assessment team's confidence that the study's data were of sufficient quality and representativeness to be used in the Piketon HHRA. Table 2 presents a summary of the conclusions of the data usability assessment.

Table 2 Data Usability Summary

Category	Number of Results from REAL	Notes
Total Results	9,600	Includes all results from all 1,179 samples.
Challenged Results	169	Less than 2% of the initial samples were challenged (162 Tc-99 soil and 7 Tc-99 surface water) during the data validation and data usability evaluation steps of the data review.
Superseded Results	168	168 of these challenged samples were selected for reanalysis. 161 soil and 7 surface water samples were reanalyzed for Tc-99. The initial sample results were replaced in the dataset by the second analysis. The original results were assigned an "S" qualifier and retained for completeness.
Rejected Results	8	This soil sample was thought to be a background sample when collected. While only the Tc-99 result was challenged, all results for this one sample were rejected.
Accepted Results	9,424	This includes results that passed data evaluation and were initially accepted, 168 results from samples that were reanalyzed and additional results collected during confirmatory sampling.

[a] These results are for soil, sediment, surface water, and settled dust.

2.5 DETERMINING DETECTED CONCENTRATIONS

In this HHRA, the methodology used for determining if an analyte is detected in a sample is consistent with the approach established in the MARLAP (2004).[8] This guidance provides a consistent approach for establishing radioanalytical laboratory data that meet project data requirements. The guidance is scientifically rigorous yet sufficiently flexible for application to diverse projects.

As part of this approach, each laboratory result was evaluated during validation to determine if the analyte was detected in a given sample. The analyte was considered to be detected if the result was greater than a statistical quantity called the critical value, sometime abbreviated as "L_c". The critical value identifies a threshold concentration that divides sample results into two groups; results that are too small to be distinguished from similar results reported for a blank sample, and results that are large enough to indicate the presence of the analyte in the sample. To put it another way, if the laboratory reports the concentration in a sample is above the L_c, it can be said that the radionuclide was detected in that sample with that method. Reported

[8] The *MARLAP Manual* which was developed in cooperation with eight federal entities, including the DOE and the EPA, "…provides a peer-reviewed, nationally consistent guidance for the planning, implementation and assessment phases of projects that require laboratory analysis of radionuclides. MARLAP addresses the need for a nationally consistent approach to producing radioanalytical laboratory data that meet a project's or program's requirements. The guidance provided by MARLAP is both scientifically rigorous and flexible enough to be applied to diverse projects and programs." - *https://www.epa.gov/radiation/multi-agency-radiological-laboratory-analytical-protocols-manual-marlap entitled Multi-Agency Radiological Laboratory Analytical Protocols Manual (MARLAP)*

concentrations that are less than the L_c indicate the analyte was not detected in that particular sample.

This quantity (L_c) is sometimes confused with the Minimum Detectable Concentration, or "MDC," reported by many laboratories. For the purposes of this investigation, the MDC can be thought of as the minimum detectable activity that can be reliably quantified. In cases where the laboratory reports a result that is greater than the L_c and less than the MDC, the sample contains detectable amounts of the analyte but the quantity of the analyte cannot be determined with certainty. Such results are identified in the database as "estimated" by assigning a "J" qualifier to them. The J qualified data values are used as reported, but findings that rely solely on J qualified data are identified as being less certain than findings based on data requiring no qualifiers.

2.6 SUMMARY STATISTICS FOR REPRESENTATIVE DATA

Statistical summaries of validated concentrations reported for ROCs are presented by medium and sampling effort (background area and CCSE) in Table 3. The data sets described in Table 3 form the basis of the risks and doses presented in this HHRA. One of the most remarkable characteristics of these data sets is the large proportion of results that are below the concentrations that can be detected using the analytical methods employed during the study.[9] This reflects the generally low concentrations reported for most ROCs across the study area.

Table 4 has been provided presenting the same statistical metrics for samples where the ROC was detected. The data in Table 4 will be used to illustrate the spatial distribution of ROCs later in the report. The locations of samples containing detectable quantities of the ROCs are presented in Attachment B.

[9] Many of these values are actually reported as negative numbers by the laboratories. Briefly stated, analytical results are determined in the laboratory by subtracting the activity of an analyte in a laboratory blank (background) from the gross activity measured in each sample. If the background measurement exceeds the gross measurement, a negative concentration is reported.

Table 3 Summary Statistics for Data Reported by REAL

Media / ROC	Background Area: No. of Samples	Range	Median	Average	St. Dev.	Study Area: No. of Samples	Range	Median	Average	St.Dev.
Soil		**(pCi/g)**	**(pCi/g)**	**(pCi/g)**	**(pCi/g)**		**(pCi/g)**	**(pCi/g)**	**(pCi/g)**	**(pCi/g)**
Am-241	51	-0.0054 - 0.015	0.004	0.004	0.004	843	-0.0084 - 0.025	0.0046	0.005	0.005
Np-237	51	-0.0035 - 0.0077	0	0.001	0.002	843	-0.0099 - 0.018	0	0.001	0.003
Pu-238	51	-0.0037 - 0.011	0.0019	0.002	0.003	843	-0.014 - 0.016	0.0018	0.001	0.003
Pu-240	51	0 - 0.025	0.0086	0.009	0.006	843	-0.006 - 0.057	0.009	0.01	0.007
Tc-99	51	-0.15 – 0.89	0.015	0.11	0.23	843	-0.26 - 6.9	0.093	0.15	0.41
U-233/234	51	0.67 - 10.3	1.41	1.9	1.6	843	-0.36 - 7.1	1.2	1.2	0.54
U-235/236	51	0.013 - 0.359	0.07	0.085	0.06	843	0.013 - 0.37	0.054	0.057	0.03
U-238	51	0.65 - 8.4	1.44	1.9	1.4	843	0.51 - 7.1	1.2	1.2	0.52
Sediment		**(pCi/g)**	**(pCi/g)**	**(pCi/g)**	**(pCi/g)**		**(pCi/g)**	**(pCi/g)**	**(pCi/g)**	**(pCi/g)**
Am-241	11	0 - 0.0074	0.0039	0.004	0.003	20	-0.0025 - 0.025	0.004	0.005	0.007
Np-237	11	-0.0017 - 0.005	0	0.001	0.002	20	-0.004 - 0.0078	0	0.001	0.002
Pu-238	11	-0.0018 - 0.0037	0.0017	0.001	0.002	20	-0.002 - 0.017	0.0018	0.003	0.004
Pu-240	11	0 - 0.018	0.0069	0.007	0.006	20	0 - 0.028	0.0044	0.006	0.007
Tc-99	11	-0.16 - 0.26	-0.045	0.011	0.14	20	-0.23 - 0.30	-0.042	-0.015	0.13
U-233/234	11	1.1 - 5.3	2.17	2.4	1.3	20	0.607 - 1.55	0.97	1.03	0.22
U-235/236	11	0.041 - 0.20	0.087	0.093	0.047	20	0.018 - 0.075	0.048	0.046	0.012
U-238	11	1.1 – 5.0	2.09	2.3	1.2	20	0.48 - 1.3	0.96	0.962	0.20
Surface Water		**(pCi/L)**	**(pCi/L)**	**(pCi/L)**	**(pCi/L)**		**(pCi/L)**	**(pCi/L)**	**(pCi/L)**	**(pCi/L)**
Am-241	13	-0.021 - 0.1	0.057	0.043	0.039	26	-0.02 - 0.11	0.019	0.03	0.034
Np-237	13	-0.02 - 0.039	0	-0.001	0.02	26	-0.041 - 0.037	0	-0.002	0.017
Pu-238	13	-0.019 - 0.077	0.019	0.026	0.025	26	-0.018 - 0.06	0.027	0.026	0.021
Pu-240	13	0 - 0.095	0.037	0.043	0.025	26	-0.019 - 0.076	0.020	0.028	0.027
Tc-99	13	-4.6 - 1.9	-0.41	-0.74	1.	26	-1.8 - 2.8	0.16	0.102	1.1
U-233/234	13	0.019 - 0.88	0.33	0.38	0.30	26	0 - 1.1	0.17	0.27	0.28
U-235/236	13	0 - 0.09	0.024	0.032	0.029	26	0 - 0.12	0.024	0.026	0.025
U-238	13	0.057 - 0.89	0.24	0.312	0.26	26	0.02 - 0.72	0.12	0.19	0.19
Dust, Interior Surfaces		**(pCi/cm^2)**	**(pCi/cm^2)**	**(pCi/cm^2)**	**(pCi/cm^2)**		**(pCi/cm^2)**	**(pCi/cm^2)**	**(pCi/cm^2)**	**(pCi/cm^2)**
Am-241	32	0 - 0.0001	0.000024	0	0	182	-0.0001 - 0.0001	2.55E-05	0	0
Np-237	32	0 - 0.0001	0	0	0	182	-0.0001 - 0.0001	0	0	0
Pu-238	32	-0.0001 - 0.0001	0.00001	0	0	182	-0.0001 - 0.0001	2.05E-05	0	0
Pu-240	32	0 - 0.0001	0.000053	0	0	182	0 - 0.0002	0.00004	0	0
Tc-99	32	-0.0081 - 0.0021	-0.00205	-0.003	0.003	182	-0.005 - 0.0126	0.001028	0.001	0.003
U-233/234	32	0 - 0.0281	0.000175	0.001	0.005	182	0 - 0.0243	0.00016	0	0.002
U-235/236	32	0 - 0.0009	0.000014	0	0	182	-0.0001 - 0.0008	0	0	0
U-238	32	0 - 0.0043	0.00016	0	0.001	182	0 - 0.024	0.00016	0	0.002

Note: Significant figures presented in this and the next table are provided for QA purposes and do not reflect the precision of the values listed.

Table 4 Summary Statistics for Detected Concentrations Only

Media / ROC	Background Area: No. of Detects[a]	Background Area: Range	Background Area: Median	Background Area: Average	Background Area: St. Dev.	Study Area: No. of Detects	Study Area: Range	Study Area: Median	Study Area: Average	Study Area: St.Dev.
Soil		**(pCi/g)**	**(pCi/g)**	**(pCi/g)**	**(pCi/g)**		**(pCi/g)**	**(pCi/g)**	**(pCi/g)**	**(pCi/g)**
Am-241	0	NA[b]	NA	NA	NA	44	0 - 0.025	0.015	0.015	0.005
Np-237	0	NA	NA	NA	NA	13	0 - 0.018	0.01	0.01	0.004
Pu-238	0	NA	NA	NA	NA	18	0 - 0.016	0.01	0.009	0.004
Pu-240	27	0.007 - 0.025	0.012	0.013	0.005	323	0.005 - 0.057	0.015	0.017	0.006
Tc-99	17	0.034 – 0.89	0.27	0.35	0.51	257	0.037 - 6.9	0.26	0.43	0.64
U-233/234	51	0.67 - 10.3	1.4	2.0	1.6	842	0.49 - 7.1	1.15	1.2	0.53
U-235/236	51	0.013 - 0.36	0.07	0.085	0.06	843	0.013 - 0.37	0.054	0.057	0.028
U-238	51	0.65 - 8.37	1.4	1.9	1.4	843	0.505 - 7.1	1.2	1.2	0.52
Sediment		**(pCi/g)**	**(pCi/g)**	**(pCi/g)**	**(pCi/g)**		**(pCi/g)**	**(pCi/g)**	**(pCi/g)**	**(pCi/g)**
Am-241	0	NA	NA	NA	NA	3	0.016 - 0.025	0.017	0.019	0.005
Np-237	0	NA	NA	NA	NA	0	NA	NA	NA	NA
Pu-238	0	NA	NA	NA	NA	1	0.017 - 0.017	0.017	0.017	NA
Pu-240	4	0.009 - 0.018	0.014	0.014	0.004	3	0.007 - 0.028	0.022	0.019	0.011
Tc-99	2	0.20 - 0.26	0.23	0.23	0.044	3	0.038 - 0.30	0.041	0.13	0.15
U-233/234	11	1.1 - 5.3	2.17	2.3	1.3	20	0.61 - 1.6	0.97	1.03	0.22
U-235/236	11	0.041 - 0.204	0.087	0.093	0.047	20	0.018 - 0.075	0.048	0.046	0.012
U-238	11	1.1 – 5.0	2.09	2.3	1.2	20	0.48 - 1.3	0.96	0.96	0.20
Surface Water		**(pCi/L)**	**(pCi/L)**	**(pCi/L)**	**(pCi/L)**		**(pCi/L)**	**(pCi/L)**	**(pCi/L)**	**(pCi/L)**
Am-241	0	NA	NA	NA	NA	0	NA	NA	NA	NA
Np-237	0	NA	NA	NA	NA	0	NA	NA	NA	NA
Pu-238	1	0.077 - 0.077	0.077	0.077	NA	2	0.038 - 0.04	0.039	0.039	0.001
Pu-240	0	NA	NA	NA	NA	0	NA	NA	NA	NA
Tc-99	1	1.9 - 1.9	1.88	1.9	NA	3	1.4 - 2.8	1.4	1.8	0.78
U-233/234	11	0.1 - 0.88	0.34	0.44	0.29	22	0.096 - 1.12	0.20	0.31	0.29
U-235/236	1	0.09 - 0.09	0.09	0.09	NA	1	0.12 - 0.12	0.12	0.12	NA
U-238	9	0.08 - 0.89	0.25	0.37	0.28	14	0.12 - 0.72	0.18	0.30	0.219
Dust, Interior Surfaces		**(pCi/cm^2)**	**(pCi/cm^2)**	**(pCi/cm^2)**	**(pCi/cm^2)**		**(pCi/cm^2)**	**(pCi/cm^2)**	**(pCi/cm^2)**	**(pCi/cm^2)**
Am-241	0	NA	NA	NA	NA	1	0 - 0	0	0	NA
Np-237	0	NA	NA	NA	NA	1	0 - 0	0	0	NA
Pu-238	0	NA	NA	NA	NA	6	0 - 0	0	0	0
Pu-240	0	NA	NA	NA	NA	3	0 - 0	0	0	0
Tc-99	2	0.001 - 0.002	0.001	0.001	0.001	27	0.001 - 0.013	0.003	0.004	0.003
U-233/234	16	0 - 0.028	0	0.002	0.007	82	0 - 0.024	0	0.001	0.003
U-235/236	3	0 - 0.001	0	0	0	5	0 - 0.001	0	0	0
U-238	26	0 - 0.004	0	0	0.001	93	0 - 0.024	0	0	0.002

[a] In this HHRA, an analyte is considered to be detected in a sample if it's concentration is greater than, or equal to, the critical value (L_c) for that analyte in that sample.

[b] NA - Not applicable.

3. HUMAN EXPOSURE ASSESSMENT

Once available data were collected and collated into a data set, the process of identifying and quantifying potential exposures began. This was accomplished by following a phased approach that involves the tasks listed below:

- Characterizing the exposure setting of the study area (Solutient 2022),
- Identifying potentially complete human exposure pathways,
- Estimating the exposure point concentrations at potential receptor locations, and
- Quantifying plausible ROC exposures.

This section presents a brief description of the methods that were used to evaluate exposures from ROCs in the study area. Section 3.1 presents a conceptual model describing sources, release mechanisms, representative receptors, and exposure routes to be evaluated. Section 3.2 presents methods for determining media-specific exposure point concentrations for ROCs. Section 3.3 presents the methods and assumptions applied in quantifying exposures by assumed receptors. All exposures addressed in this document are based on the soil, dust, surface water, and sediment analytical results that are included in the HHRA data set.

3.1 CONCEPTUAL MODEL

Figure 10 presents the conceptual model depicting the exposure media and potential exposure pathways in that scenario. This model was developed with Community questionnaire responses during preparation of the HHRA Work Plan and it traces common routes that radioactive material may take in the local environment and identifies potential exposure mechanisms and routes that may result.

This type of graphic illustrates the potentially complete exposure pathways considered for quantitative evaluation in this HHRA. Each complete exposure pathway evaluated consists of:

- a source (e.g., soil);
- an exposure mechanism (e.g., direct contact, food from local gardens)
- an exposure route (e.g., inhalation, ingestion); and
- a potential receptor (e.g., resident or recreational user).
- For some exposure pathways to be complete, additional elements are required, such as a release mechanism (e.g., wind, erosion) and/or a transport mechanism (e.g., root uptake). If any required element is missing, the exposure pathway under consideration is incomplete and no exposure can occur.

An overview of the elements of the conceptual model depicted in Figure 10 are discussed in the following subsections. This HHRA report's conceptual model describes hypothetical receptor behaviors during theoretical current land use.

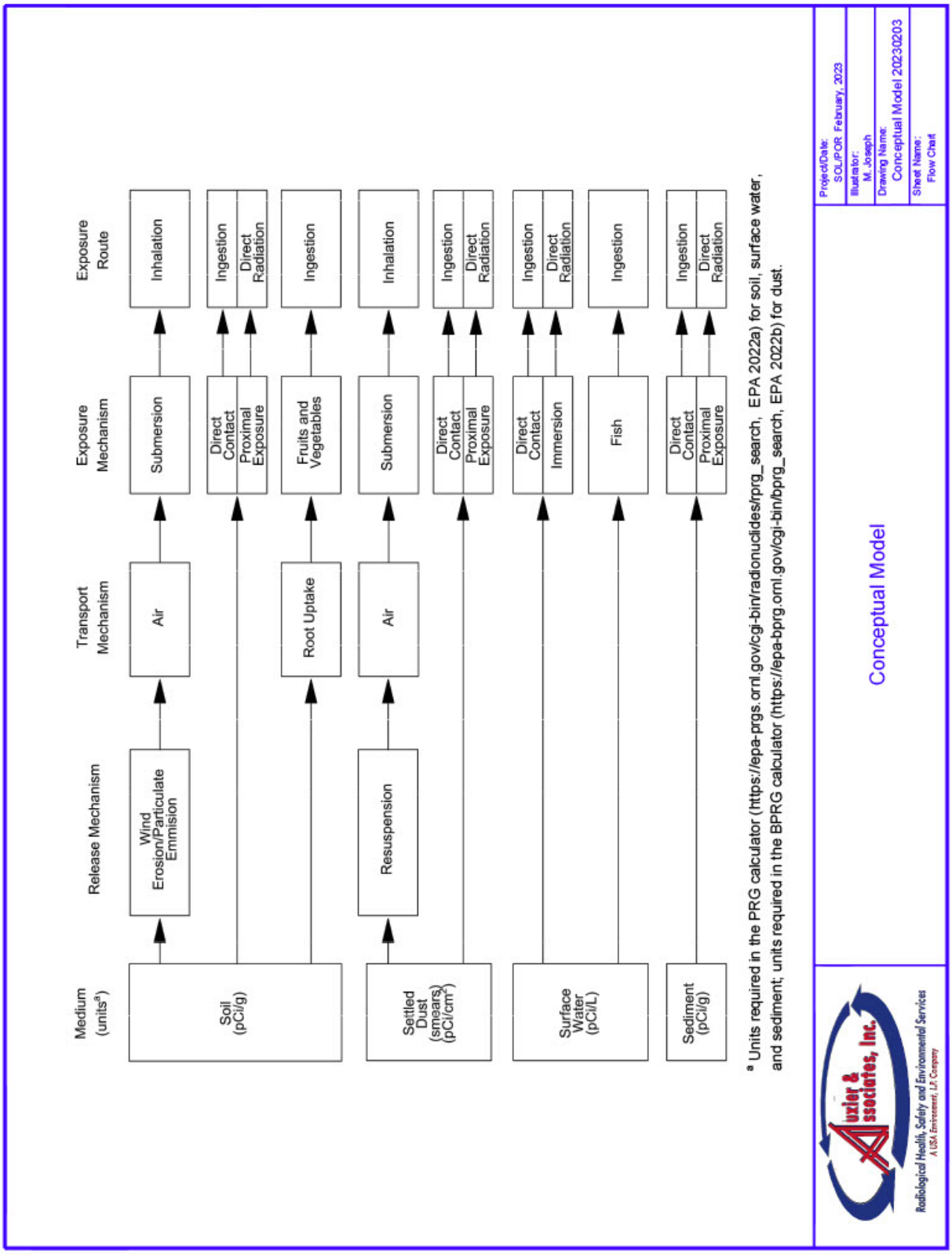

Figure 10 Conceptual Model

The bases for identifying complete exposure pathways from ROCs detected in the study area include the following assumptions:

- Currently, the land within the study area is partially vegetated, contains homes and other structures, and is used primarily for residential purposes.
- Surface water runoff within the study area is currently channeled to existing creeks and the Scioto River.

The text that follows provides the rationale for focusing the analysis on the specific receptors, exposure routes, and constituent sources in addressing contributions to exposure.

3.1.1 Sources

The media considered in this HHRA report are soil, settled dust, surface water, and sediment within the study area. These source media potentially contain the ROCs identified in Section 2.

3.1.2 Potential Release Mechanisms

Radionuclides may be released to the environment from source media in the study area by a number of processes. These processes are referred to as "release mechanisms" in this HHRA report. Release mechanisms in the study area were identified by discerning the potential interactions of the physical environment with the sources of radionuclides. Potential release mechanisms are discussed in the following subsections. Figure 10 identifies release mechanisms evaluated.

3.1.2.1 Resuspension of Soil

Loose surface soil particles containing ROCs can be released by mechanical agitation or picked up by winds passing over areas of exposed loose soil and become suspended for a time in air. Once released, particulates can become airborne and move with the wind. Figure 10 identifies soil release mechanisms that are evaluated in this HHRA.

3.1.2.2 Resuspension of Dust

Dust particles containing ROCs can be stirred by air currents passing over indoor surfaces where exposed loose dust lies. Once stirred, these particulates can become airborne and, with sufficient currents, can shift or travel with air currents. This potential release mechanism is not addressed in this HHRA, as assessment of this pathway is unattainable with given data and is not part of the scope of work. Exposures from outdoor dust are expected to dominate exposures from indoor dust.

3.1.2.3 Surface Water Overflow

Rivers and streams, as well as ditches, can overflow their banks during flooding events like rainstorms. This water may carry both dissolved and suspended materials along with it and some of these materials could deposit on soil outside the waterbody when waters subside. This possibility is addressed in this assessment via sampling soil in selected areas where surface runoff may have occurred, as described in the SAP (Solutient 2020a).

3.1.2.4 Soil Erosion by Surface Water

Soil particles can be picked up by surface water runoff during precipitation events and carried to surface water bodies such as creeks. Such particles may remain suspended in natural water or may be deposited as sediment. In addition, soluble materials in the soil might be dissolved and transported downstream by the flowing water. This possibility is addressed in this assessment via sampling sediments and water in selected creeks and ponds within the watershed, as well as the Scioto River.

3.1.2.5 Leaching from Soil to Groundwater

Water percolating through the soil can dissolve soluble materials within a soil matrix. These dissolved materials can then be carried by water through the soil and enter groundwater. The degree to which materials dissolve in water or remain adsorbed to a soil matrix has been measured during various studies over the past 50 years (IAEA 2014, ATSDR 2013a, and EPA 1996).

Many elements, including plutonium, have been determined to be less insoluble and therefore less mobile in water than many other elements. Others, like technetium, tend to be more mobile and are expected to follow groundwater migration pathways (AECL 1984, EPA 1978, EPA 1999a, Hoeffner 1985, NRC 1992, ORNL 1984). A systematic groundwater sampling effort was not included in the SAP (Solutient 2020a), but sampling of two groundwater wells was performed in response to a request by the Community. As this is an isolated sampling event, Community impacts from this potential release mechanism are not addressed further in this HHRA.

3.1.3 Potential Exposure Routes

An exposure route describes how a ROC is delivered to the receptor. Generally, radiological exposures are divided into two types: direct external exposures and internal exposures.

Direct external radiation exposures occur when a person is irradiated by an external source. They do not require physical contact and can occur when a person is near gamma-emitting radionuclides. Increasing the distance between a radiation source and the receptor reduces the intensity of the radiation field at the point of exposure. (The magnitude of exposure is inversely related to the distance of the receptor from the source.) Direct radiation exposures can also be reduced when shielding, such as soil or water, is placed between the receptor and the source of radioactivity. Sources of direct exposure may include gamma-emitting ROCs contained in soil, settled dust, surface water, and sediment, as well as in airborne particulates borne out of disturbed soil or dust.

Internal radiation exposures occur when ROCs are introduced directly into the human body through, for example, inhalation and inadvertent or intentional ingestion of soil, crops or water. Once inside the body, these ROCs could irradiate organs and tissues. Based on their low permeability through human skin, dermal absorption of these ROCs through the skin was not considered to be a complete exposure pathway.[10]

[10] The ROCs investigated in this study are metals. Dermal absorption of these metals through skin exposures has not been found to be an important source of internal exposure (EPA 1989).

Several examples of potentially complete, media-specific exposure routes evaluated in the HHRA are presented below:

- Soil: A receptor can be exposed to radioactive materials in soil via direct external radiation. In addition, a receptor may come into physical contact with soil or soil particulates in air and be internally exposed to ROCs via ingestion or inhalation, respectively. Also, a receptor can indirectly consume radioactive materials in soil via root uptake by fruits and vegetables.
- Sediment: A receptor may come into physical contact with sediment while participating in surface water activities and be internally exposed to ROCs via ingestion. As with other media, a receptor can be exposed via direct external radiation to radioactive materials in sediment. However, both the water and the sediment provide shielding between ROCs and an immersed receptor.
- Surface Water: A receptor may come into physical contact with surface water and be internally exposed to ROCs via ingestion. A receptor can be exposed via direct external radiation to radioactive materials while submerged in surface water. However, the water provides shielding between ROCs and an immersed receptor. In addition, fish living in surface water can be caught and consumed by a receptor, thereby exposing the receptor to ROCs in surface water via fish ingestion.
- Settled Dust on Surfaces: A receptor may come into physical contact with settled dust and be internally exposed to ROCs via ingestion or externally exposed due to proximity.

There may be more than one complete exposure pathway for a postulated receptor. An example of a receptor with the potential to be exposed via multiple pathways is a resident with a garden. Potential complete pathways to a gardener include:

- Inhalation: resuspension of soil,
- Direct radiation: proximity to soil, sediment, or settled dust; submersion in air or surface water during recreation,
- Ingestion: incidental or intentional ingestion of soil, sediment, or surface water; root uptake by fruits and vegetables; fish ingestion.

3.1.4 Potential Receptors

The study area is predominately a residential area. The area is primarily zoned R-1 (single-family dwelling district). This and other residential land uses (including preschool and other educational uses) are present within six miles of PORTS. Local creeks and the Scioto River are assumed to be used for recreational purposes, such as wading, swimming, and fishing.

From that description, the most representative receptor type for the HHRA is the resident. The residential receptors in the Community consist of both children and adults. A conservative approach assumes that the residential receptors in the Community maintain residency in childhood and adulthood. A “receptor” in this case is representative of a local population and should not be considered as a specific individual. As such, results are not representative of or applicable to any particular person but are considered representative of an exposed population.

3.2 EXPOSURE POINT CONCENTRATIONS

The exposure point concentration represents the concentration of a ROC in an exposure medium that may be contacted by a hypothetical receptor. Establishing an exposure point concentration depends on several factors, including:

- The location of a potential receptor (Section 3.1.4),
- The availability of validated and usable data for ROCs (Section 2),
- The population distribution of a particular data set such as Tc-99 in soil and
- Supporting information such as the data on radionuclides in the same radioactive decay series.[11]

For the evaluation of current land use and related study area conditions, exposure point concentrations were determined using available analytical data for each medium. The exposure point concentrations developed in this report are consistent with EPA's concept of Reasonable Maximum Exposure (RME) as presented in EPA guidance (EPA 1989). In that guidance, the EPA remarks that each exposure metric used in describing the RME should be chosen such that the resulting exposure estimate is consistent with the higher end of the array of plausible exposures expected to occur in the area of interest (EPA 1989, EPA 1991a). The method does not require that every exposure factor value used in exposure calculations be upper-bound estimates, but the final results should provide confidence that the RME is equal to or greater than actual exposures (EPA 2019, page 63).[12]

3.2.1 Influence of RME Guidance on Selection of Exposure Point Concentration

In the case of exposure concentrations, EPA recommends the use of the average concentration of a contaminant as the most representative concentration that would be contacted over time. Environmental samples are, by character, subject to variability which leads to uncertainties. While it is not possible to know the "true" average of a contaminant's concentration across a large study area, it is possible to estimate it. Any such estimate will, by its nature, be somewhat uncertain and EPA has stated in its 1992 *Supplemental Guidance to RAGS: Calculating the Concentration Term* (EPA 1992b) that, because of the uncertainty associated with estimating the true average concentration for a study area, the 95% Upper Confidence Limit of the arithmetic average (95% mean UCL concentration) should be used in RME calculations.

The 95% mean UCL concentration is basically a probability statement. It is the concentration where there is a 95% chance that the true mean is at or below the estimated mean. In other words, there is a 95% confidence that the actual distribution of the data set for that analyte in that medium has a mean that is less than or equal to the calculated UCL. All other things being equal, this RME approach generally produces an overestimate of the resulting exposure.

3.2.2 Selection of Exposure Point Concentration

Column 2 of Table 5 presents the 95% mean UCL concentration for each ROC in soil listed in Table 2, as estimated using the most recent version of EPA's *Statistical Software ProUCL 5.2*

[11] For more information on what a decay series is, see Section 4.

[12] *Guidelines for Human Exposure Assessment* (EPA 2019)

for Environmental Applications for Data Sets with and without Nondetect Observations (EPA 2022c). As can be seen in the data, ProUCL reports some 95% mean UCL values as negative concentrations. This reflects the high number of negative values reported by the laboratory.

The ProUCL Users Guide (EPA 2022c) encourages users to seek assistance from a professional statistician when impractical results, such as negative means, occur. Splitstone & Associates was retained to determine more appropriate values to represent exposure point concentrations within the study area. Splitstone employed the commercially available statistical software package Systat® to calculate basic statistical summaries of the radionuclide concentrations by sampled media. Splitstone's estimated exposure point concentrations are reproduced in Column 3 of Table 5.[13] Attachment C contains the report detailing the statistical analysis provided by Splitstone and Associates.

Typically the exposure point concentration can not be greater than the maximum concentration detected. If the ROC's 95%UCL in Column 3 of Table 5 is greater than the maximum detected value, the exposure point concentration is set to the maximum. In the cases where the ROC was not detected, the exposure point concentration in Column 4 of Table 5 was set to zero. Column 4 of Table 5 lists the concentration selected to represent the media-specific exposure point concentrations for each ROC.

3.3 QUANTIFICATION OF EXPOSURE

This section presents general rationale and assumptions that can be used to quantify the magnitude of exposures expected to result from all reasonable exposure pathways. As noted in Section 3.1.3, exposures include both internal exposures and direct external exposures. Internal exposures require the intake of ROCs. Pathway-specific intake calculations may vary due to differences in exposure methods and types of media. Specific equations used in this HHRA are part of the EPA's PRG and BPRG calculators (EPA 2022a and EPA 2022b, respectively), whose algorithms are incorporated by reference and are presented in Attachment D.

The HHRA includes numerical descriptions of the residential receptor during the periods of childhood and adulthood and the respective behaviors (such as inhalation rate, ingestion rate, and the time spent outdoors each day). The selection of parameter values introduces some uncertainty in calculations. These parameter values are selected to yield exposure estimates that are intended to produce risk estimates that are in the higher range of the distribution of risk but not greater than the highest conceivable risk (i.e., the RME). If the RME is determined to be acceptable, as defined in Section 3.2, then it is likely that all other lesser exposures within the study area will also be acceptable.

[13] A parallel evaluation was performed at Auxier & Associates. All negative concentration values in the data set were set to zero (0) creating a series of censured data sets. Additional ProUCL 5.2 runs were performed on this censured data. These results are not reported here, as this approach has questionable statistical value, but it did produce positive concentration results that were used to provide additional context and confidence in Splitstone's Systat results.

Table 5 Exposure Point Concentrations in the Study Area

Radionuclide	ProUCL's Recommended Concentration Using HHRA Data Set	Statistician's Selections Using Systat® & HHRA Data Set	Selected Exposure Point Concentration
Soil (pCi/g)			
Am-241	-0.00674	0.005811	0.005811
Np-237	-0.00943	0.000925	0.000925
Pu-238	-0.0133	0.001702	0.001702
Pu-239/240	0.0036	0.010701	0.010701
Tc-99	-0.0165	0.179273	0.179273
U-233/234	1.247	1.253277	1.253277
U-235/236	0.059	0.059291	0.059291
U-238	1.272	1.277565	1.277565
Sediment (pCi/g)			
Am-241	0.00454	0.0086	0.0086
Np-237	ND [a]	0.0023	--[b]
Pu-238	0.017[c]	0.0048	0.0048
Pu-239/240	0.00657	0.0097	0.0097
Tc-99	-0.105	0.04537	0.04537
U-233/234	1.116	1.134273	1.134273
U-235/236	0.0501	0.05103	0.05103
U-238	1.04	1.05639	1.05639
Surface Water (pCi/L)			
Am-241	ND	0.04337	--[b]
Np-237	ND	0.00451	--[b]
Pu-238	-0.00339	0.03488	0.03488
Pu-239/240	ND	0.03832	--[b]
Tc-99	-0.874	0.54298	0.54298
U-233/234	0.361	0.38381	0.38381
U-235/236	0.12[c]	0.03568	0.03568
U-238	0.238	0.26671	0.26671
Settled Dust (pCi/cm^2)			
Am-241	0.00014[c]	0.000040	0.000040
Np-237	0.0001[c]	0.000008	0.000008
Pu-238	-0.00005633	0.000026	0.000026
Pu-239/240	-0.00001632	0.000048	0.000048
Tc-99	-0.00393	0.001413	0.001413
U-233/234	0.00048797	0.000578	0.000578
U-235/236	-0.00004698	0.000027	0.000027
U-238	0.00045534	0.000557	0.000557

[a] ND – This radionuclide was not found in any CCSE sample of this medium.
[b] As this radionuclide was not detected in any sample, the exposure point concentration has been set to zero. This is consistent with the HHRA Work Plan (Auxier 2022) which states risks will be assessed from ROCs detected in the study area.
[c] ProUCL requires a minimum of three detected concentrations. For the specified medium, the value presented is the single highest detected concentration in the HHRA data set.

Quantitative estimates of exposure are based on: (i) radionuclide exposure point concentrations in media at the exposure points, as discussed in Section 3.2, and (ii) quantifiable receptor behaviors expressed as exposure parameters. Notable exposure parameters used are presented by medium in Section 3.3.2. Parameter values were extracted from EPA PRG calculators, including the BPRG calculator for dust, unless noted otherwise.

The impact of multiple ROCs within a decay series (discussed as daughters in Section 4) on the output from the EPA's PRG and BPRG calculators can lead to erroneous conclusions unless exposure point concentrations are selected considering the assumptions made within the calculators. Additional considerations in the exposure point concentration calculation process are discussed below.

3.3.1 Quantification Exposures from Multiple Pathways

The receptor is initially assumed to be exposed to all media and via all pathways included in the HHRA. Thus, multi-media and multi-route exposures are assumed to be additive. In other words, EPA's web-based calculators, specifically the PRG calculator and the BPRG calculator, assume the receptors may be exposed to more than one exposure pathway and provides both intermediate results for individual pathways and aggregate results. These EPA web-based calculators and their algorithms are incorporated by reference. Attachment D presents pertinent equations used in the calculators.

The EPA web-based PRG calculators require certain types of input including media concentrations. As each medium is discussed below, the medium for which an input concentration is required will be identified along with the required units.

3.3.2 Medium-Specific Assumptions and Exposure Parameters

Exposure parameters are dependent upon medium-specific assumptions and limitations within the PRG and BPRG calculators. As stated in the HHRA Work Plan (cite), these calculators are populated with EPA's recommended parameter values. For example, as 90% of people in the U.S. move at least once every 26 years, the EPA recommends the use of 26 years to represent the residential exposure duration in CERCLA-style risk evaluations. [14]

Exposures across this 26-year period are summed by medium to produce the calculated risks for a residential receptor. Where appropriate, these parameter values are age-adjusted to include a receptor's exposures as a child (6 years) and later as an adult (20 years). In the case of incidental soil ingestion, recommended soil intake rates for these ages vary over time, ranging from 100 to 200 milligrams per day (Section 3.3.2.1). The EPA recommends risk assessors use age-specific soil intake rates when calculating the quantity of soil ingested over the 26-year exposure period, $IFS_{res\text{-}adj}$ (EPA 2022a).

3.3.2.1 Exposure to Soil

The EPA PRG calculator was used to calculate exposure to soil from a variety of receptor-specific exposure pathways (i.e., incidental ingestion of soil, inhalation of resuspended

[14] CERCLA – EPA's 1980 Comprehensive Environmental Response, Compensation, and Liability Act.

particulates, direct radiation exposure, and via root uptake into produce). The calculator requires that the user select the receptor type, exposure media, the ROCs, and the representative concentrations prior to running. For example, when evaluating potential impacts across the study area the resident receptor was selected and the exposure point concentrations, in picoCuries per gram (pCi/g), of the identified ROCs were input. Some parameter values can be changed from default in the PRG calculator (EPA 2022a). While the default (temperate) climate zone was selected, the results were confirmed with two additional applications, once using Cleveland, Ohio (temperate) and once using Huntington, WV (temperate). These three applications produced similar results. Once required parameter values were input, the calculator then evaluated exposures from complete soil pathways.

As stated previously, risks of exposure to ROCs are related to the receptor's behavior. Behavior determines how much time receptors might spend in potentially impacted areas, how rapidly they breathe, how much local food they consume, etc. Aspects of these behaviors can be quantified for receptors like the resident, as shown in Table 6.

Table 6 Parameters Used to Estimate Potential Soil Exposure

Pathway (units)	Adult[a]	Child[a]
Resident Exposure Duration (years)	20	6
Resident Exposure Frequency (days/year)	350	350
Resident Exposure Time (inhalation) (hours/day)	24	24
Resident Exposure Time (direct exposure) - indoor (hours/day)	16.4	16.4
Resident Exposure Time (direct exposure) - outdoor (hours/day)	1.75	1.75
Inhalation Rate of Resuspended Particles (m^3/day)	20	10
Intake/Ingestion Rate (mg/day)	100	200
Resident Produce Ingestion Rate (g/day)	1,486	816.4
Resident Produce Exposure Frequency (day/yr)	92	92

[a] With the exception of produce, these are default value in the EPA PRG Calculator (https://epa-prgs.ornl.gov/cgi-bin/radionuclides/rprg_search) (EPA 2022a). Produce exposure frequency is one-fourth of a 365-day year.

The EPA has compiled a database of parameters describing human physiology and behaviors (EPA 2011). It has used this information to populate its calculators with default values intended to produce liberal exposure estimates. Unless noted, these default parameters will be used in this evaluation. One notable group of exceptions are the parameters describing ingestion of local produce. In the PRG calculator, the default value for this time is 350 days per year. For southern Ohio, this value does not represent a typical growing season. Rather than including an unrealistic parameter value of 350 days per year, a lesser value must be considered. One-fourth of a 365-day year, or 92 days per year, is more a reasonable estimate of the harvest period for a given crop and will be the time set for the resident receptor's exposure to produce grown in the study area. The soil input values for the resident in the PRG calculator represent this intake rate as the "produce exposure frequency". In the PRG calculator, the list of default produce consumed daily by a resident includes 6 fruits, 3 leafy vegetables, and 14 other vegetables, all of which are included in this HHRA.

3.3.2.2 Exposure to Dust on Surfaces

The EPA's BPRG calculator was used to calculate exposure to dust on surfaces (ingestion and direct radiation exposure). The user selected the resident receptor and the ROCs for exposure to dust then input exposure point concentrations. For all parameters except the fraction transferred surface to skin (FTSS), default parameters were used. The default values for the FTSS for hard surfaces is 0.4 for the adult and 0.64 for the child. For the adult, this means that 40% of the dust on a hard surface (i.e., wood, concrete, etc.) can be transferred to skin. The default values for the FTSS for soft surfaces (such as carpet, fabric, etc.) is 0.08 for the adult and 0.14 for the child. For the adult, this means that 8% of the dust on a soft surface can be transferred to the skin. In the HHRA, the value for all FTSS parameters were very conservatively set at one (1) for the adult and for the child, meaning 100% of the dust on surfaces can be transferred to skin.

The BPRG calculator includes a parameter of "hand to mouth" events. It represents the number of times per day a receptor (adult or child) is likely to insert fingers into the receptor's own mouth. For the child, the BPRG calculator includes 17 events per day and, for the adult, 3 events per day.

Table 7 contains a summary of the primary dust exposure parameter values for the resident.

Table 7 Parameters Used to Estimate Potential Dust Exposure

Pathway (units)	Adult[a]	Child[a]
Resident Exposure Duration (years)	20	6
Resident Exposure Frequency (days/year)	350	350
Resident Exposure Time (direct exposure) (hours/day)	24	24
Resident Exposure Time (ingestion) - hard surface (hours/day)	6	6
Resident Exposure Time (ingestion) - soft surface (hours/day)	10	10
Resident Frequency of Hand to Mouth (events/hour)	3.025	17.7
Fraction Transferred Surface to Skin (hard surfaces) (unitless)	1	1
Fraction Transferred Surface to Skin (soft surfaces) (unitless)	1	1
Fraction of Hand to Mouth (unitless)	1	1

[a] With the exception of the Fraction Transferred Surface to Skin (hard and soft surfaces) and the Fraction of Hand to Mouth, these are default value in the EPA BPRG Calculator (https://epa-bprg.ornl.gov/cgi-bin/bprg_search) (EPA 2022b).

For the medium under discussion, settled dust, the PRG calculator requires concentrations to be entered in units of pCi per square centimeter (pCi/cm^2).

3.3.2.3 Exposure to Surface Water, Swimming

The EPA PRG calculator (EPA 2022a) was used to calculate exposure to radionuclides in surface water while swimming (ingestion and direct radiation exposure). The user selected the recreational receptor, surface water medium, and the ROCs. Medium-specific exposure point concentrations, in picoCuries per liter (pCi/L), were entered into the calculator.

Given that the PRG calculator contains default parameter values only for the rates of incidental ingestion of water while swimming (one for the child and one for the adult), an additional source of information for other required parameter values was needed. Swimming in surface water is primarily recreational. The EPA's *Exposure Factors Handbook* (EPA 2011, the *Handbook*) contains recommended parameter values for swimming that are based on published studies of time spent swimming. The *Handbook* does not present recommended parameter values for swimming in natural water bodies vs swimming pools separately. To be conservative, all time reported as "swimming" is designated herein as swimming in natural water bodies within the study area, specifically creeks and the Scioto River.

There are three parameters that necessitate a detailed calculation for swimming because there is no direct correlation between the required parameters (and units) in the PRG calculator and the parameters provided in the *Handbook*. To aid in organizing the information, Table 8 lists the parameters and their respective units of measure required by the PRG calculator for the recreational swimmer.

Table 8 Default Surface Water Units in the PRG Calculator

Parameter Name	Required Units
EV	events/day
Exposure Frequency	days/year
Exposure Time	hours/event

An "event" is one use of a water body for the purpose of swimming.

The *Handbook* shows tabulated information for swimming events in units of minutes per month. Although information concerning swimming events in natural water bodies is unavailable, the *Handbook* does contain information about swimming in pools. That information was used herein to assess exposures from swimming in natural water bodies.

The information provided in the *Handbook* must be converted into the units of measure required by the PRG calculator. The conversions used in this evaluation for each of the three parameters listed in Table 8 are addressed separately below.

EV – The *Handbook* offers no direct numerical guidance on this parameter. Consequently, an assumption must be made. To simplify the calculations and stay within the realm of reason it is assumed that a receptor only swims once on a given day and does not swim intermittently throughout the day; hence one event per day.

Exposure Frequency – Section 16.3.2.6 of the *Handbook* presents the timeframe for outdoor activities as April through October. As the water temperatures in local waters are expected to be uncomfortably cool during April, May, September, and October, swimming was assumed to be a viable exposure pathway for the three remaining months per year. As the *Handbook* provides no direct recommendation on exposure frequency, a reasonable regularity for swimming in natural water bodies during the summer months is assumed to be four times per month, or 12 times per year, as shown below.

$$Exposure\ frequency\ = \frac{4\ events}{month} x \frac{3\ months}{year} x \left(\frac{1\ day}{1\ event}\right) = 12 \frac{days}{year}$$

Exposure Time, Adult – The swimming duration provided in Table 16-1 of the *Handbook* is age-specific. Exposure times associated with the adult age range are 6 years old to adult. The *Handbook* provides three entries in that range, as shown in Table 9. The time-weighted average of the swimming durations over a 15-year period published in the *Handbook* produced a monthly duration of 145 minutes.

Table 9 Swimming Durations for the Adult

Age range	Swimming Duration [a] (minutes/month)
6 to <11 years	151
11 to <16 years	139
16 to <21 years	145
Time-weighted average for adult	145

[a] Table 16-1 of the EPA's *Exposure Factors Handbook* (EPA 2011).

Assuming four events per month, the exposure time for "time in the water" is 36.25 minutes per event, as shown below.

$$(Exposure\ Time)_{adult} = \left(\frac{145\ minutes}{1\ month}\right)_{adult} x \left(\frac{1\ month}{4\ events}\right) = 36.25\ \frac{minutes}{event}$$

The PRG calculator requires exposure time for swimming to be entered as hours per event. Converting the previous result and rounding to the nearest tenth of an hour, this becomes:

$$(Exposure\ Time)_{adult} = \left(\frac{36.25\ minutes}{event}\right)_{adult} x \left(\frac{1\ hour}{60\ minutes}\right) = 0.6\ \frac{hours}{event}$$

Exposure Time, Child – There are, likewise, four swimming durations provided for the child in Table 16-1 of the *Handbook*. Exposure times associated with the child age range are birth to <6 years old, as shown in Table 10. As with the adult, the time-weighted average of the swimming durations over a 6-year period published in the *Handbook*, produces a monthly exposure duration of approximately 121.3 minutes.

Table 10 Swimming Durations for the Child

Age range	Swimming Duration[a] (minutes/month)
Birth to <1 year	96
1 to <2 years	105
2 to <3 years	116
3 to <6 years	137
Time-weighted average	113.5

[a] Table 16-1 of the EPA's *Exposure Factors Handbook* (EPA 2011).

Given that there are four events per month, the child exposure time for swimming was established at 0.5 hours per event, as shown below.

$$(Exposure\ Time)_{child} = \left(\frac{113.5\ min}{1\ month}\right)_{child} x \left(\frac{1\ month}{4\ events}\right) x \left(\frac{1\ hour}{60\ min}\right) = 0.5\ \frac{hours}{event}$$

Table 11 contains a summary of the primary parameters describing recreational use of surface water, expressed in the PRG calculator.

Table 11 Parameters Used to Estimate Exposures to Hypothetical Swimmer

Pathway (units)	Adult	Child
Recreational Exposure Duration (years)[a]	20	6
Recreational Exposure Frequency (days/year)[b]	12	12
Recreational Exposure Time (hours/event)[b]	0.6	0.5
Recreational Exposure Events per Day (events/day) [b]	1	1
Recreational Incidental Water Intake Rate (liters/hour) [a]	0.11	0.12
Recreational Incidental Sediment Intake Rate (mg/day) [c]	100	200

[a] These are default values in the EPA PRG Calculator (https://epa-prgs.ornl.gov/cgi-bin/radionuclides/rprg_search) (EPA 2022a).

[b] Section 3.3.2.3.

[c] This is the default value for soil ingestion in the EPA PRG Calculator (https://epa-prgs.ornl.gov/cgi-bin/radionuclides/rprg_search) (EPA 2022a), and is very conservatively applied to sediment in this assessment.

3.3.2.4 Exposure to Sediment

Exposure to sediment (ingestion and direct radiation exposure) were estimated using the EPA PRG calculator and the ROC exposure point concentrations in sediment. Given that the receptor would be exposed to both surface water and sediment simultaneously, it is reasonable to perform the assessment for both media simultaneously.

Table 11 contains a summary of the primary sediment parameter values used to assess exposures for hypothetical receptors using local water bodies for recreational activities. It should be noted that the PRG calculator does not offer ingestion rates for sediment, but it does offer ingestion rates for soil. Lacking study area-specific ingestion rates for sediment during recreational use of

local water bodies, the default rates for residential soil ingestion were used to represent sediment ingestion (Table 6). Considering the very limited access for ingesting sediment in comparison with ingesting soil, this approach likely overestimates the amount of sediment incidentally ingested during recreational use of local water bodies.

3.3.2.5 Exposure to Surface Water, Fish Ingestion

The SAP (Solutient 2020a) does not include sampling fish, so exposure point concentrations from fish flesh are not possible. Exposures from consumption of fish were estimated using the EPA PRG calculator (EPA 2022a) and its default parameters. The hypothetical farmer option allows the user to input water concentrations to estimate exposures from eating fish. Surface water sampling is included in the SAP (Solutient 2020a) and the fish pathway in the PRG calculator (farmer receptor) was used to evaluate exposure to surface water via fish ingestion.

To be consistent with other pathway evaluations, the exposure duration for fishing was set at 20 years.

The EPA's *Handbook* recommends using the months of April through October for outdoor activities like fishing and, for the purpose of this evaluation it was assumed that a receptor may consume fish daily during those months. Summing the number of days in those months provides an exposure frequency of 214 days, as shown in Table 12. As no local anglers reported that they fished and ate their catch every day of the season, a 214-day exposure frequency very likely exaggerates exposures from consumption of fish.

Table 12 Exposure Frequency for Fish Consumption

Month	Number of Days	Month	Number of Days
April	30	August	31
May	31	September	30
June	30	October	31
July	31	Total:	214 days

The mass of fish ingested per day is another parameter to be considered. Table 10-5 of the *Handbook* provides a summary of relevant studies on freshwater recreational fish intake. The nearest state to Ohio that was included in the study is Indiana. The recommended 95th percentile ingestion rate for Indiana is 61 grams/day. No age distinction is provided, so 61 grams/day is set as the freshwater fish ingestion rate for both adults and children. Parameters used in estimating exposure to surface water via fish ingestion are provided in Table 13.

Table 13 Parameters Used to Estimate Potential Exposure via Fish Ingestion

Pathway	Adult	Child
Fishing Exposure Duration (years)[a]	20	6
Fishing Exposure Frequency (days/year)[b]	214	214
Fish Ingestion Rate (grams/day)[c]	61	61
Contaminated Fraction of Fish (unitless)[d]	1	1

[a] These are consistent with the exposure duration for other pathways assessed in the HHRA.

[b] Assumes daily fish consumption during months of outdoor activities, April through October (EPA 2011).

[c] Recommended 95th percentile freshwater recreational fish intake rate for adults in Indiana, the closest state offered in Table 10-5 of the EPA *Exposure Factors Handbook* (EPA 2011). Adult rate applied to child likely to greatly overestimate fish consumption by children.

[d] This is the default value in the EPA PRG Calculator (https://epa-prgs.ornl.gov/cgi-bin/radionuclides/rprg_search) (EPA 2022a).

4. TOXICITY ASSESSMENT

A toxicity assessment is an integral part of a risk assessment. It provides a description of the relationship between the exposure received and the potential to experience an adverse health effect.

In the EPA system of risk assessment, the toxicity assessment yields a quantitative estimate of the inherent toxicity of radionuclides for use in risk characterization. This estimate is embodied in a radionuclide-specific numerical value referred to as an EPA "slope factor" in this assessment.

"The chemical properties of the radionuclide (or the compound in which it may be incorporated) determine its behavior within the body, including absorption, elimination route, elimination rate and also transfer to and retention at deposition sites and subsequent redistribution." (WHO 2001)

Chemical properties establish the absorption characteristics and destination(s) of elements/compounds, as well as their elimination from the body. Once in the body, elimination occurs at a rate called the biological half-time. Whether the atoms have been deposited, absorbed, ingested, or inhaled, when one biological half-time has passed, half of the atoms have been eliminated from the body. After seven biological half-times, essentially none of the original material remains in the body (CDC 2015).

To provide context to this approach, this Section provides brief overviews of the physical and toxicological properties of each ROC assessed in this HHRA. It then presents a compendium of the EPA slope factors used to convert radionuclide intakes and exposures to risks in the CERCLA assessment system.

4.1 RADIONUCLIDES AND RADIATION

Radionuclides (also called isotopes) are radioactive atoms of a single type, often identified by their element name and atomic mass (i.e. uranium-238). Radioactive atoms are unstable atoms that spontaneously transform into other another type of atom in a variety of processes known collectively as "radioactive decay". Radioactive atoms decay at radionuclide-specific rates, called half-lives. A radionuclide's half-life is the length of time required for half of the atoms in the material to decay into atoms of a different element. A short half-life (days, minutes, seconds, etc.) means a high activity (rapid decay). When seven half-lives have passed, the original radionuclide is essentially gone, with less than one percent remaining (CDC 2015).

As radionuclides decay, they often emit radiation. This radiation includes charged particles (electrons, alpha particles, beta particles and protons), uncharged particles (neutrons), electromagnetic radiation emissions (gamma and x-rays), or a combination thereof during their transformation to a more stable state.

Alpha particles are emitted at a consistent radionuclide-specific energy level. Of the emitted particles, the alpha particle is of substantial size and carries a +2 electrical charge. Alpha particles can react with and/or ionize other molecules. Due to their large size, they have little penetrating power, lacking even the capacity to pass through a sheet of paper. While unable to penetrate the skin's surface, alpha particles are of concern for internal exposure via inhalation or

ingestion of the alpha-emitting radionuclide. Also due to their large size and charge, alpha particles deposit their energies in dense concentrations. This characteristic is called high linear energy transfer (LET) and thus results in short travel paths with highly localized ionizations. High LET increases the probability of cell damage. For example, the alpha-emitting radionuclide polonium-210 is common in tobacco products and may contribute to cancer incidence in smokers. In addition, high LET may also be the reason for increased cancer incidence caused by inhalation of radon gas, a natural radionuclide that emits alpha particles.

Beta emissions generally refer to negatively charged beta particles. Beta particles originate in the nucleus of the atom and their energy and mass are essentially the same as electrons. Comparatively, alpha particles are roughly 8,000 times the size of beta particles. Beta radiation, like alpha radiation, is directly ionizing but differ significantly in track length. Beta particles have low LET because they deposit their energy over a much longer track length, thus giving rise to fewer ionizations over the same distance traveled (i.e., more distance between ionization events). Beta particles deposit most of their energy in the medium through which they pass. Beta-emitting radionuclides can penetrate and deposit energy in the skin from outside the body, but pathways of greater concern are inhalation and ingestion.

Gamma emissions (or gamma rays) are produced in the nucleus of an atom and consist of energy. While gamma rays and x-rays behave similarly, their points of origin differ, as x-rays are produced through changes in the orbiting electron structure, rather than the nucleus. Gamma rays are highly penetrating in human tissues and able to reach every internal body organ. As such, gamma rays can produce both internal and external effects. Neither ingestion nor inhalation is required for gamma rays to penetrate sensitive organs because, without proper shielding, gamma radiation can penetrate the body from the outside. Shielding types include appropriate thicknesses and placement of lead, concrete, or steel. While characterized as low-LET radiation, like beta particles, gamma rays often escape the medium due to their higher energies.

Emissions from radioactive decay can interact with surrounding matter by either colliding directly with atoms or by ionizing nearby atoms as they pass. [15] In most cases, such interactions with living cells produce no noticeable macro affect but, given ample energies deposited within in a critical volume of a cell (such as an industrial or medical radiography exposure), such reactions within a cell can disrupt the overall health of the cell. In addition, free radicals can interact with deoxyribonucleic acid (DNA), potentially triggering cell death, inducing cancer, or causing genetic damage.

4.2 HEALTH EFFECTS FROM RADIATION

Radiation exposures are often measured in units of dose, which express the quantity of energy absorbed by an object or a person. The amount of energy absorbed without regard to the sensitivity of the target material is called absorbed dose. The units used to describe quantities of

[15] Ionization is the process through which a neutral atom or molecule gains or loses at least one electron, resulting in a charge (negative or positive), often concurrently with other chemical changes. The resulting charged atom/ molecule is known as an ion. Some charged ions (also known as free radicals) are exceedingly reactive and readily combining with other elements or compounds.

absorbed dose are either “gray” (Gy, international system) or “rad” (rad, U.S. unit). A second type of dose, called the effective dose takes the absorbed dose and adjusts it for to account for the radiation type and radiosensitivity of living tissue. The resulting effective dose, expressed as Sieverts (Sv, international system) or rem, (rem, U.S. unit) is an indicator of potential long-term health effects (i.e., cancer and hereditary effects) from an exposure.

Radiological health effects can be divided into outcomes related to dose (stochastic effects) and those not related to dose (nonstochastic effects). When the probability of an effect increases with dose, the effect is stochastic. Any dose, without a threshold, has a probability of producing a stochastic effect. The risk of development of cancer from exposure to radiation is a stochastic effect. Conversely, nonstochastic effects depend on dose for their incidence and severity, but there is a threshold dose below which there is no effect. Examples of nonstochastic effects include acute radiation syndrome and cataract formation, which occur only at high levels of exposures.

Irradiated cells can respond in one of four ways. The cell may exhibit no effect; it may be able to recover via self-repair and function normally; it may die; or it may survive but function abnormally. Division and reproduction of an abnormally functioning cell could generate a tumor or mutation in the tissue. It is during division that cells are the most likely to experience damage or death from ionizing radiation. Therefore, rapidly dividing cells are most sensitive to radiation. For example, blood cells in bone marrow and cells that line the intestines and stomach are extremely sensitive to radiation. Damage to individual cells can produce organ damage. Such results have been reported from acute doses of 10 to 500 rads (0.1 to 5.0 gray, in SI units). Acute doses exceeding 70 rads (0.7 gray) are required for acute radiation sickness (CDC 2018a). Such doses are typically attained only from a nuclear incident or explosion.

Radiation-damaged reproductive cells can produce genetic damage in the offspring of the exposed individual. Given the inherent rapid cell division, a developing fetus is extremely sensitive to radiation. Upon exposure, the cells that are differentiating are of particular importance when considering the type of aberration that may occur. Possibilities include impaired growth, impaired brain function, and disfigurements (CDC 2020). The unborn child(ren)’s dose is in direct relation to the pregnant mother’s dose, but is not necessarily equal (CDC 2020).

Atomic bomb survivors from Hiroshima and Nagasaki, Japan, form the most extensively studied human group that is known to have significant exposure to radiation. Gathered data suggest rate increases for development of leukemia and other cancers. The acute exposures experienced by this group, however, cannot be assumed to predict impacts on cancer incidence from chronic low-level exposures. The potential for cancer due to natural background radiation and impacts from industrially contaminated areas is uncertain. Additional information regarding radionuclides of concern in this assessment are provided in the following subsections. More information on radiation, radioactive materials, and radiation protection can be found at https://hps.org/publicinformation/.

The EPA classifies all radionuclides as Group A carcinogens. The bases for this classification lie in both their ionizing radiation emissions and the substantial weight of evidence gleaned from human epidemiological studies of cancers produced by high doses of radiation. A summary of

the properties and health effects associated with ROCs evaluated in this HHRA is presented in the following subsections.

4.3 RADIONUCLIDES OF CONCERN

4.3.1 Americium-241

Americium (CAS 014596-10-2) is a radioactive element not found in nature, but measurable quantities have been introduced into the environment through nuclear weapons testing. It is a silvery metal with two important isotopes, Am-241 and Am-243. The isotope of interest herein, Am-241 with a half-life of 432 years, is commonly used in smoke detectors. Per the EPA (2022d), radiation in "smoke detectors poses no radiation health risk when they are properly handled." While Am-241 does emit low-energy gamma rays, its radioactive decay produces Np-237 (produced through alpha-particle emission).

Given americium's global distribution through nuclear weapons testing, humans can be exposed to it through inhalation and ingestion. Individuals who handle americium in smoke detectors or at nuclear facilities may be exposed to higher levels than those who do not handle the material. (ATSDR 2012)

Some forms of americium are soluble and, if inhaled, can remain in the lungs for months or years. Whether by inhalation or ingestion, americium can enter the bloodstream over a period of a few days. In animal studies, it was found that equal percentages (45%) of the americium in the blood finds as its target organs (points of deposition) the bone and the liver. Biological half-time for removal from the bones is 50 years and for the liver, 20 years. (ICRP 1988a)

Internal and external cancer slope factors are presented in Section 4.3.7. A cancer slope factor from dermal exposure was not calculated, as dermal exposure to radionuclides is not considered significant and is, therefore, not evaluated in this HHRA. Non-cancer systemic toxicity from Am-241 exposure is not quantified herein because oral, dermal, and inhalation RfDs are unavailable.

4.3.2 Neptunium-237

Neptunium (CAS 013994-20-2) is a hard, yet ductile, silvery radioactive metal that is primarily introduced as a byproduct of nuclear reactions, but has been found in trace amounts in nature (Stoll 2017), specifically in association with uranium ores (ANL 2007). Neptunium is quite reactive, often combining with other elements. As the direct daughter of Am-241 discussed in Section 4.3.1, Np-237 is found in smoke detectors. With a half-life of two million years, Np-237 decays by alpha emission to protactinium-233.

Sources of neptunium include spent nuclear fuel, radioactive wastes commonly associated with reactor operations and the (re)processing of spent nuclear fuel (ANL 2007) and it is widely distributed from nuclear weapons testing. As an alpha emitter, its potential for impacting health is primarily from internal exposure via inhalation and ingestion, more the latter than the former. This radionuclide also emits gamma radiation and can produce external exposures (ANL 2007). The major health concern, however, stems from internal deposits in the liver and on bone surfaces (ANL 2007).

As previously stated, neptunium can enter the body through inhalation and ingestion. While data from human studies were not found in literature, some animal studies have been performed. Using a soluble compound of neptunium nitrate, rats were found to absorb between 1% and 3% of the material's mass (ICRP 1988a). However, when rats were exposed to lower masses of the compound, absorption fell to 0.1%, which was accepted as the most appropriate estimate of absorption of neptunium via the gastrointestinal tract (ICRP 1988a). Over the body, it is accepted by the ICRP (1988) that of the neptunium that leaves the blood, 75% goes to bone and 15% goes to the liver. As with americium, the biological half-time for removal of neptunium from the bone is 50 years and for the liver, 20 years.

Internal and external cancer slope factors are presented in Section 4.3.7. A cancer slope factor from dermal exposure was not calculated, as dermal exposure to radionuclides is not considered significant and is, therefore, not evaluated in this HHRA. Non-cancer systemic toxicity from Np-237 exposure is not quantified herein because oral, dermal, and inhalation RfDs are unavailable.

4.3.3 Plutonium-238, 239, and 240

Plutonium (CAS 013981-16-3, 015117-48-3, and 014119-33-6) is a silvery-gray radioactive metal that, when exposed to air, changes to a yellowish color (EPA 2022e). By far, its presence is due to human production via nuclear weapons, but plutonium has been found in trace amounts in nature (EPA 2022e). Uses of plutonium include providing power to satellites and providing heat to sensitive electrical components in satellites (EPA 2022e). Plutonium-238 decays to U-234; Pu-239 decays to U-235, and Pu-240 decays to U-236, all of which are radioactive. Half-lives of Pu-238, Pu-239, and Pu-240 are approximately 88 years, 24,000 years, 6,600 years, respectively.

As with previously discussed radionuclides, plutonium can be taken into the body through inhalation or ingestion due to its pervasive presence and uptake from media into foodstuffs. Ingested plutonium poses no serious threat to human health because the stomach does not absorb plutonium easily, thus it is excreted (CDC 2018b and ICRP 1972). As an alpha-emitter, internal exposure via inhalation is of primary concern for human health. In addition to lung exposure, plutonium can travel through the blood and kidneys, ultimately finding as its primary target organs which are the bones and liver (CDC 2018b and ICRP 1988a). Soluble forms tend to enter the bloodstream while insoluble forms remain in the lungs. Like americium, 45% of the plutonium that enters the blood is deposited in the bones and 45% in the liver. As with americium and neptunium, the biological half-time for removal of plutonium from the bone is 50 years and for the liver, 20 years (ICRP 1988a).

Internal and external cancer slope factors are presented in Section 4.3.7. A dermal cancer slope factor was not calculated because this route of exposure is not considered significant for radionuclides and is not evaluated in the HHRA. Oral, dermal, and inhalation RfDs are not available for plutonium; therefore, systemic toxicity is not quantified in the HHRA.

4.3.4 Technetium-99

Technetium (CAS 014133-76-7) is a platinum-colored radioactive metal exhibiting anti-corrosive and, at very low temperatures, superconducting properties (EPA undated). At room temperature, it is used as a coating to protect carbon steels from corroding (EPA undated).

Technetium-99 is a by-product of nuclear fission and rarely found in nature. The meta-stable form of technetium (Tc-99m) is produced and harvested from molybdenum-99 by the radiopharmaceutical industry. The half-life of Tc-99 is 213,000 years.

Per the EPA, "Organic matter in soils and sediments plays a significant role in controlling the mobility of technetium-99. In soils rich in organic matter, technetium-99 is retained and does not have high mobility. Under aerobic conditions, technetium compounds in soils are readily transferred to plants." (EPA undated) This radionuclide is quite mobile in the environment, particularly when oxygen is present, and can travel downward with percolating water due to its aversion to binding with soil particles (ANL 2007).

Technetium-99 emits low-energy beta particles and its absorption within the body following an intake varies by its compound (chemical form). Approximately 80% of technetium that enters the gastrointestinal tract is readily absorbed. Of the technetium leaving the bloodstream, roughly 4% finds its destination in the thyroid, with 10% depositing in the stomach and 3% in the liver. The biological half-time of technetium in the thyroid is 0.5 days. In other organs and tissues, the highest biological half-time found in literature is 22 days (ICRP 1980).

Internal and external cancer slope factors are presented in Section 4.3.7. A dermal cancer slope factor was not calculated because this route of exposure is not evaluated in the HHRA. Oral, dermal, and inhalation RfDs are not available for technetium; therefore, systemic toxicity due to exposure to technetium-99 is not quantified in the HHRA.

4.3.5 Uranium and Its Isotopes

Uranium is a mildly radioactive metallic element that occurs widely in the earth's crust. It is found in all soils (IAEA 2023), most rocks, and, in lesser concentrations, in water, vegetation, and animals - including humans. In its metallic form, uranium is a hard, silvery white amphoteric radioactive metal. Unlike other contaminants of concern in this study, uranium salts and oxides occur naturally in measurable quantities and it is ubiquitous in soil.

For most common forms of uranium found in an oxygenated environment, uranium is poorly absorbed via inhalation, ingestion or dermal absorption. Human exposure to uranium in non-occupational environments occurs primarily through ingestion. Since it is natural and ubiquitous, uranium is found in trace amounts in many plants, particularly cereals (NCBI 1988). However, root crops contribute the highest amounts of uranium in human diets (ATSDR 2015).

The majority of inhaled uranium is retained in the lungs where it is slowly removed by physical processes like mucociliary clearance, coughing, and migration to the lymphatic system. Most of the uranium eventually passed through the gut where it is excreted in the feces. Inhalation of uranium can be a concern in occupational settings where more soluble forms can be used in manufacturing (ICRP 1988b).

After being taken into the body, absorption is dependent on the chemical form of the uranium compound and the route of exposure, with soluble compounds being more readily absorbed through the gut than insoluble compounds. For example, the retention time of uranium particulates in the lungs can vary widely, depending on the chemical form of uranium in the inhaled compound. Of the portion that does reach the bloodstream, approximately 67% of uranium in the blood leaves the body via excretion through the kidneys in the first 24 hours of exposure (ATSDR 2013a). Bones, liver, and kidney become the primary destinations for the

remaining material. Over 90% of the uranium remaining in systemic tissues at one day after exposure is excreted with a biological half-time ranging from two to six days and the remainder is excreted with half-lives ranging from 30 to 340 days (Mettler 2008). Typical adults maintain an equilibrium of uranium in the body (meaning intake and excretion are roughly equal), approximately 90 micrograms (Kathren 2008 and ATSDR 2013a).

Uranium is a heavy metal that exhibits toxic chemical effects in sufficiently high doses and it is classified as a Group A carcinogen by the EPA (1991b). This uranium toxicity profile continues in two parts that separately present the chemical and radiological health effects from uranium exposures.

4.3.5.1 Chemical Toxicity of Uranium (metal and soluble salts)

Studies of humans exposed to an average of 100-600 micrograms per liter (µg/L) of uranium (CAS 007440 61 1) in drinking water for many years suggest uranium may cause minor damage to kidney tissue, including a mild decrease in the kidney's ability to hold onto proteins, sugar, and other compounds. However, this damage is reversible after the exposure to uranium stops. Studies performed after long-term consumption of drinking water containing high levels of uranium studies found no specific symptoms.

Studies of workers exposed to uranium as part of their jobs "…have not shown any evidence of serious kidney disease or other health effects…" from their uranium exposures (VDH 2018). For measurable effects, kidney concentrations should exceed 3 micrograms (µg) of uranium per gram of kidney tissue. Likewise, for life endangerment, a threshold of 50 micrograms of uranium per gram of kidney tissue was selected. Both of these thresholds are based primarily on human exposure studies (Kathren 2008).

Under the system used by EPA to evaluate health effects, a contaminant can be considered to produce adverse or toxic effects if it reaches particular end points in the human body at or above a minimum (threshold) dose and after an adequate duration to yield such an effect. This approach can be used to derive allowable limits for various exposure scenarios. For example, EPA's Maximum Concentration Limit for uranium in drinking water is 30 micrograms per liter (approximately 20 pCi/L uranium in water).

An EPA weight-of-evidence classification for uranium metal was not located in the available literature, but EPA has published oral and inhalation reference values (i.e., RfDs and RfCs) for uranium. Table 14 reproduces the latest EPA reference doses for both inhalation and ingestion of uranium. These toxicity values can be used to estimate the potential for systemic toxicity or noncarcinogenic risk.

Table 14 Uranium Metal Noncancer Toxicity Values from ATSDR

Metal	Chronic Oral Reference Dose (RfD) (mg/kg-day)	Chronic Inhalation Reference Concentration (RfC) (mg/m^3)
Uranium	2.00E-04	4.00E-5

Source: ATSDR 2013b https://www.atsdr.cdc.gov/toxguides/toxguide-150.pdf

Note: As uranium is a metal and dermal exposure to metals is not a significant exposure pathway, EPA has not recommended a uranium dermal absorption value that may be used to calculate dermal exposure. Therefore, systemic toxicity due to exposure to uranium is not quantified in the HHRA.

4.3.5.2 Radiotoxicity of Isotopic Uranium: U-234, U-235, U-236, and U-238

While this HHRA assessed risks from both ingestion and inhalation, it should be noted that inhalation of insoluble uranium compounds is the only circumstance in which uranium's radiogenic health effects are commonly thought to equal or exceed its chemical effects (Kathren 2008). In its natural state, uranium consists of three isotopes: U-234 (CAS 013966-29-5), U-235 (CAS 15117-96-1), and U-238 (CAS 24678-82-8). Natural uranium contains the uranium isotopes U-238 (which averages 99.27 percent of total uranium mass), U-235 (0.72 percent), and U-234 (0.0055 percent) (ANL 2007). These isotopes are weakly radioactive, have very long half-lives, ranging from 250,000 years to 4.5 billion years, and exhibit a relatively slow rate of decay[16]. Uranium-236 is not naturally occurring and is formed from thermonuclear weapons and plutonium-240 decay.

Uranium primarily emits alpha particles as it decays, but does also emit gamma rays. Since alpha particles are unable to penetrate skin and travel exceptionally short distances, uranium represents a significant carcinogenic hazard only when taken into the body. Once inside, alpha particle energy can be absorbed by relatively small volumes of adjacent living tissue.

Uranium miners provide an uncontrolled study group for potential effects of uranium. While uranium miners have death rates from lung cancer that are considered higher than expected, the impact is attributed to radiological impacts of radon gas and its decay products. Such studies have not been shown to assess competing carcinogenic impacts of tobacco smoking or inhalation of diesel engine exhaust in the mine. Studies of uranium mill workers, however, show "…no significant increase in overall deaths attributable to exposure to uranium…" (ATSDR 2013a).

Internal and external cancer slope factors published by the EPA are presented in Section 4.3.7. A dermal cancer slope factor was not calculated because this route of exposure is not considered significant for radionuclides and is not evaluated in the HHRA.

[16] Uranium that has remained undisturbed for 30 days is accompanied by radionuclide daughter products produced by the decay of U-238 and U-235 (Section 4.3.6). Other uranium decay products found in older uranium deposits like uranium ore (thorium-230, radium-226, protactinium-231 and their daughters) were removed from PORTS uranium feed stock before its arrival at the plant and therefore are not included in this assessment.

4.3.6 Health Effects from Short-lived Decay Products

Care must be taken to include all pertinent radionuclides when using the EPA PRG and BPRG risk calculators. The development of a toxicity assessment for this report began with the development of the ROC's listed in the SAP (Solutient 2020a). They are Am-241, Np-237, Pu-238, Pu-239, Pu-240, Tc-99, U-234, U-235, U-236, and U-238.

The selected radionuclides of concern have relatively long half-lives. As discussed previously in this section, the EPA has assigned slope factor values to many radionuclides using information drawn from *Calculation of Slope Factors and Dose Coefficients* prepared by the Center for Radiation Protection Knowledge (ORNL 2014). These slope factors are incorporated as default values in EPA's PRG and BPRG calculators.

However, some of these radionuclides produce other, shorter lived, radioactive decay products as they decay. In some cases those decay products, also known as "daughters", can contribute additional exposures to humans. Table 15 presents a list of the parent radionuclides included in the risk evaluation portion of the HHRA, as well as their short-lived daughters. This assessment accounts for these additional exposures by assigning each decay daughter's potential health effects to the appropriate "parent" radionuclide. Thus, the values used to convert intakes and exposures to risk in this HHRA include the additional effects from their various daughters.

Table 15 Assignment of Potential Health Effects from Decay Products

Radionuclide			
Progenitor	**Daughter**	**Daughter Half-life**	**Radiotoxicity Assigned to:**
Am-241			Am-241
Np-237			Np-237
	Pa-233	27 days	Np-237
Pu-238			Pu-238
Pu-239			Pu-239
	U-235m[a]	26 minutes	Pu-239
Pu-240			Pu-239
Tc-99			Tc-99
U-233/234			U-234
U-235/236			U-235
	Th-231	1.1 days	U-235
U-238			U-238
	Th-234	24 days	U-238
	Pa-234m	1.2 minutes	U-238
	Pa-234	6.7 hours	U-238

[a] m – metastable

4.3.7 Slope Factors Used in HHRA

Information provided in this section of the HHRA draws from EPA's website *Preliminary Remediation Goals for Radionuclide Contaminants at Superfund Sites* (EPA 2022a).[17] The EPA expresses the relationship between exposures and contaminant intakes and probabilistic cancer

[17] https://epa-prgs.ornl.gov/radionuclides/ (EPA 2022a)

risks as a deterministic numeric ratio called a "slope factor", as presented in *Calculation of Slope Factors and Dose Coefficients* prepared by the Center for Radiation Protection Knowledge (ORNL 2014).[18] The EPA's slope factors represent the excess lifetime cancer risk[19] corresponding to a unit (such as a pCi) of intake or to an external exposure. These slope factors, sometimes referred to as risk coefficients, are derived from values published in the Federal Guidance Report 13 (EPA 1999b), supplemented by updated data from the International Commission on Radiological Protection 107 publication (ICRP 2008). Relevant slope factors associated with internal and external exposure addressed in this HHRA report are presented in Table 16 and Table 17, respectively. External exposure slope factors are used to calculate direct radiation risks.

Table 16 Internal Slope Factors for Radionuclides of Concern

Isotope	Inhalation Slope Factor (risk/pCi)	Food Ingestion Slope Factor (risk/pCi)	Soil Ingestion Slope Factor (risk/pCi)	Water Ingestion Slope Factor (risk/pCi)
Am-241	3.77E-08	1.34E-10	1.84E-10	1.04E-10
Np-237	2.87E-08	8.29E-11	1.25E-10	6.22E-11
Pa-233	1.53E-11	8.95E-12	1.65E-11	6.14E-12
Pa-234	1.20E-12	3.00E-12	5.37E-12	2.07E-12
Pa-234m	0	0	0	0
Pu-238	5.22E-08	1.69E-10	2.25E-10	1.31E-10
Pu-239	5.55E-08	1.74E-10	2.28E-10	1.35E-10
Tc-99	3.81E-11	4.00E-12	7.25E-12	2.75E-12
Th-231	1.50E-12	3.22E-12	5.96E-12	2.19E-12
Th-234	3.08E-11	3.39E-11	6.25E-11	2.31E-11
U-234	2.78E-08	9.55E-11	1.48E-10	7.07E-11
U-235	2.50E-08	9.44E-11	1.48E-10	6.96E-11
U-235m	1.87E-18	1.06E-17	1.65E-17	7.62E-18
U-238	2.36E-08	8.66E-11	1.34E-10	6.40E-11

[18] Assigning a carcinogenic category to an element or chemical is the culmination of numerous investigative steps designed to assemble and evaluate historic documentation, including the mechanics and results of studies, directly associated with the carcinogenic impact that element or chemical has on humans and/or animals. High-quality studies are allocated greater weight than those of lesser quality. Greater significance is placed on similarities of effects among both humans and animals and greater credence is offered to studies wherein the mechanisms generating the effect(s) are well-characterized.

[19] Excess cancer risk, also called incremental cancer risk, is an increase in cancer risk in the exposed population over the cancer risk that would occur in the absence of the exposure.

Table 17 External Slope Factors for Radionuclides of Concern

Isotope	Soil External Exposure Slope Factor (risk/yr per pCi/g)	Water Immersion Slope Factor (risk/yr per pCi/L)	Dust External Exposure Slope Factor (Ground Plane) (risk/yr per pCi/cm^2)
Am-241	2.77E-08	1.32E-13	1.87E-08
Np-237	5.17E-08	1.72E-13	2.10E-08
Pa-233	8.03E-07	1.87E-12	1.88E-07
Pa-234	6.62E-06	1.35E-11	1.28E-06
Pa-234m	9.06E-08	1.82E-13	2.86E-08
Pu-238	6.91E-11	5.95E-16	3.68E-10
Pu-239	2.09E-10	7.25E-16	2.06E-10
Tc-99	8.28E-11	5.62E-16	5.34E-11
Th-231	2.49E-08	8.89E-14	1.24E-08
Th-234	1.77E-08	6.39E-14	7.33E-09
U-234	2.53E-10	1.17E-15	3.82E-10
U-235	5.51E-07	1.39E-12	1.39E-07
U-235m	0	0	0
U-238	1.24E-10	5.98E-16	2.48E-10

5. HEALTH RISK CHARACTERIZATION

Potential human health effects resulting from exposure to ROCs were estimated using methods established by the EPA. These methods are published in a series of guidance documents, including the *Risk Assessment Guidance for Superfund, Volume 1, Human Health Evaluation Manual* ("RAGS", EPA 1989) and integrated into web-based calculators hosted by the EPA (EPA 2022a and EPA 2022b).

This EPA method is designed to allow the estimation of health effects from both chemical and radiological exposures. In this study, no ROCs were present in quantities that exceeded chemical toxicity thresholds and the investigation focused on potential carcinogenic effects from radiological exposures.

Cancer is regrettably common among humans. The American Cancer Society estimates that one in three Americans will experience cancer during their lifetime and one in five will die of the disease. This baseline cancer incidence rate of 1 in 3 or 3.3×10^{-1} should be considered when reviewing the results of any risk assessment.

The EPA has developed risk assessment methodology to comply with requirements set forth in the 1980 Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). This risk assessment methodology was selected to estimate hypothetical risks during this assessment. Using this established methodology, risks attributed to exposure to radiological carcinogens are estimated and expressed as a probability of excess cancers above the baseline cancer risk in a population during a lifetime. This probability is also called the Incremental Lifetime Cancer Risk or "ILCR" in this HHRA.

The procedures prescribed by the EPA use specific algorithms to calculate the excess human health risks as a function of radionuclide concentration, various human exposure parameters, and radionuclide-specific characteristics. This approach is designed to be health-protective and the estimates produced are likely to overestimate risks in an exposed population.

5.1 GENERAL METHODOLOGY

The general approach for estimating ILCR, expressed as a unitless probability, resulting from chronic or periodic exposures to a radionuclide depends on the radiation source's position relative to the receptor. One method applies when the radiation source is inside the human body and another when the source is located outside the body. The general forms of the two methods are presented below:

5.1.1 General Form of Internal Radiation Exposure Risk Calculation

At low dose rates, risks from internal exposures to radionuclides in exposure media (e.g., intake via inhalation or ingestion) are calculated using the following general form:

$$ILCR_{i,r} = \left(Intake_{i,r}\right) * \left(SF_{i,r}\right)$$

where:

$ILCR_{i,r}$ = incremental lifetime cancer risk, for radionuclide "i" via exposure route "r"
$Intake_{i,r}$ = intake for radionuclide "i" via exposure route "r" (pCi)
$SF_{i,r}$ = cancer slope factor for radionuclide "i" via exposure route "r" (pCi^{-1})

Specific equations and pathway-specific considerations are available in the previously cited web calculators and incorporated by reference.

5.1.2 General Form of External Radiation Exposure Calculation

Risks from external exposure to gamma-emitting radionuclides in contaminated media are calculated as follows:

where:

$$ILCR_{i,ext} = \left(A_{i,ext}\right) * \left(B_{i,ext,x}\right) * \left(SF_{i,ext}\right)$$

$ILCR_{i, ext}$ = incremental lifetime cancer risk, for radionuclide "i"
$A_{i, ext}$ = activity concentration of radionuclide "i" (pCi/g)
$B_{i, ext, x}$ = combined geometry and shielding term for isotope "i" and overburden thickness “x” (y)
$SF_{i, ext}$ = cancer slope factor (external) of radionuclide "i" (g/pCi-y)

Specific equations and pathway-specific considerations are available on the previously cited web calculators and incorporated by reference.

5.1.3 Multiple Pathways

Multiple exposure pathways included in the conceptual model for the hypothetical receptors are evaluated in this assessment. By convention, risks from various exposure pathways are assumed to be additive with a receptor receiving exposures from more than one pathway. Risks and hazards from multiple pathways are summed to determine the total risk/hazard to that receptor.

5.2 RISK CALCULATION METHODS

The EPA PRG and BPRG on-line calculators (EPA 2022a and EPA 2022b) were utilized to determine the estimated incremental lifetime cancer risks (ILCRs). These calculators use the equations presented in Attachment D as well as radionuclide-specific data, such as half-life and transport characteristics to estimate ROC intakes and exposures to hypothetical receptors.

While these calculators contain pre-selected default values that quantitatively describe various exposure scenarios and receptor types, the calculators allow the substitution of “site-specific” values that better describe a scenario or receptor of interest. Section 3.3 lists study area-specific values used in the calculators to describe the behavior of potential types of receptors that may be found in the local community.

5.2.1 Additive Effects of Multiple Radionuclides

Concentrations of the ROCs were found to display variations across the study area. These variations sometimes coincided with variations displayed by other ROCs but sometimes they did

not. In keeping with the conservative assumption in this HHRA, the hypothetical receptor was assumed to be exposed to every ROC at the respective exposure point concentration.

5.2.2 Inclusion of Short-lived Decay Products Not Listed in the ROC List

As discussed in Section 4.3.6, the EPA risk assessment methodology converts intakes and exposures to a risk estimate using radionuclide-specific slope factors. These slope factors do not always account for risks from a radionuclide's decay products. For example, any long-term risk presented for uranium-238 in this evaluation must also include the risk created by the ingrowth of its short-lived decay products thorium-234, protactinium-234m and protactinium-234.

While the EPA calculators used in this evaluation offer various options that account for risks from decay products, these options are generic and can erroneously include risks from decay products that are not present. To continue the example in the previous paragraph, feedstock received by PORTS consisted of processed uranium. This uranium had been separated from its decay products by chemical extractions before its arrival at PORTS. Most of those decay products have not had time to re-accumulate and including those daughters in this HHRA would not be appropriate. Thus care must be taken when using the EPA web calculators to account for risks from all decay products likely to be present without omitting or double-counting their projected effects.

The calculator option selected for use in this HHRA was labeled "Does not assume secular equilibrium, provides results for selected isotopes only". This option allowed assessors to calculate risks for all ROCs and their decay products, as listed in Table 15, by manually entering the exposure point activity concentration (in pCi/g or pCi/L) for each short-lived daughter present. The resulting risk estimates generated by the EPA PRG and BPRG calculators were summed within a medium for each parent ROC and associated daughters specified in Table 15.

5.3 RISK CALCULATION RESULTS

Hypothetical receptor populations were quantitatively evaluated in this HHRA. All exposures addressed in this section are based on the exposure point concentrations selected for each medium (Section 3.2) and behavioral parameters chosen for each exposure pathway (Section 3.3). Media evaluated include soil, surface water, sediment, and settled dust. Calculated risks are summed within each medium and across media, allowing for the possibility that Community members are involved in activities spanning every complete pathway evaluated herein.

5.3.1 Risks to Hypothetical Resident

The hypothetical resident is an idealized human living in the study area, whose behaviors and physiological characteristics are a composite of behavior and characteristics drawn from national databases and supplemented by information gathered from local community members (Section 3.1). Risks to this receptor from representative concentrations of ROCs in soil in the study area and interior dust within structures are presented in Table 18. Similar risks from background area soils and dust are presented in Table 19 for context.

Comparing results in these two tables, it appears the sum of the calculated risks from background area soil and dust are slightly higher than the sum of the risks calculated from soil ROC's in the study area. This is largely attributable to the observation that the average concentrations of

isotopic uranium are higher in background area soil than their corresponding concentrations in the CCSE study area soil. It is important to note that these differences are within the margin of error for the study area. As these risk values are comparable, risks to most local residents from soil and dust, as calculated using EPA's assessment methodology, are expected to be indistinguishable from background area risks from the same media.

5.3.2 Potentially Critical Subpopulations

Critical subpopulations are groups of people within a larger group that that may be at higher risk than most people in the larger group. This may be due to a greater susceptibility to external stressors like contamination or a propensity to experience larger exposures due to unique behaviors or higher localized exposures. This study cannot comment on variable sensitivities to radiological exposures among subpopulations but it did query the Piketon community about behaviors that might produce higher exposures. Four additional receptor types were identified and selected for evaluation: those who eat a lot of local produce, those who eat a lot of locally grown fish, life-long residents of the study area and those who swim and wade in local streams and ponds. Risks were assessed for each of those receptor types.

5.3.2.1 Potential Risks from Vegetables Grown in Family Garden

This hypothetical receptor was assumed to consume 1,486 g/day of local vegetables and fruit during the growing season (300 lbs each year). Using EPA's CERCLA risk assessment system, the calculated risks for this scenario are more than an order of magnitude greater than the calculated risks from all other residential activities combined (Table 20), even after subtracting comparable background area risks which are presented in Table 21.

5.3.2.2 Potential Risks from Eating Locally Caught Fish

This hypothetical receptor was assumed to consume fish flesh from local streams and ponds that are downstream from PORTS outfalls. These risks are comparable to, or slightly larger than, risks from all other residential activities combined after subtracting comparable background area risks from eating local fish caught outside the 6-mile study area (Table 22 and Table 23).

5.3.2.3 Potential Risks from 78-year Residency

This hypothetical receptor was assumed to live in the study area for longer than the default residency time used by the EPA to assess risks under the CERCLA program. Hypothetical risks to this receptor were calculated using a 78-year exposure duration. The calculated risks to this receptor are approximately double the corresponding values calculated for the more typical resident. Calculated risks for the study area and background are presented in Table 24 and Table 25, respectively.

5.3.2.4 Potential Risks from Attending Local Schools

After consulting the Pike County School District calendar of 2022-2023, this hypothetical receptor was assumed to attend a local school in the study area for 7.5 hours/day, 178 days/year, with a duration of 13 years. Default values were maintained for other parameters with the exception of the FTSS, which was incorporated as presented in Section 3.3.2.2.

For this hypothetical receptor, only dust samples collected within local schools were considered. Complexities with the full data set, including negative exposure point concentrations described in Section 2.6, were also encountered with this subset of results. Combining the few detections and the negative analytical results, as well as acknowledging the Community's sensitivity to this type of receptor, a highly conservative diversion from the RME method was taken by the risk assessment team. The maximum detected settled dust concentrations in schools within the study area were used as the exposure point concentrations, offering a method likely to produce estimated risks that significantly overestimate potential risks to this subpopulation. Calculated risks associated with settled dust in local schools for the study area and the background area are presented in Table 26 and Table 27. Additional details concerning radiological conditions in local schools is provided in Attachment F.

Table 18 Estimated Study Area Risks to Hypothetical Resident Receptor

	Soil				Settled Dust			
Isotope	**Soil Concentration (pCi/g)**	**Ingestion Risk**	**Inhalation Risk**	**External Exposure Risk**	**Dust Concentration (pCi/cm²)**	**Ingestion Risk**	**External Exposure Risk**	**Summed Risk**
Am-241	0.00581	1.17E-09	2.54E-11	1.36E-09	0.000040	8.19E-08	1.82E-11	8.45E-08
Np-237	0.000925	1.29E-10	3.14E-12	4.13E-10	0.000008	1.13E-08	4.19E-12	1.18E-08
Pa-233	0.000925	6.99E-14	6.86E-18	2.63E-11	0.000008	6.13E-12	1.54E-13	3.27E-11
Pa-234	1.28	3.26E-13	7.70E-18	3.10E-09	0.000557	1.44E-12	7.57E-13	3.10E-09
Pa-234m	1.28	«[a]	«	1.24E-13	0.000557	«	4.91E-17	1.24E-13
Pu-238	0.00170	3.87E-10	9.51E-12	9.19E-13	0.000026	5.99E-08	2.16E-13	6.03E-08
Pu-239/240	0.0107	2.73E-09	7.03E-11	1.93E-11	0.000048	1.24E-07	2.46E-13	1.27E-07
Tc-99	0.179	1.46E-09	8.09E-13	1.28E-10	0.001413	1.16E-07	1.88E-12	1.18E-07
Th-231	0.0593	6.40E-14	1.71E-18	2.06E-12	0.000027	2.95E-13	1.35E-15	2.42E-12
Th-234	1.28	3.28E-10	1.71E-14	7.18E-10	0.000557	1.45E-09	3.73E-13	2.50E-09
U-233/234	1.25	2.08E-07	4.13E-09	2.74E-09	0.000578	9.73E-07	5.50E-12	1.19E-06
U-235/236	0.0593	9.80E-09	1.76E-10	2.82E-07	0.000027	4.52E-08	9.35E-11	3.37E-07
U-235m	0.0107	5.43E-22	6.50E-27	«	0.000048	2.47E-20	0.00E+00	2.52E-20
U-238	1.28	1.92E-07	3.58E-09	1.37E-09	0.000557	8.49E-07	3.44E-12	1.05E-06
Summed Risk	**---**	**4.16E-07**	**8.00E-09**	**2.92E-07**	**---**	**2.26E-06**	**1.28E-10**	**2.98E-06**

[a] The slope factor in EPA's PRG or BPRG Calculator (EPA 2022a and EPA 2022b, respectively) is zero or does not exist.

Table 19 Estimated Background Area Risks to Hypothetical Resident Receptor

	Soil				Settled Dust			
Isotope	**Soil Concentration (pCi/g)**	**Ingestion Risk**	**Inhalation Risk**	**External Exposure Risk**	**Dust Concentration (pCi/cm²)**	**Ingestion Risk**	**External Exposure Risk**	**Summed Risk**
Am-241	-[a]	-	-	-	-	-	-	-
Np-237	-	-	-	-	-	-	-	-
Pa-233	-	-	-	-	-	-	-	-
Pa-234	1.919	4.89E-13	1.16E-17	4.66E-09	0.000380	9.83E-13	5.17E-13	4.66E-09
Pa-234m	1.919	«[b]	«	1.86E-13	0.000380	«	3.35E-17	1.86E-13
Pu-238	-	-	-	-	-	-	-	-
Pu-239/240	0.0092	2.35E-09	6.05E-11	1.66E-11	-	-	-	2.43E-09
Tc-99	0.110	8.93E-10	4.96E-13	7.87E-11	neg[c]	neg	neg	9.72E-10
Th-231	0.085	9.17E-14	2.45E-18	2.95E-12	0.000049	5.38E-13	2.45E-15	3.58E-12
Th-234	1.919	4.92E-10	2.56E-14	1.08E-09	0.000380	9.89E-10	2.55E-13	2.56E-09
U-233/234	1.952	3.24E-07	6.43E-09	4.27E-09	0.001250	2.10E-06	1.19E-11	2.43E-06
U-235/236	0.085	1.41E-08	2.52E-10	4.05E-07	0.000049	8.24E-08	1.70E-10	5.02E-07
U-235m	0.0092	4.67E-22	5.59E-27	«	-	-	-	4.67E-22
U-238	1.919	2.89E-07	5.37E-09	2.05E-09	0.000380	5.79E-07	2.35E-12	8.75E-07
Summed Risk	**---**	**6.31E-07**	**1.21E-08**	**4.17E-07**	**---**	**2.76E-06**	**1.85E-10**	**3.82E-06**

[a] There are no detected concentrations of this analyte in this medium within the background area.
[b] The slope factor in EPA's PRG or BPRG Calculator (EPA 2022a and EPA 2022b, respectively) is zero or does not exist.
[c] The average concentration of Tc-99 from background area samples in this medium is negative.

Table 20 Estimated Study Area Risks from Eating 300 lbs of Local Produce

	Soil		
Isotope	**Soil Concentration (pCi/g)**	**Produce Consumption Risk**	**Summed Risk**
Am-241	0.00581	2.51E-09	2.51E-09
Np-237	0.000925	2.53E-09	2.53E-09
Pa-233	0.000925	1.17E-12	1.17E-12
Pa-234	1.28	5.61E-12	5.61E-12
Pa-234m	1.28	«[a]	«
Pu-238	0.00170	7.81E-10	7.81E-10
Pu-239/240	0.0107	5.58E-09	5.58E-09
Tc-99	0.179	5.44E-05	5.44E-05
Th-231	0.0593	1.41E-13	1.41E-13
Th-234	1.28	7.29E-10	7.29E-10
U-233/234	1.25	2.97E-06	2.97E-06
U-235/236	0.0593	1.39E-07	1.39E-07
U-235m	0.0107	7.74E-21	7.74E-21
U-238	1.28	2.74E-06	2.74E-06
Summed Risk	**---**	**6.03E-05**	**6.03E-05**

[a] The slope factor in the EPA PRG Calculator (EPA 2022a) is zero or does not exist.

Table 21 Estimated Background Area Risks from Eating 300 lbs of Local Produce

Isotope	Soil		Summed Risk
	Soil Concentration (pCi/g)	Produce Consumption Risk	
Am-241	-[a]	-	-
Np-237	-	-	-
Pa-233	-	-	-
Pa-234	1.92	8.42E-12	8.42E-12
Pa-234m	1.92	«[b]	«
Pu-238	-	-	-
Pu-239/240	0.0092	4.80E-09	4.80E-09
Tc-99	0.110	3.34E-05	3.34E-05
Th-231	0.085	2.03E-13	2.03E-13
Th-234	1.92	1.09E-09	1.09E-09
U-233/234	1.95	4.62E-06	4.62E-06
U-235/236	0.085	1.99E-07	1.99E-07
U-235m	0.0092	6.65E-21	6.65E-21
U-238	1.92	4.12E-06	4.12E-06
Summed Risk	---	**4.23E-05**	**4.23E-05**

[a] There are no detected concentrations of this analyte in this medium within the background area.
[b] The slope factor in the EPA PRG Calculator (EPA 2022a) is zero or does not exist.

Table 22 Estimated Study Area Risks from Eating 28.8 lbs/y of Fish Flesh

Isotope	Surface Water		Summed Risk
	Surface Water Concentration (pCi/L)	Finfish Ingestion Risk	
Am-241	-[a]	-	-
Np-237	-	-	-
Pa-233	-	-	-
Pa-234	0.267	2.72E-09	2.72E-09
Pa-234m	0.267	«[b]	«
Pu-238	0.0349	4.21E-05	4.21E-05
Pu-239/240	-	-	-
Tc-99	0.543	1.10E-08	1.10E-08
Th-231	0.0357	2.34E-10	2.34E-10
Th-234	0.267	1.84E-08	1.84E-08
U-233/234	0.384	1.19E-08	1.19E-08
U-235/236	0.0357	1.10E-09	1.10E-09
U-235m	-	-	-
U-238	0.267	7.52E-09	7.52E-09
Summed Risk	**---**	**4.22E-05**	**4.22E-05**

[a] There are no detected concentrations of this analyte in this medium.

[b] The slope factor in the EPA PRG Calculator (EPA 2022a) is zero or does not exist.

Table 23 Estimated Background Area Risks to Eating 28.8 lbs/y of Fish Flesh

	Surface Water		
Isotope	**Surface Water Concentration (pCi/L)**	**Finfish Ingestion Risk**	**Summed Risk**
Am-241	-[a]	-	-
Np-237	-	-	-
Pa-233	-	-	-
Pa-234	0.312	3.18E-09	3.18E-09
Pa-234m	0.312	«[b]	«
Pu-238	0.026	3.14E-05	3.14E-05
Pu-239/240	-	-	-
Tc-99	neg[c]	neg	neg
Th-231	0.032	2.10E-10	2.10E-10
Th-234	0.312	2.16E-08	2.16E-08
U-233/234	0.377	1.17E-08	1.17E-08
U-235/236	0.032	9.84E-10	9.84E-10
U-235m	-	-	-
U-238	0.312	8.80E-09	8.80E-09
Summed Risk	---	**3.14E-05**	**3.14E-05**

[a] There are no detected concentrations of this analyte in this medium within the background area.

[b] The slope factor in the EPA PRG Calculator (EPA 2022a) is zero or does not exist.

[c] The concentration for this analyte in this medium is negative; the input concentration is zero.

Table 24 Estimated Study Area Risks to Hypothetical Long-Term Resident Receptor

	Soil				Settled Dust			
Isotope	**Soil Concentration (pCi/g)**	**Ingestion Risk**	**Inhalation Risk**	**External Exposure Risk**	**Dust Concentration (pCi/cm^2)**	**Ingestion Risk**	**External Exposure Risk**	**Summed Risk**
Am-241	0.00581	2.96E-09	7.96E-11	3.92E-09	0.000040	1.64E-07	5.25E-11	1.71E-07
Np-237	0.000925	3.39E-10	1.02E-11	1.24E-09	0.000008	2.36E-08	1.26E-11	2.52E-08
Pa-233	0.000925	6.12E-14	7.46E-18	2.63E-11	0.000008	4.25E-12	1.54E-13	3.08E-11
Pa-234	1.28	2.85E-13	8.37E-18	3.10E-09	0.000557	9.99E-13	7.57E-13	3.10E-09
Pa-234m	1.28	«[a]	«	1.24E-13	0.000557	«	4.91E-17	1.24E-13
Pu-238	0.00170	8.39E-10	2.56E-11	2.28E-12	0.000026	1.03E-07	5.34E-13	1.04E-07
Pu-239/240	0.0107	7.16E-09	2.29E-10	5.79E-11	0.000048	2.58E-07	7.37E-13	2.65E-07
Tc-99	0.179	3.82E-09	2.64E-12	3.85E-10	0.001413	2.42E-07	5.64E-12	2.46E-07
Th-231	0.0593	5.60E-14	1.85E-18	2.06E-12	0.000027	2.05E-13	1.35E-15	2.32E-12
Th-234	1.28	2.87E-10	1.86E-14	7.18E-10	0.000557	1.00E-09	3.73E-13	2.01E-09
U-233/234	1.25	5.47E-07	1.35E-08	8.23E-09	0.000578	2.03E-06	1.65E-11	2.60E-06
U-235/236	0.0593	2.57E-08	5.73E-10	8.47E-07	0.000027	9.42E-08	2.81E-10	9.68E-07
U-235m	0.0107	4.75E-22	7.07E-27	«	0.000048	1.71E-20	«	1.76E-20
U-238	1.28	5.04E-07	1.17E-08	4.10E-09	0.000557	1.77E-06	1.03E-11	2.29E-06
Summed Risk	**---**	**1.09E-06**	**2.61E-08**	**8.69E-07**	**---**	**4.69E-06**	**3.81E-10**	**6.67E-06**

[a] The slope factor in EPA's PRG or BPRG Calculator (EPA 2022a and EPA 2022b, respectively) is zero or does not exist.

Table 25 Estimated Background Area Risks to Hypothetical Long-Term Resident Receptor

	Soil				Settled Dust			
Isotope	**Soil Concentration (pCi/g)**	**Ingestion Risk**	**Inhalation Risk**	**External Exposure Risk**	**Dust Concentration (pCi/cm²)**	**Ingestion Risk**	**External Exposure Risk**	**Summed Risk**
Am-241	-[a]	-	-	-	-	-	-	-
Np-237	-	-	-	-	-	-	-	-
Pa-233	-	-	-	-	-	-	-	-
Pa-234	1.92	4.28E-13	1.26E-17	4.66E-09	0.000380	6.82E-13	5.17E-13	4.66E-09
Pa-234m	1.92	«[b]	«	1.86E-13	0.000380	«	3.35E-17	1.86E-13
Pu-238	-	-	-	-	-	-	-	-
Pu-239/240	0.0092	6.16E-09	1.97E-10	4.98E-11	-	-	-	6.41E-09
Tc-99	0.110	2.34E-09	1.62E-12	2.36E-10	neg[c]	neg	neg	2.58E-09
Th-231	0.085	8.01E-14	2.65E-18	2.95E-12	0.000049	3.73E-13	2.45E-15	3.57E-12
Th-234	1.92	4.31E-10	2.79E-14	1.08E-09	0.000380	6.86E-10	2.55E-13	2.50E-09
U-233/234	1.952	8.51E-07	2.10E-08	1.28E-08	0.001249	4.38E-06	3.57E-11	2.98E-06
U-235/236	0.085	3.68E-08	8.20E-10	1.21E-06	0.000049	1.72E-07	5.11E-10	1.33E-06
U-235m	0.0092	4.08E-22	6.08E-27	«	-	-	-	4.08E-22
U-238	1.92	7.58E-07	1.75E-08	6.16E-09	0.000380	1.21E-06	7.04E-12	1.36E-06
Summed Risk	**---**	**1.65E-06**	**3.95E-08**	**1.23E-06**	**---**	**5.76E-06**	**5.54E-10**	**8.69E-06**

[a] There are no detected concentrations of this analyte in this medium within the background area.

[b] The slope factor in EPA's PRG or BPRG Calculator (EPA 2022a and EPA 2022b, respectively) is zero or does not exist.

[c] The concentration for this analyte in this medium is negative; the input concentration is zero.

Table 26 Estimated Study Area Risks to Hypothetical Student at Local Schools

Isotope	Settled Dust			Summed Risk
	Dust Concentration (pCi/cm^2)	Ingestion Risk	External Exposure Risk	
Am-241	0.000140	2.40E-08	5.13E-12	2.40E-08
Np-237	-[a]	-	-	-
Pa-233	-	-	-	-
Pa-234	0.000720	3.08E-13	1.56E-13	4.63E-13
Pa-234m	0.000720	«b	1.01E-17	1.01E-17
Pu-238	0.000100	2.00E-08	6.93E-14	2.00E-08
Pu-239/240	0.000160	3.42E-08	6.51E-14	3.42E-08
Tc-99	0.008234	5.60E-08	8.70E-13	5.60E-08
Th-231	0.000110	1.99E-13	8.72E-16	2.00E-13
Th-234	0.000720	3.10E-10	7.67E-14	3.10E-10
U-233/234	0.000570	7.94E-08	4.31E-13	7.94E-08
U-235/236	0.000110	1.52E-08	3.03E-11	1.53E-08
U-235m	0.000160	1.36E-20	«	1.36E-20
U-238	0.000720	9.08E-08	3.53E-13	9.08E-08
Summed Risk	**---**	**3.20E-07**	**3.75E-11**	**3.20E-07**

[a] There are no detected concentrations of this analyte in this medium within the background area.
[b] The slope factor in the EPA's BPRG Calculator (EPA 2022b) is zero or does not exist.

Table 27 Estimated Study Area Risks to Hypothetical Student at Local Schools

	Settled Dust			
Isotope	**Dust Concentration (pCi/cm^2)**	**Ingestion Risk**	**External Exposure Risk**	**Summed Risk**
Am-241	-[a]	-	-	-
Np-237	-	-	-	-
Pa-233	-	-	-	-
Pa-234	0.00028	1.20E-13	6.05E-14	1.80E-13
Pa-234m	0.00028	«[b]	3.92E-18	3.92E-18
Pu-238	-	-	-	-
Pu-239/240	-	-	-	-
Tc-99	-	-	-	-
Th-231	-	-	-	-
Th-234	0.00028	1.20E-10	2.98E-14	1.20E-10
U-233/234	0.00043	5.99E-08	3.25E-13	5.99E-08
U-235/236	-	-	-	-
U-235m	-	-	-	-
U-238	0.00028	3.53E-08	1.37E-13	3.53E-08
Summed Risk	**---**	**9.53E-08**	**5.52E-13**	**9.53E-08**

[a] There are no detected concentrations of this analyte in this medium within the background area.
[b] The slope factor in the EPA's BPRG Calculator (EPA 2022b) is zero or does not exist.

5.3.2.5 Potential Risks from Swimming and Wading in Local Streams and Ponds

This hypothetical receptor was assumed to spend time during the summer swimming and wading in local streams and ponds that are downstream from PORTS outfalls. These risks (Table 28) are much lower that than risks from all residential activities even before subtracting comparable background area risks (Table 29).

Table 28 Estimated Study Area Risks to Hypothetical Swimmer

	Swimming						
	Sediment			Surface Water			
Isotope	Sediment Concentration (pCi/g)	Ingestion Risk	External Exposure Risk	Surface Water Concentration (pCi/L)	Ingestion Risk	External Exposure Risk	Summed Risk
Am-241	0.00860	5.96E-11	4.79E-12	-[a]	-	-	6.44E-11
Np-237	-	-	-	-	-	-	-
Pa-233	-	-	-	-	-	-	-
Pa-234	1.06	9.24E-15	6.10E-12	0.267	1.11E-11	7.42E-14	1.73E-11
Pa-234m	1.06	«[b]	2.43E-16	0.267	«	9.98E-16	1.24E-15
Pu-238	0.00480	3.74E-11	6.16E-15	0.0349	9.24E-11	4.27E-19	1.30E-10
Pu-239/240	0.00970	8.49E-11	4.16E-14	-	-	-	8.49E-11
Tc-99	0.0454	1.26E-11	7.72E-14	0.543	3.01E-11	6.27E-18	4.28E-11
Th-231	0.0510	1.89E-15	4.22E-15	0.0357	1.58E-12	6.51E-17	1.59E-12
Th-234	1.06	9.30E-12	1.41E-12	0.267	1.24E-10	3.50E-16	1.35E-10
U-233/234	1.13	6.46E-09	5.91E-12	0.384	5.47E-10	9.20E-18	7.01E-09
U-235/236	0.0510	2.89E-10	5.78E-10	0.0357	5.00E-11	1.02E-15	9.17E-10
U-235m	0.0097	1.69E-23	«	-	-	-	1.69E-23
U-238	1.06	5.45E-09	2.69E-12	0.267	3.44E-10	3.28E-18	5.80E-09
Summed Risk	**---**	**1.24E-08**	**5.99E-10**	**---**	**1.20E-09**	**7.67E-14**	**1.42E-08**

[a] There are no detected concentrations of this analyte in this medium.
[b] The slope factor in the EPA PRG Calculator (EPA 2022a) is zero or does not exist.

Table 29 Estimated Background Area Risks to Hypothetical Swimmer

	Swimming						
	Sediment			Surface Water			
Isotope	Sediment Concentration (pCi/g)	Ingestion Risk	External Exposure Risk	Surface Water Concentration (pCi/L)	Ingestion Risk	External Exposure Risk	Summed Risk
Am-241	-[a]	-	-	-	-	-	-
Np-237	-	-	-	-	-	-	-
Pa-233	-	-	-	-	-	-	-
Pa-234	2.29	2.00E-14	1.32E-11	0.312	1.30E-11	8.68E-14	2.63E-11
Pa-234m	2.29	«[b]	5.26E-16	0.312	«	1.17E-15	1.70E-15
Pu-238	-	-	-	0.026	6.88E-11	3.18E-19	6.88E-11
Pu-239/240	0.007	6.12E-11	3.01E-14	-	-	-	6.12E-11
Tc-99	0.011	3.06E-12	1.87E-14	neg[c]	neg	neg	3.08E-12
Th-231	0.093	3.44E-15	7.68E-15	0.032	1.42E-12	5.84E-17	1.43E-12
Th-234	2.29	2.01E-11	3.05E-12	0.312	1.45E-10	4.09E-16	1.68E-10
U-233/234	2.33	1.33E-08	1.21E-11	0.377	5.37E-10	9.04E-18	1.38E-08
U-235/236	0.093	5.27E-10	1.05E-09	0.032	4.49E-11	9.14E-16	1.62E-09
U-235m	0.007	1.22E-23	«	-	-	-	1.22E-23
U-238	2.29	1.18E-08	5.81E-12	0.312	4.03E-10	3.83E-18	1.22E-08
Summed Risk	**---**	**2.57E-08**	**1.08E-09**	**---**	**1.21E-09**	**8.94E-14**	**2.80E-08**

[a] There are no detected concentrations of this analyte in this medium within the background area.

[b] The slope factor in the EPA PRG Calculator (EPA 2022a) is zero or does not exist.

[c] The concentration for this analyte in this medium is negative; the input concentration is zero.

6. UNCERTAINTY ASSESSMENT

There are uncertainties associated with the information and data used in each phase of a risk assessment. These uncertainties are due to a number of factors, including parameter bias, parameter variability (random errors or natural variations) and artifacts of the modeling process.

As this HHRA progressed, some parameters were identified as having a noticeable influence on calculated risks. Changes in the values of these more "sensitive" parameters produced larger changes in the risk results than other, less-sensitive, parameters. Research data on many of these parameters are expressed as ranges of plausible values. To reduce the chances that risks are underestimated, EPA's risk calculators incorporate parameter values that follow the RME approach and those values were often selected that yielded higher risk estimates.

Some of the more influential uncertainties are presented below:

6.1 SOIL-TO-PLANT UPTAKE FACTORS

One of the most influential values in this HHRA is the value of the soil-to-plant transfer factor of Tc-99. This factor is used to convert the concentration of technetium in soil to a concentration of technetium in plants growing in that soil. Technetium, in the form of pertechnetate, is soluble in water. According to the values found in the EPA PRG calculator's database, it is absorbed much more readily by plants than other water-soluble elements like sodium, potassium and chloride. Thus, a soil-to-plant transfer factor that predicts a relatively high bio-concentration of technetium in food crops, particularly leafy vegetables, was used in this HHRA. This may result in a calculated risk result that overestimates the actual exposure potential of consuming local produce. If additional investigations into radiological exposures are planned, sampling of local leafy vegetables and the soil around their roots should be considered.

6.2 COMPOUNDING EFFECT OF THE RME APPROACH

The practice of overestimating individual exposure parameter values to minimize the possibility of underestimating its contribution to the calculated risk can, if taken to extremes, produce a compounded estimate that greatly overestimates exposures and risks. This conservatism is intended, and this HHRA recognizes this tendency as a necessary artifact of the EPA's risk assessment process. Where possible, input from the local community was used to reduce the net uncertainty associated with calculated risks.

6.3 SLOPE FACTORS

The EPA methodology for estimating radionuclide carcinogenic risks is currently being re-evaluated by EPA and its contractors. The current dose-response relationship between cancer and ionizing radiation has been extrapolated from the cancer risk established using data on past exposures like the Japanese Atomic Bomb Survivors database and a relative risk projection model.

As stated by the EPA, "…*so far as is known, any dose of ionizing radiation, no matter how small, might give rise to a cancer or to a genetic effect in future generations. Conversely, there is no way to be certain that a given dose of radiation, no matter how large, has caused an observed cancer in an individual or will cause one in the future.*" (EPA 1989)

The EPA's current interpretation follows the historic "linear-no-threshold model", which has come under increasing criticism from scientific professionals in recent years (Doss 2018). Most objections to the linear-no-threshold model focus on its failure to account for biological repair processes and its potential to overestimate risks from low levels of radiation.

6.4 POSSIBLE EXISTENCE OF CRITICAL SUBPOPULATIONS WITHIN THE STUDY AREA

Risks to the larger group of receptors in the study area may not be representative of risks to a smaller group with unique behaviors or susceptibilities. For example, some receptors' behaviors may produce more frequent or more intense exposures than those experienced by the larger group. This was explored in this HHRA by evaluating risks from eating local food like vegetables and fish.

The EPA's PRG calculator contains a list of 25 types of fruits and vegetables that risk assessors may include when calculating exposures from produce consumption. The intent of this large variety is to allow selection of those vegetables commonly consumed by the local population being assessed. In this HHRA, the 23 types of produce included in default parameters within the PRG calculator are included in the assessment of risks from consuming local produce (even those unlikely to grow in southern Ohio). This yields an ingestion rate of 1,485 grams (3.27 pounds) of produce per day for an adult. For a child residential receptor, the rate is 816 grams (1.8 pounds) of produce per day. While it can be said that these generous portions would be likely to overestimate risks to a typical residential receptor from local produce, the additional conservativism is offered to acknowledge a subpopulation that may exist in the rural study area.

Similarly, consumption of local fish was assessed to address the possibility that a sub-set of the local population may exhibit atypical behaviors that bring them into sustained contact with less frequented locations and media. In an effort to minimize the possibility that calculated risks would underestimate actual risks from consumption of local fish, generous portions were assumed when calculating risk estimates. This HHRA assumed a consumption rate of 13.1 kg/y[20] (28.8 lbs of fish flesh per year), which is approximately 50% greater than the 8.8 kg/y (19.5 lbs/y) limit recommended by the Ohio EPA due to methylmercury and PCBs levels reported in Ohio fish (ODH 2019).

Some receptors could display an increased susceptibility to an external stressor like radiation. This uncertainty is partially off-set by use of the RME approach, but stake-holders may wish to explore this possibility in a subsequent investigation.

6.5 BACKGROUND AREA RISKS

Radiation from natural sources is ubiquitous in the global environment. It is supplemented by smaller amounts of radiation from human activities such as the application of fertilizer on fields and fallout generated by weapons-testing and other large-scale nuclear events around the world. The EPA's risk assessment methodology suggests subtracting background area concentrations from concentrations in similar media collected within the study area, where practicable. In this case, that technique is impractical for most of the ROCs evaluated, as concentrations of these

[20] 61 g of fish per day for 214 d/y

ROCs in the study area are often indistinguishable from the range of concentrations found in background area samples collected outside the study area.

This HHRA presents calculated risks to evaluated receptors from the background area (Section 2.1) and study area concentrations separately rather than subtracting an average background concentration from representative concentrations reported in the study area. This treatment produced two sets of risks, one representative of background area conditions and one including contributions of both background area and study area ROCs. The resulting presentation allows stakeholders to compare the relative magnitude of the study area risks with the ever-present risks from background area concentrations of ROCs in soils.

7. CONCLUSIONS AND RECOMMENDATIONS

At the request of the Community, DOE provided funding to the Community via a financial assistance award Ohio University for an investigation to 1) define the nature and extent of the radionuclides of concern within six miles of the PORTS site and 2) evaluate potential health impacts to members of the Community, as described in Section 1.2. In May 2019, Ohio University's Voinovich School of Leadership and Public Service agreed to work closely with County and Community representatives and serve as the independent coordinator for the project. In addition, DOE monitors progress through regular reporting and meetings with OU. However, no technical direction, such as methods, choices of parameter values, selection of pathways, or use of analytical results, was provided by the DOE. Therefore, this HHRA was performed without computational or conclusional input or influence by the DOE. It is based on data collected by a third-party contractor with guidance from local community members. Risks were calculated using EPA methodology and calculational tools. Results, observations, conclusions and recommendations are summarized below.

7.1 RADIONUCLIDES OF CONCERN

In March of 2019, the DOE published the *Portsmouth Gaseous Diffusion Plant Annual Site Environmental Report – 2017 Piketon, Ohio* (DOE 2019a). The report indicated Np-237, Pu-239/240, Tc-99, U-233/234, U-235/236, and U-238 had been detected beyond the PORTS property boundaries. The Community started with DOE's list of detected radionuclides and expanded it to include Am-241 and Pu-238 (Solutient 2020a) during a series of planning discussions. The list of radionuclides the Community established for investigation was included in this HHRA. For completeness, the effects of additional short-lived daughters were incorporated via the respective parent's concentration (Section 4.3.6). The full list of radionuclides regarded in this HHRA is presented in Table 30.

Table 30 Radionuclides Included in this HHRA

Radionuclides (Parent of short-lived daughter)
Am-241
Np-237
Pa-233 (short-lived daughter of Np-237)
Pa-234 (short-lived daughter of U-238)
Pa-234m (short-lived daughter of U-238)
Pu-238
Pu-239/240
Tc-99
Th-231 (short-lived daughter of U-235)
Th-234 (short-lived daughter of U-238)
U-233/234
U-235/236
U-235m (short-lived daughter of Pu-239)
U-238

[a] m – metastable

7.2 EXPOSURE ASSESSMENT

The description of the exposure assessment offered in Section 3 outlines the types of data needed to estimate risks and processes used to gather and evaluate that information. During the initial stages of the project, the resident was determined to be the most appropriate receptor type and a conceptual model of potential exposures (Figure 10) was constructed as described in Section 3.1. As part of this step, risk assessors gathered information about potential receptors in the study area and the exposure pathways identified during construction of the conceptual model. Questionnaires about behavior patterns and diet were circulated among Community members. Information gathered from responses to those questionnaires was supplemented by data from peer-reviewed EPA data sources to create the quantitative descriptions of exposure parameters to be used in the risk assessment (Section 3.3).

Background area and exposure point concentrations of ROCs were then determined in the media identified in the SAP (Solutient 2020a) and the conceptual model (Figure 10); soil, sediment, surface water, and dust. Given that the laboratories reported a number of analytical results as negative values, and many other results were reported within the range of background, the EPA's preferred analytical tool, ProUCL, calculated some negative 95% UCL values. Following the recommendation of the EPA ProUCL Users Guide (EPA 2022c), a professional statistician was then retained to provide more appropriate, media-specific 95% UCLs for ROCs detected in the study area (Section 3.2).

7.3 TOXICITY ASSESSMENT

The toxicity assessment presented in Section 4 provides a general description of radiological cancer induction and introduces EPA's approach to quantitatively assess risks from various exposures to the ROCs evaluated in this HHRA. The EPA's approach assumes a linear relationship exists between exposure and risk and that a simple ratio of risk/unit of exposure, expressed as a "Slope Factor" can be used to convert exposures to risk.

Section 4 presents abbreviated toxicity profiles for the five radioelements evaluated in this HHRA: americium, neptunium, plutonium, technetium and uranium. Radioelements are processed in the body per their respective chemical properties. Some are eliminated with little or no retention. Others deposit in a specific organ, such as bone or a kidney, and are either eliminated from the body at element-specific rates or remain in the organ. These profiles also contain information about the types of health-effects such exposures may produce. Table 16 and Table 17 present the Slope Factors used to convert the exposures quantified in Section 3 to estimates of potential risk.

7.4 RISK CHARACTERIZATION

Concentrations of ROCs in the study area could include contributions from background and non-background sources. The EPA focuses on the extra risks added by non-background sources. Typically, these extra risks are calculated by subtracting background concentrations from the concentrations reported in a study area. In this case, this was not always possible as the study area concentrations were indistinguishable from, or in some cases less than, background concentrations. (An example of U-234 and U-238 soil results is provided in Table 31.) Therefore, the decision was made to calculate and present the total risk and corresponding background risks separately.

Table 31 Comparative Example of Soil Concentrations

Analyte	Soil Average Conc ± StDev [a] Background (pCi/g)	Soil Average Conc ± StDev [a] Study Area (pCi/g)	Statistician's UCL for Study Area Soil (pCi/g)
U-234	1.9±1.6	1.2±1.2	1.25
U-238	1.9±1.4	1.2±1.2	1.28

Potential human health effects from exposure to ROCs were estimated using methods established by the EPA. The EPA PRG and BPRG on-line calculators (EPA 2022a and 2022b) were utilized to determine estimated cancer risks.

Projected risks to a hypothetical receptor consuming relatively large portions of food grown within areas of the study area may exceed EPA's allowable risk range of 10^{-4} (Table 32). As calculated, the greatest contributors to these receptors risk are Tc-99 via produce ingestion (soil) and Pu-238 via ingestion of fish flesh (surface water). For risks from eating produce to exceed 10^{-4}, crops must be grown in soil containing more than 0.327 pCi/g of Tc-99 and hundreds of pounds of local produce must be consumed annually over a lifetime before this pathway is projected to produce risks in excess of 10^{-4}.

It should be noted that the influence of local produce on these projected risks is heavily dependent on the amount of Tc-99 that plants actually absorb through their roots. The EPA's models contain a method to estimate this quantity, but the method uses a single parameter value to represent a phenomenon that has been shown to vary between plant species, soil types and moisture levels (IAEA 2009).

Table 32 Summary of Calculated Risks within the Study Area

Isotope	Resident: Risk from Soil	Resident: Risks from Settled Dust	Gardener: Risks from Produce Consumption	Fisher: Risks from Finfish Ingestion	Swimmer: Risks from Sediment	Swimmer: Risks from Surface Water	Summed Risk
Am-241	2.56E-09	2.31E-08	2.51E-09	-	6.44E-11	-	2.82E-08
Np-237	5.45E-10	3.19E-09	2.53E-09	-	-	-	6.27E-09
Pa-233	2.64E-11	1.88E-12	1.17E-12	-	-	-	2.94E-11
Pa-234	3.10E-09	1.16E-12	5.61E-12	2.72E-09	6.11E-12	1.12E-11	5.84E-09
Pa-234m	1.24E-13	4.91E-17	-	-	2.43E-16	9.98E-16	1.25E-13
Pu-238	3.97E-10	1.69E-08	7.81E-10	4.21E-05	3.74E-11	9.24E-11	4.21E-05
Pu-239/240	2.82E-09	3.50E-08	5.58E-09	-	8.49E-11	0.00E+00	4.35E-08
Tc-99	1.59E-09	3.28E-08	5.44E-05	1.10E-08	1.27E-11	3.01E-11	5.44E-05
Th-231	2.12E-12	8.46E-14	1.41E-13	2.34E-10	6.11E-15	1.58E-12	2.38E-10
Th-234	1.05E-09	4.08E-10	7.29E-10	1.84E-08	1.07E-11	1.24E-10	2.07E-08
U-234	2.15E-07	2.74E-07	2.97E-06	1.19E-08	6.47E-09	5.47E-10	3.48E-06
U-235/236	2.92E-07	1.29E-08	1.39E-07	1.10E-09	8.67E-10	5.00E-11	4.46E-07
U-235m	5.43E-22	6.96E-21	7.74E-21	-	1.69E-23	-	1.53E-20
U-238	1.97E-07	2.39E-07	2.74E-06	7.52E-09	5.45E-09	3.44E-10	3.19E-06
Summed Risk	**7.28E-07**	**6.84E-07**	**6.04E-05**	**4.22E-05**	**1.34E-08**	**1.25E-09**	**1.04E-04**

For comparative purposes, calculated risks for the hypothetical resident exposed within the background area are presented in Table 33.

Table 33 Summary of Calculated Risks within the Background Area

	Resident		Gardener	Fisher	Swimmer		
Isotope	**Risk from Soil**	**Risks from Settled Dust**	**Risks from Produce Consumption**	**Risks from Finfish Ingestion**	**Risks from Sediment**	**Risks from Surface Water**	**Summed Risk**
Am-241	-	-	-	-	-	-	-
Np-237	-	-	-	-	-	-	-
Pa-233	-	-	-	-	-	-	-
Pa-234	4.66E-09	1.50E-12	8.42E-12	3.18E-09	1.32E-11	1.31E-11	7.88E-09
Pa-234m	1.86E-13	3.53E-17	-	-	5.26E-16	1.17E-15	1.88E-13
Pu-238	-	-	-	3.14E-05	-	6.88E-11	3.14E-05
Pu-239240	2.43E-09	-	4.80E-09	-	6.12E-11	-	7.29E-09
Tc-99	9.72E-10	-	3.34E-05	-	3.08E-12	-	3.34E-05
Th-231	3.04E-12	5.40E-14	2.03E-13	2.10E-10	1.11E-14	1.42E-12	2.15E-10
Th-234	1.57E-09	9.89E-10	1.09E-09	2.16E-08	2.32E-11	1.45E-10	2.54E-08
U-234	3.35E-07	2.10E-06	4.26E-06	1.17E-08	1.33E-08	5.37E-10	6.72E-06
U-235/236	4.19E-07	8.26E-08	1.99E-07	9.84E-10	1.58E-09	4.49E-11	7.03E-07
U-235m	4.67E-22	-	6.65E-21	-	1.22E-23	-	7.13E-21
U-238	2.96E-07	5.79E-07	4.12E-06	8.80E-09	1.18E-08	4.03E-10	5.02E-06
Summed Risk	**1.06E-06**	**2.76E-07**	**4.23E-05**	**3.14E-05**	**2.68E-08**	**1.21E-09**	**7.51E-05**

7.5 DOSE ASSESSMENT

The results of a companion dose assessment have been provided in Attachment E. The dose assessment uses a different set of metrics (dose rates instead of risks) to evaluate the health protectiveness of an exposure scenario. This is offered to provide a way to evaluate the reasonableness of the risk assessment results.

Peak dose rates were projected to be < 1 mrem/y, with isotopes of uranium and Tc-99 contributing the largest shares. These dose rates are far below the 25 mrem/y Nuclear Regulatory Commission limit for doses from inactive sites (10 CFR 20.1402).

7.6 SPATIAL DISTRIBUTION OF ROCS IN STUDY AREA

In accordance with the SAP (Solutient 2020a), a great deal of concentration data has been collected in preparation for this HHRA. Many of the ROC concentrations reported in samples collected from the study area are indistinguishable from background samples collected outside the study area. To provide some context to the results that are above the range of background, the concentration results (Conc) for each ROC were divided into four "bins" and plotted on maps of the study area using different colors for each bin. These bins are described and listed in ascending order below:

- $\underline{Conc < L_c}$ (Samples in which the ROC was not detected.)
- $\underline{L_c \leq Conc < 10^{-6}}$ (Samples in which the ROC was detected at concentrations less than the concentration corresponding to EPA's 10^{-6} risk value for that ROC.
- $\underline{10^{-6} \leq Conc < 10^{-4}}$ (Samples in which the ROC was detected at concentrations greater than or equal to the concentration corresponding to EPA's 10^{-6} risk value for that ROC but less than the concentration corresponding to EPA's 10^{-4} risk value for that ROC.)
- $\underline{Conc \geq 10^{-4}}$ (Samples in which the ROC was detected at concentrations greater than the concentration corresponding to EPA's 10^{-4} risk value for that ROC.)

7.6.1 Use of the Critical Value, L_c

As discussed in Section 2.5, the critical value, L_c, identifies a threshold concentration that divides sample results into two groups; results that are too small to be distinguished from blank samples (i.e. not detected), and results that are large enough to indicate the presence of the analyte in the sample (i.e. detected).

7.6.2 Use of EPA's 10^{-6} to 10^{-4} Risk Range

Under the CERCLA program (42 USC §9601), EPA compares calculated risks to a range of risks that it considers to be health protective. This risk range has been designated by the EPA as the "acceptable" risk range for sites regulated by the CERLA Program. This is a legal term, as defined in the National Contingency Plan (the "NCP" 40 CFR 300), which is the regulation that provides the organizational structure and procedures for responding to releases of contaminants in the environment. Acceptable risk levels should not be interpreted as a stringent boundary that separates harm and safety. To exceed the acceptable risk level in the HHRA does not necessarily suggest a potential for harm. Likewise, meeting the acceptable risk levels does not necessarily assure that exposure is harmless.

In the NCP, an acceptable exposure level is defined as the "…concentration level of a contaminant to which the human population, including sensitive subgroups, may be exposed without adverse effect during a lifetime or part of a lifetime..." For known or suspected carcinogens, like radionuclides, acceptable exposure levels are generally expressed as an excess lifetime cancer risk range starting at 10^{-6} (1 in 1,000,000) and extending up to 10^{-4} (1 in 10,000).

As stipulated in the NCP, the "… 10^{-6} risk level shall be used as the point of departure for determining remediation goals [in] the presence of multiple contaminants at a site or multiple pathways of exposure…". The EPA has further clarified the extent of the acceptable risk range by stating that the upper boundary generally is not a discrete line at $1x10^{-4}$. Risks slightly greater

than $1x10^{-4}$ may be considered to be health protective on a case-by-case basis for purposes of a risk assessment performed in accordance with CERCLA.

The ROC concentrations corresponding to EPA's "acceptable risk range" for a receptor eating local produce were selected as reference concentrations to provide perspective for the concentration data collected during this study. This does not signify that risks in the vicinity of a particular data point correspond to the listed risk level. An estimation of risk at that location would require additional measurements sufficient to characterize concentrations in a large garden.

7.6.3 Observations Regarding Spatial Distribution of ROCs in Study Area

Attachment B contains maps of sample locations where individual samples contained ROC concentrations corresponding to $1x10^{-6}$ and $1x10^{-4}$ risk values. This compilation allows stakeholders to identify individual samples, sample groups and spatial trends in the data.

Concentrations of ROCs are unevenly distributed across the study area. This uneven distribution can be seen by examining a map of Tc-99 results plotted within the study area (Figure 11). This is further illustrated by zooming into the area around ZCMS (Figure 12). Soil samples collected approximately 200 feet to the north of ZCMS contained relatively low concentrations of Tc-99 (-0.51 to 0.206 pCi/g), while the highest reported Tc-99 soil concentration was measured in a sub-surface soil sample approximately 2,000 feet to the northeast of ZCMS.[21]

7.7 CONCLUSIONS

Concentrations of ROCs are not evenly distributed across the study area. This mottled pattern does not conclusively implicate a particular source, but the presence of above background levels of the fission product Tc-99 in local soils, combined with the knowledge that PORTS handled recycled uranium from reactor fuel, suggests PORTs may have been a source of the Tc-99.

Calculated risks to typical residents in the study area, as described in Section 3, from the ROCs listed in Section 2 can be expected to be less than the point of departure (1 in a million or 10^{-6}) used by EPA to identify potentially harmful situations evaluated under the CERCLA program.

Potential subpopulations were identified by the community and the risk assessment team during the course of the investigation, including school children, residents consuming substantial quantities of local foods, life-long residents and recreational users of local streams. Of these groups, the highest projected risks were projected to residents eating more than 300 pounds of produce from local sources each year (approximately 6 in 100,000). Similarly, risks to an individual eating 29 pounds of fish flesh per year were calculated to approach 5 in 100,000. Risks to other groups, such as students attending schools in the study area and swimmers in local water bodies were estimated to range between 1×10^{-8} to 8×10^{-7}, which are below EPA's acceptable risk range.

[21] Additional samples were collected from the first foot of soil at that location and Tc-99 was found throughout that 12-inch interval. The highest Tc-99 concentration in soil (6.9 pCi/g) was reported in sample SJ22-SO-J-06-A, which was collected from the 8-12 inch interval below ground surface.

An initial survey of items in Zahn's Corner Middle School was conducted by Solutient at the request of the Scioto Valley Local Board of Education. Solutient concluded "(t)here was no evidence of radioactive contamination identified. All surveyed materials removed from the school and those remaining are free from any radioactive contamination above background." (Exhibit A in Attachment F). A subsequent investigation by Solutient collected dust samples from a variety of surfaces in other local schools. A composite risk from all ROC's in this dust was calculated using a compilation of the highest concentration reported for each radionuclide. This approach was designed to produce an estimate of the maximum credible risk to local students in the schools (Attachment F). Using this approach, risks to students were calculated to be 3.2×10^{-7}, which is less than the lower end of EPA's acceptable risk range.

Technetium-99 in local produce was the largest contributor to both risks and doses, followed by Pu-238 in fish. Large amounts of these foods must be consumed over a lifetime before calculated risks approach the upper end of EPA's acceptable risk range of 10^{-6} to 10^{-4}.

7.8 RECOMMENDATIONS

It is recommended that supplemental sampling of plants and associated soil be conducted in gardens and farms within the study area and the Tc-99 content of the samples collected be measured. This will directly measure Tc-99 concentrations in food crops and produce a site-specific soil-to-plant transfer factor for this potentially important pathway, thus reducing the considerable uncertainty imparted by the simple first-order partitioning model used by EPA's calculators to estimate this uptake.

It is recommended that supplemental sampling of fish in surface waters that are downstream of PORTS outfalls and non-point sources and that the Pu-238 content of the fish flesh be measured. This will address uncertainties in the pathway producing the second highest exposure potential estimated during the course of this investigation.

If the community still has questions about the radiological condition of ZCMS, it will be important to verify that the interior of ZCMS is not contaminated. It is recommended that access to the interior of the school be granted and additional sampling be conducted inside the building. In lieu of such verification sampling, a *Multi-Agency Radiation Survey and Site Investigation* Manual (MARSSIM 2000)[22] closure of the building should be considered prior to any demolition or local disposal. The MARSSIM methodology provides guidance for assessing radiological contamination on building surfaces and is intended to demonstrate that a site meets the regulatory requirements.

[22] As of the writing of this document, the MARSSIM Revision 2, published in May 2020, is still listed as proposed on the EPA website (https://www.epa.gov/radiation/multi-agency-radiation-survey-and-site-investigation-manual-marssim-proposed-revision-2). Therefore, the MARSSIM 2000 is cited.

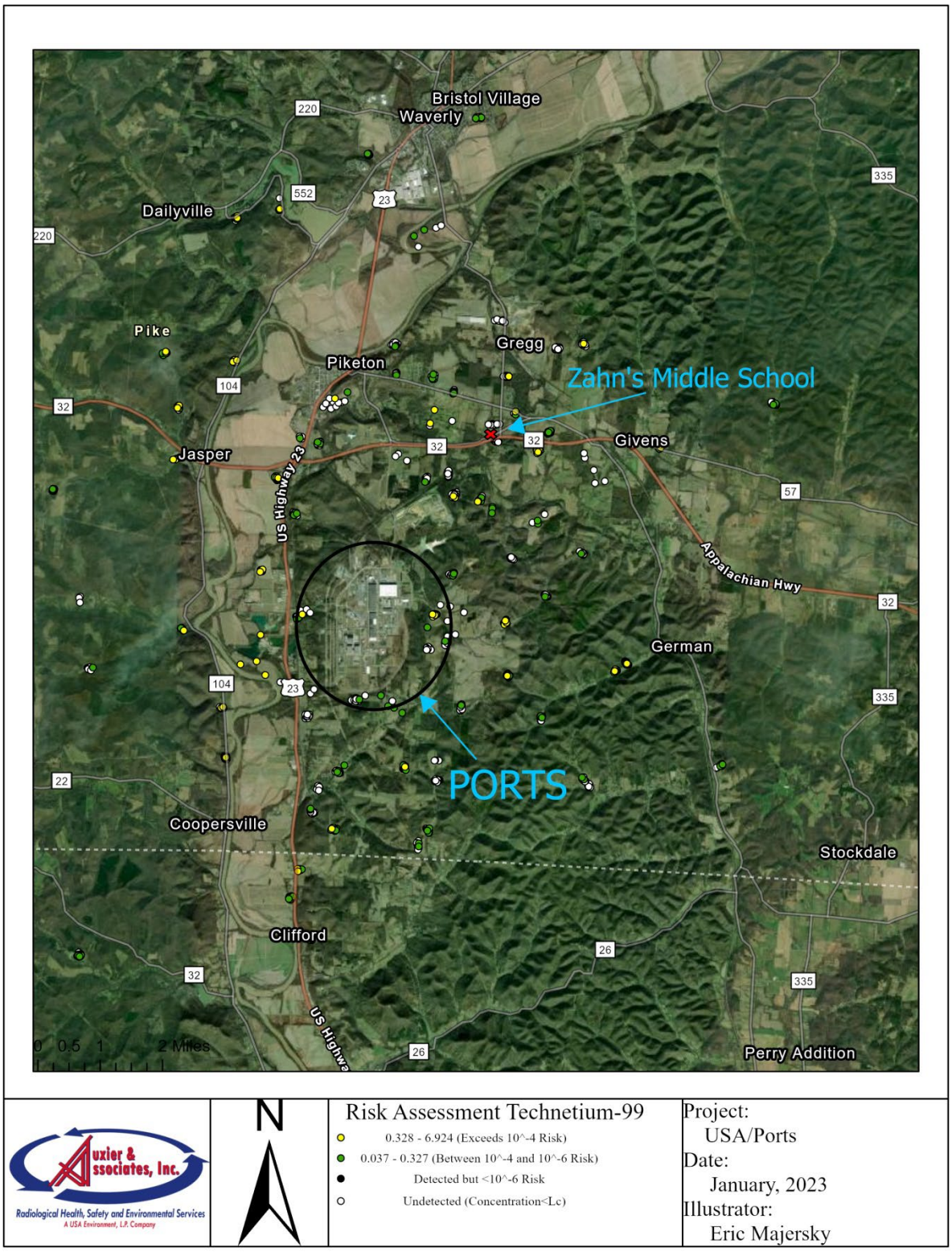

Figure 11 Distribution of Tc-99 within Study Area

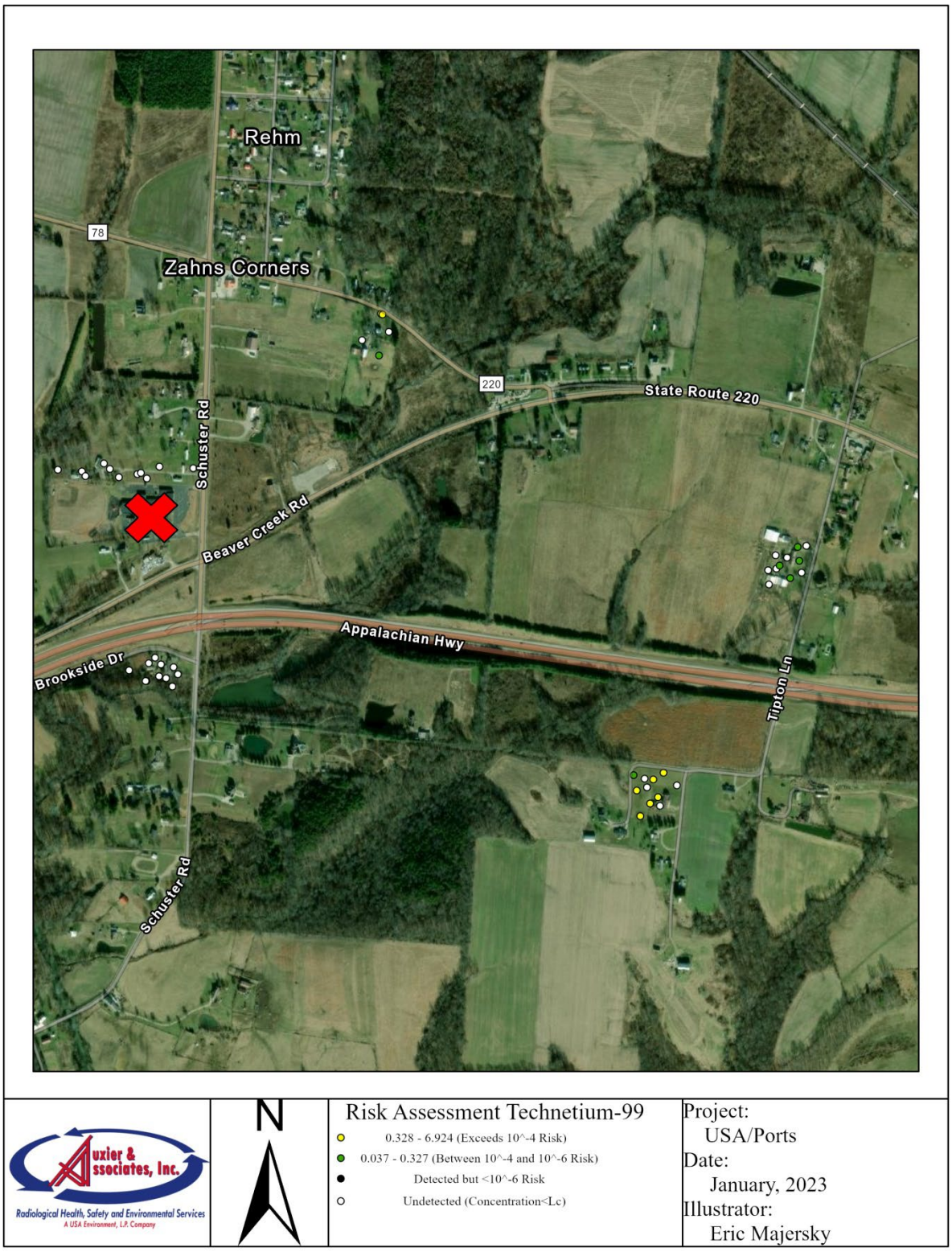

Figure 12 Distribution of Tc-99 near ZCMS

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