APPENDIX 3A:
Subsistence Farmer and Revised Industrial Worker Exposure Scenarios

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APPENDIX 3A. SUBSISTENCE FARMER AND REVISED INDUSTRIAL WORKER EXPOSURE SCENARIOS

3A.1 INTRODUCTION

The Luckey Remedial Investigation (RI) Report (USACE 2000) includes baseline risk calculations for a number of receptors, including a resident farmer and an industrial worker. Subsequent meetings between site planners and stakeholders resulted in the introduction of an additional, more conservative receptor based on the requirements of 10 Code of Federal Regulations (CFR) Part 20 Subpart E and Ohio Administrative Code (OAC) 3701:1-38-22 to evaluate the "critical group" for radionuclides. In Ohio, the critical group for unrestricted land use has been consistently defined as the subsistence farmer. The evaluation of the industrial worker was updated utilizing RESRAD 6.1 and updated RESRAD input parameters per stakeholder input. This appendix specifically addresses the risk calculations and revised cleanup goals resulting from the evaluation of the subsistence farmer and the revised industrial worker scenarios. Although not required by either 10 CFR Part 20 Subpart E or OAC 3701:1-38-22, exposure to chemical constituents also was evaluated using the subsistence farmer scenario. Re-evaluation of the industrial worker is required only for radiological constituents because only RESRAD-specific parameters have been revised (industrial exposure parameters for chemical constituents are consistent with the RI). Additionally, radiological dose estimates are presented for consideration in the Feasibility Study (FS) alternative development, given compliance with the dose-based limits in 10 CFR Part 20 Subpart E may be required. The focus of this appendix is to summarize the risk assessment method and risk results for the new and revised receptors without repeating information presented in the RI Report.

The risk assessment process used to evaluate the subsistence farmer and the revised industrial worker scenarios is consistent with the RI Report. The exposure units, exposure point concentrations (EPCs), and constituents of potential concern (COPCs) are the same as those identified in the RI Report. The subsistence farmer is an extension of the resident farmer scenario evaluated in the RI Report. As with the resident farmer, the soil ingestion, dust inhalation, external gamma, and groundwater ingestion (from an on-site well) pathways were evaluated under the subsistence farmer scenario. However, the subsistence farmer is assumed to be exposed through additional pathways. These additional pathways include ingestion of various foodstuffs (homegrown produce, milk, and beef) produced/cultivated onsite. A subsistence farmer at the Luckey site is assumed to produce fruits, vegetables, beef, and milk on-site. It is not likely that subsistence fishing would also occur on the site, given the limited area of the site, as well as current land-use surrounding the site. It is considered conservative to assume the area will be used for human occupancy, farming, and raising livestock, instead of using the same contaminated area to build a pond large enough to maintain a substantial food-fish population. The revised industrial worker is identical to that presented in the RI except that a few geotechnical parameters used in RESRAD have been revised to be more site-specific and consistent with the subsistence farmer scenario.

Evaluation of the more conservative receptors, subsistence farmer, and revised industrial worker, may identify additional constituents that should be considered constituents of concern (COCs) and may reduce previously identified cleanup goals. In the baseline human health risk assessment, Section 6 of the RI Report, risks from chemicals (Section 6.1) and radionuclides (Section 6.2), were presented separately. The following Atomic Energy Commission (AEC)-related soil constituents were identified as COPCs: beryllium, lead, protactinium-231, radium-226, thorium-230, uranium-234, and uranium-238. In the RI Report, these constituents were evaluated using the resident farmer and original industrial worker scenarios. This Appendix evaluates these same constituents using the subsistence farmer scenario (chemicals and radionuclides) and revised industrial worker scenario (radionuclides only). The evaluations of chemical and radionuclide COPCs are presented in Sections 3A.2 and 3A.3, respectively.

3A.2 REVISION OF CLEANUP GOALS FOR FINAL CHEMICAL COCS

In the RI chemical risk assessment for the resident farmer scenario, only two AEC-related constituents, (beryllium and lead), were identified as COCs in soil. The remaining two AEC-related constituents, (arsenic and barium), were not identified as COPCs in soil because on-site concentrations did not exceed background and/or screening criteria used to identify COPCs (see Section 6.2 of RI Report, USACE 2000). Therefore, evaluation of the subsistence farmer scenario cannot result in the identification of additional AEC-related chemical constituents as final COCs, and revision of the chemical risk assessment is not necessary. However, the cleanup goals established for beryllium and lead must be re-evaluated to ensure that pathways based on the new subsistence farmer scenario have been addressed.

There are three potential sources of media-specific cleanup goals: concentrations based on site-specific background data, applicable or relevant and appropriate requirements (ARARs), and risk-based concentrations (RBCs). In the RI Report, the resident farmer (child) was identified as the most sensitive receptor for exposure to the two final chemical COCs identified in soil, beryllium and lead. There are no ARARs for beryllium and lead in soil; therefore, RBCs were developed as potential cleanup goals to ensure the protection of this receptor. The following sections discuss the impact of altering the receptor scenario from resident farmer (child) to subsistence farmer (child) with respect to the RBC.

3A.2.1 Revision of Beryllium RBC

The RBC for beryllium in soil was originally published in the RI Report. This RBC was 156 mg/kg based on exposures to the most sensitive receptor evaluated, the future resident farmer (child). Exposure pathways quantitatively evaluated were soil ingestion, dermal contact, and inhalation of fugitive dust. This RBC has been revised to include food intake pathways to be consistent with a subsistence farmer scenario. Food intake pathways were evaluated quantitatively (ingestion of home-grown produce) and qualitatively (ingestion of meat and milk). A resident farmer (child) scenario modified to address food intake pathways thus becomes a subsistence farmer (child) scenario. Evaluation of the food pathways revealed only home-grown plant uptake/consumption contributed to risk from beryllium. This pathway is a reasonable addition to the resident farmer scenario, which was determined in the RI to be a potential future land use of the Luckey site. Ingestion of home-grown produce is likely to occur under a resident farmer scenario and it is likely to contribute to risk. Therefore, this pathway was evaluated quantitatively and used to revise to the RBC for beryllium. This evaluation is presented below.

3A.2.1.1 Quantitative Evaluation of Ingestion of Home-grown Produce

In order to evaluate the ingestion of home-grown produce pathway quantitatively, two calculations are necessary. The first calculation estimates the amount of beryllium uptake by plants that are consumed by the receptor (i.e., soil-to-plant transfer factor). The second calculation estimates the receptor's daily average exposure to beryllium from the consumption of produce (i.e., daily intake rate).

Soil-to-Plant Transfer Factor

Produce is not currently grown at the Luckey site; therefore, beryllium concentrations in produce cannot be measured directly. Instead, they must be modeled from concentrations in other environmental media. Beryllium contamination is limited primarily to soil and direct uptake by plants is expected to be the primary mechanism of beryllium transfer to plants. Soil-to-plant transfer factors (SP) for both fruiting parts (1.00×10^{-2}) and vegetative parts (1.50×10^{-3}) of plants are derived using literature values for transfer rates and converting dry weight to wet weight. These values were used to estimate transfer of beryllium in soil to plants using the following calculations:

$$SP_v = Ct_v/Cs \times CFv \text{ and}$$

$$SP_r = Ct_r/Cs \times CFr$$

Where:

SP_v = the soil to plant transfer factor (vegetative parts) adjusted for wet weight
SP_r = the soil to plant transfer factor (fruiting parts) adjusted for wet weight
Ct_v/Cs = ratio of beryllium in plant tissue (vegetative parts) to beryllium in soil = 1.5×10^{-3} Kg_{soil}/kg_{tissue} (Baes et. al. 1984, as per Table 7.A.5, USACE 2000)
Ct_r/Cs = ratio of beryllium in plant tissue (fruiting parts) to beryllium in soil = 1.0×10^{-2} Kg_{soil}/kg_{tissue} (Baes et. al. 1984, as per Table 7.A.5, USACE 2000)
CF_v = dry weight to wet weight (vegetative parts) conversion factor (see below)
CF_r = dry weight to wet weight (fruiting parts) conversion factor (see below)

Plant concentration must be adjusted from dry weight to wet weight using a conversion factor (CF). Table 9-27 of United States Environmental Protection Agency's (EPA) Exposure Factors Handbook, Volume II (EPA 1997) contains moisture content percentages for many common fruits and vegetables. Based on a review of this material, the following CF values are proposed:

Fruiting Parts
Temperate fruits (apples, pears, grapes, etc) – 83 to 91%
Vegetables (carrots, onions, cauliflower, etc) – 79 to 96%
Beans and grains (beans and corn) - 67 to 90%

Approximate average = 85%; CF = 0.15

Vegetative Parts
Leafy greens (cabbage, lettuce, collard, etc) – 89 to 95%

Approximate average = 92%; CF = 0.08

Using these values, SP_v is equal to 8.0×10^{-4} and SP_r is equal to 2.25×10^{-4}. These values enable the estimation of the beryllium concentration in edible plant parts as follows:

$$\text{Beryllium concentration in plants (vegetative parts)} = Be_v = EPCsoil \times SP_v \text{ and}$$

$$\text{Beryllium concentration in plants (fruiting parts)} = Be_r = EPCsoil \times SP_r$$

Where:

EPCsoil = the exposure concentration in soil (mg/kg)
SP_v = Soil-to-plant (vegetative parts) uptake factor (kg soil/kg plant)
SP_r = Soil-to-plant (fruiting parts) uptake factor (kg soil/kg plant)

Daily Intake Rate for Plant Intake Pathway

The daily intake rates from consumption of home-grown produce are estimated using the following equation:

$$\text{Intake from vegetative parts (mg/kg-day)} = (Be_v \times IRv \times FI \times EF \times ED) / (BW \times AT)$$

$$\text{Intake from fruiting parts (mg/kg-day)} = (Be_r \times IRr \times FI \times EF \times ED) / (BW \times AT)$$

Where:

Be_v = Beryllium concentration in plants - vegetative parts (mg/kg)
Be_r = Beryllium concentration in plants - fruiting parts (mg/kg)
IR_v = Ingestion rate for produce – vegetative parts (kg/meal)
IR_r = Ingestion rate for produce – fruiting parts (kg/meal)
FI = Fraction ingested from contaminated source (unitless)
EF = Exposure frequency (meals/year)
ED = Exposure duration (year)
BW = Body weight (kg)
AT = Averaging time (days)

The values for each of these parameters and an example calculation are presented in Figure 3A.1. The total intake rate is the sum of the intake rates for vegetative and fruiting parts.

Risk Characterization for Plant Intake Pathway

The plant intake pathway is an oral exposure route; therefore, oral toxicity criteria are used to estimate cancer and noncancer risks. There is no U.S. EPA approved oral cancer slope factor (SF_o) for beryllium; therefore, cancer risks from this pathway cannot be estimated. The oral noncancer reference dose (RfDo) is 2.0×10^{-3} mg/kg-day^{-1}. The following equation is used to estimate noncancer risk.

Noncancer hazard quotient = total intake x RfDo.

Table 3A.1 presents the risks from exposure to beryllium at Exposure Unit (EU) 2 at the Luckey site. This EU had the highest noncancer risk to the resident farmer receptor of any of the units evaluated in the RI Report. The plant (produce) ingestion pathway has been added to the previous soil exposure pathways (ingestion and inhalation) evaluated in the RI Report. The plant ingestion pathway accounts for approximately 16% of the total noncancer risk. The hazard quotient for the plant ingestion pathway is 9.48×10^{-1}, and total HI for EU 2 is 5.8. The total cancer risk is 4.6×10^{-8}, which is more than an order of magnitude less than the lower end of the EPA target risk range of 10^{-4} to 10^{-6}.

3A.2.1.2 Qualitative Evaluation of Other Pathways (meat and milk)

Ingestion of meat and milk from beryllium-contaminated areas is not expected to be a significant exposure pathway for exposure to beryllium relative to direct pathways such as soil ingestion. According to EPA's National Primary Drinking Water Regulations, Technical Fact Sheet on Beryllium, beryllium is not expected to bioaccumulate. In addition, beryllium is not on EPA's list of priority persistent, bioaccumulative, and toxic (PBT) chemicals (www.epa.gov/pbt). PBT pollutants are chemicals that are toxic, persist in the environment, and bioaccumulate in food chains, and thus pose risks to human health. Mercury and alkyl-lead are the only two metals listed.

Beryllium has low gastrointestinal (GI) absorption potential. According to EPA's Toxic Review of Beryllium and Compounds (EPA 1998), oral administration results in less than 1% absorption and storage. The remainder is eliminated in the feces. The RI used a factor of 0.7% based on Reeves (1965). This value is currently proposed for use in EPA's Dermal Exposure Assessment Guidance. Beryllium that is inhaled has a greater absorption potential; however, the absorbed beryllium is incorporated in the bone and organs rather than in muscle. Muscle is the primary food product of meat, compared to organs and bone.

The low potential for bioaccumulation and low GI absorption indicate that beryllium is unlikely to be present in milk and meat in concentrations that would cause significant exposure relative to the

direct exposure pathways such as soil ingestion. The small amounts of beryllium that would be absorbed by grazing animals will be incorporated into portions of the animals that are rarely eaten. If eaten, the low GI absorption in humans would reduce exposure to even lower levels. As a result of these considerations, a quantitative assessment of the milk and meat pathways is not warranted.

3A.2.1.3 Revised RBC for Beryllium

The revised RBC for beryllium in soil is based on exposures to the most sensitive receptor, the subsistence farmer (child). Exposure pathways included in the calculation are soil ingestion, inhalation of fugitive dust, and consumption of homegrown produce. The RBC is based on the EPA target threshold for noncancer risk of 1 and corresponds to a soil concentration of 131 mg/kg. This value is approximately 16% less than the previously calculated RBC (156 mg/kg) for the resident farmer child, which did not include the plant ingestion pathway.

It is important to note that this RBC is designed to protect a child receptor. The National Oil and Hazardous Substances Pollution Contingency Plan (NCP) requires the protection of the reasonable maximum exposure (RME) receptor, which typically is an adult exposure duration of 30 years. The risk calculations in the RI demonstrated that, for beryllium, a child receptor is a more sensitive receptor for the pathways evaluated. In addition, sensitization to beryllium, which may predispose an individual to the development of berylliosis, is not well understood. The potential for the child receptor to represent a sensitive subgroup of the exposed population and the uncertainties surrounding the beryllium sensitization process suggest a conservative RBC based on the child receptor is more appropriate for the Luckey site than the less conservative RME adult receptor. The RBC for an adult receptor would be approximately 10 times higher than the RBC for the child receptor. Therefore, the RBC of 131 mg/kg is recommended as the cleanup goal for beryllium in soil.

3A.2.2 Lead RBC

The RBC for lead was not calculated in the same manner as beryllium or other chemical constituents at the Luckey site. Lead does not have toxicological reference values because risks from exposure to lead are better evaluated by predicting the associated blood lead level. Blood lead levels have been accepted as the best measure of external lead dosing. Sensitive populations include preschool age children and fetuses. In these populations, a blood lead level of between 10 and 15 micrograms per deciliter (µg/dL) has been associated with a level at which no adverse effects would be expected. The approach used herein relates intake of lead from soil to blood lead concentrations in residential children and to women of child-bearing age who may be exposed to lead in soil while working at the site. Protection of a hypothetical fetus of an occupationally-exposed mother ensures other workers at the site also will be adequately protected.

A risk-based cleanup goal of 400 mg/kg lead in soil was established by EPA based on the Revised Interim, Soil Lead Guidance for CERCLA sites RCRA Corrective Action Facilities (EPA 1994a). This concentration is supported by EPA's Integrated Exposure Uptake Biokinetic Model (IEUBK) for Lead in Children (EPA 2001). The IEUBK predicts that 400 mg/kg of lead in soil could cause a six year old resident child (averaged across the preceding 84 months) to have a probability of no greater than 5% of having a blood lead level of 10 µg/dL. For current and future resident farmer scenarios, the RBC for lead is 400 mg/kg. This RBC is consistent with EPA's recently issued 400 mg/kg standard for lead in bare soil in children's play areas as presented in Section 403 of the Toxic Substances Control Act (TSCA) (40 CFR Part 745, Lead; Identification of Dangerous Levels of Lead; Final Rule). This RBC is less than the standard of 1200 mg/kg average for soil outside of children's play areas.

The IEUBK model used to develop the 400 mg/kg lead in soil value accounts for a number of exposure pathways other than direct exposures to soil that can contribute to an individual's total lead exposure. One of these additional pathways is dietary lead intake. These default dietary intake values account for lead in various food products. While not specifically a subsistence farmer scenario, the default exposure scenario in the IEUBK model does account for the types of pathways one would evaluate for this receptor. In addition, according to the User's guide for IEUBK (EPA 2001, p. 25), "Model predictions are not very sensitive to … this parameter"; where "this parameter" refers to change in concentration of lead in food. Since this is not a very sensitive input parameter, there is no need to evaluate this pathway further for the subsistence farmer (relative to resident farmer), where we might expect a higher concentration of lead in food produced in contaminated soils. Therefore, the 400 mg/kg is believed to be protective of receptors under a subsistence farmer scenario.

3A.3 REVISION OF RADIONUCLIDE RISK ASSESSMENT

Revising the radiological risk assessment to include a subsistence farmer and the revised industrial worker has the potential to both identify new radiological COCs and to lower cleanup goals for previously identified final COCs. Therefore, additional baseline risk calculations are necessary. These calculations are presented using the same radionuclide EPCs and exposure unit assumptions as presented in the RI Report. Revised cleanup goals are developed based on the additional baseline risk calculations. Radiological dose calculations also are presented for the new/revised receptors, assuming FS alternatives may require compliance with the dose-based standards in 10 CFR Part 20 Subpart E.

3A.3.1 Method

The RESidual RADiation computer code (RESRAD), Version 6.1, is used to estimate baseline risk to the subsistence farmer and revised industrial worker. RESRAD Version 6.1 uses slope factors derived from Federal Guidance Report No. 13 morbidity values (EPA 1999) to estimate pathway-specific risk. Exposure pathways for the subsistence farmer include external gamma, inhalation (excluding radon), plant ingestion, meat ingestion, drinking water ingestion, and soil ingestion. As stated earlier, the aquatic foods ingestion pathway is not evaluated considering the limited radiologically contaminated surface area at the site and competing pathways. Exposure pathways for the revised industrial worker include external gamma, inhalation (excluding radon), drinking water ingestion, and soil ingestion. Risk estimates are performed to evaluate potential risks within a 1,000-year period, allowing the RESRAD code to account for leaching, radiological ingrowth and decay, erosion, etc. over the evaluation period.

RESRAD uses over 100 relevant exposure parameters to estimate risk. Table 3A.2a lists these parameters for the subsistence farmer scenario along with the associated units, RESRAD default value, selected value, and the source of the selected value. Table 3A.2b lists parameters for the revised industrial worker (the RI industrial worker parameters also are presented for comparison). Many of the selected values are RESRAD defaults, as site-specific data or more appropriate literature values are not currently available. Other parameters are selected to be consistent with the RI receptors, as appropriate, or otherwise using information presented in the RI Report. Parameter values also are selected to be consistent with the existing Luckey site groundwater model and to correspond with guidance currently used by the State of Ohio.

A sensitivity analysis was performed on the value of the uranium Kd parameter to be utilized in RESRAD. This analysis was performed to estimate the relationship between Kd and uranium breakthrough times (in groundwater) at the Luckey site. Results indicate that a Kd of 15 cm^3/g, while conservative, allows for the evaluation of exposure to uranium in both soil and groundwater.

Radionuclides considered in the RI baseline risk calculations include actinium-227, protactinium-231, radium-226, radium-228, thorium-228, thorium-230, thorium-232, uranium-234, uranium-235, and uranium-238. The same screening process used in the RI Report was applied to these constituents to identify the five radionuclide COPCs: protactinium-231, radium-226, thorium-230, uranium-234, and uranium-238. It is assumed that radium-226 is in equilibrium with lead-210, thus radium-226 risks are calculated assuming equal concentrations of radium-226 and lead-210.

RESRAD output, having used appropriate input parameter values, contains risk-to-source ratios (RSRs) that represent the risk associated with a soil concentration. RESRAD generates the RSRs values for individual radionuclides and pathways after modeling environmental transport, radiological ingrowth and decay, and receptor exposure (e.g., inhalation and external gamma exposure). Baseline risk is then calculated by multiplying the EPCs by the appropriate RSRs. Summing the risk estimate across pathways and radionuclides provides the total risk from the exposure unit of interest. This method is consistent with that used in the RI Report.

Baseline risk estimates are used to identify exposure units with unacceptable risk and to identify preliminary COCs. In the FS, final COCs are defined as any individual radionuclide with a total risk (across all pathways) greater than 1 in 100,000 (or 10^{-5}) given that the total risk to a receptor is greater than 10^{-4}.

Similar methods are used to estimate radiological dose to the subsistence farmer. The same exposure pathways are considered, the same radionuclides are considered, and the same parameter values are selected. There are two primary differences in the dose versus risk calculations. First, RSRs are replaced with dose-to-source ratios (DSRs). A DSR represents the yearly dose for a given soil concentration and is reported with the units mrem/yr/pCi/g, while an RSR represents the lifetime cancer risk from exposure to soil over the 30-year exposure duration with unit of risk/lifetime/pCi/g. Second, total doses greater than 25 mrem/yr are assumed to be significant (to match the base 10 CFR Part 20 Subpart E limit), while no radionuclide-specific threshold is considered.

3A.3.2 Results

Table 3A.3a presents RSRs for the subsistence farmer scenario, including values for year 0.0 (current) and year 1,000. Table 3A.3b presents the revised industrial worker RSRs. Confirmatory RESRAD evaluations were executed to demonstrate risk results did not peak between years 0.0 and 1,000. Thus, risk estimated using year 0.0 and year 1,000 RSRs are assured to represent maximums for the evaluation period. The 1,000-year values are listed because some radionuclide and pathway combinations tend to produce maximum risks at the end of the evaluation period. Risk estimates are calculated using both sets of RSR values to assure that maximum risk estimates may be compared to risk criteria. RESRAD output shows that radionuclides do not produce maximum risk estimates between years 0.0 and 1000, thus assuring that maximum total risks are estimated using Table 3A.3a and Table 3A.3b RSRs. Tables 3A.3a and 3A.3b also present DSRs for the subsistence farmer and revised industrial worker, respectively. Maximum doses also are assured using the year-0.0 or year 1000 DSR values.

Tables 3A.4a and 3A.4b, respectively, present subsistence farmer and revised industrial worker risk estimates for exposure units using data from zero to 10 ft below the ground surface. Tables 3A.5a and 3A.5b, respectively, present subsistence farmer and revised industrial worker risk estimates for exposure units using data from zero to 2 ft below the ground surface. Tables 3A.6a and 3A.6b, respectively, present subsistence farmer and revised industrial worker radiological dose estimates for exposure units using data from zero to 10 ft below the ground surface. Tables 3A.7a and 3A.7b, respectively, present subsistence farmer and revised industrial worker radiological dose estimates for

exposure units using data from zero to 2 ft below the ground surface. The exposure units and calculation method are consistent with the approach presented in the RI Report.

The subsistence farmer baseline risk calculations shown in Tables 3A.4a and 3A.5a indicate unacceptable risk for all three exposure units and regardless of the evaluation period. Risks are higher using zero to 2 ft exposure point concentrations, reaching a maximum of 2.0×10^{-3} in EU 1. These total risk estimates indicate that there is unacceptable risk for a subsistence farmer at the Luckey site. Individual radionuclides with risk estimates above 10^{-5} include radium-226 (including lead-210), thorium-230, uranium-234, and uranium-238. These radionuclides are identified in the FS as final COCs for the subsistence farmer.

The radiological dose calculations shown in Tables 3A.6a and 3A.7a indicate doses exceeding the 25 mrem/yr limit only in EUs 1 and 2. The maximum dose in EU 3 is 21 mrem/yr using the zero to 2 ft exposure concentration and the year-0.0 DSRs. In general, doses are higher using zero to 2 ft exposure point concentrations for all exposure units, reaching a maximum of 127 mrem/yr in EU 1. These estimates indicate that there is unacceptable risk for a subsistence farmer in Luckey site EUs 1 and 2. Doses in EU 3 may be considered acceptable because the maximum estimate is less than 25 mrem/yr.

The revised industrial worker baseline risk calculations shown in Tables 3A.4b and 3A.5b indicate acceptable risk for all three exposure units regardless of evaluation period. Risks are higher using zero to 2 ft exposure point concentrations, reaching a maximum of 6.3×10^{-5} in EU 1. These total risk estimates indicate risk averaged over an exposure unit is acceptable for an industrial worker at the Luckey site. Therefore, no radionuclides are identified in the FS as risk-based COCs for the revised industrial worker.

The radiological dose calculations shown in Tables 3A.6b and 3A.7b indicate no exceedences of the 25 mrem/yr dose limit. The maximum dose estimate is 16 mrem/yr using the zero to 2 ft exposure concentration and the year-1000 DSRs from EU 1. In general, doses are higher using zero to 2 ft exposure point concentrations for all exposure units. These total risk estimates indicate doses averaged over an exposure unit are acceptable for the revised industrial worker at the Luckey site. Therefore, no radionuclides are identified in the FS as dose-based COCs for the revised industrial worker.

3A.3.3 Conclusion

Baseline risk and radiological dose calculations are presented for a subsistence farmer, a more conservative receptor than those evaluated in the RI Report, and a revised industrial worker. Risk and dose calculations mirror those completed in the RI Report with the same exposure unit definitions, exposure point concentrations, and general method. RESRAD Version 6.1 is used to calculate risk from radiological constituents in site soils to determine if results exceed the unacceptable total risk threshold of 10^{-4}. RESRAD also is used to compare dose estimates against the 25 mrem/yr standard in 10 CFR Part 20 Subpart E.

Results indicate that total risks exceed the 10^{-4} threshold for all exposure units for the subsistence farmer scenario. Additionally, radium-226, thorium-230, uranium-234, and uranium-238 are identified as final COCs for the Luckey site and the subsistence farmer scenario. Results also indicate subsistence farmer total doses exceed 25 mrem/yr in EUs 1 and 2, but are less than 25 mrem/yr in EU 3. Total risk estimates for the revised industrial worker are below 10^{-4} for all exposure units and total dose estimates are below 25 mrem/yr for all exposure units. Therefore, no radiological COCs are identified for the revised industrial worker.

3A.4 REVISED CLEANUP GOALS FOR FINAL RADIOLOGICAL COCS

Having identified the four radiological COCs for the subsistence farmer scenario, cleanup goals are calculated for use in site planning (e.g., volume estimates) and, eventually, remedial design. This section describes the method used to calculate cleanup goals and presents these values for each radiological COC.

As mentioned above, risk calculations were performed for a subsistence farmer scenario. Baseline risks were calculated using the RESRAD code, Version 6.1. The code generates baseline risk calculations and RSRs plus DSRs that can be used to calculate cleanup goals. An RSR, in unit risk per pCi/g, represents the total lifetime risk associated with 1 pCi/g of a particular radionuclide in soil. Similarly, a DSR, in units mrem/yr per pCi/g, represents the total yearly dose associated with 1 pCi/g of a particular radionuclide in soil. RSRs and DSR values are used to calculate cleanup goals as follows:

$$CG_{Rj}\ (pCi/g) = \frac{Risk\ Limit}{RSR_j\ (risk/pCi/g)}, \qquad \text{Equation 1}$$

and

$$CG_{Dj}\ (pCi/g) = \frac{Dose\ Limit\ (mrem/yr)}{DSR_j\ (mrem/yr/pCi/g)}. \qquad \text{Equation 2}$$

Where:

CG_{Rj} = risk-based cleanup goal for radionuclide j, and
CG_{Dj} = dose-base cleanup goal for radionuclide j.

Cleanup goals are calculated given a dose limit and DSR values for each final COC. For the Luckey site, a dose of 25 mrem/yr is established as a relevant and appropriate limit for radiological COCs (as per 10 CFR Part 20 Subpart E and OAC 3701:1-38-22). Cleanup goals in this FS are presented for 25 mrem/yr dose-based endpoint. Cleanup goals are also presented, per the subsistence farmer scenario baseline calculation, for years 0.0 and 1000. This approach is taken because some radionuclides produce a maximum risk/dose at year 0.0 while others produce maximum risk/dose at the end of the 1,000-year evaluation period. For example, radium-226 produces the largest risk/dose at year 0.0, thorium-230 produces the maximum risk at year 1,000 due to the ingrowth of radium-226, and uranium isotopes produce maximum risk/dose at year 1,000 when concentrations in groundwater are the most elevated. Thus the time at which the total risk/dose reaches a maximum value is dependent on the distribution of radiological COCs. Cleanup goals for years 0.0 and 1000 are provided in Table 3A.8.

The cleanup goal values listed in Table 3A.8 represent single radionuclide concentrations that produce a dose limit. Note these cleanup goals should be considered in excess of concentrations of those constituents that occur naturally at the site (i.e. background). For example, 2.0 pCi/g of radium-226 produces 25 mrem/yr to the subsistence farmer during year 1000, as does 5.8 pCi/g of thorium-230, 26 pCi/g of uranium-234 and 26 pCi/g of uranium-238. If all four COCs are present at the respective cleanup goal concentrations, the total dose would be 25 +25 + 25 + 25 = 100 mrem/yr. A sum-of-the-ratios (SOR) approach is required in order to limit the total dose from all COCs to 25 mrem/yr or less. An SOR is utilized in volume estimates, remedial design, etc. using the following approach:

$$SOR = \sum_j \frac{Concentration_j\ (pCi/g)}{CG_j\ (pCi/g)} \leq 1 \qquad \text{Equation 3}$$

Where:

$Concentration_j$ = soil concentration of radionuclide j, and
CG_j = cleanup goal for radionuclide j.

If the SOR result using Equation 3 is less than 1.0, then the total risk/dose is less than the associated limit. It is most conservative to use the minimum allowable concentration associated with the respective limit (dose or risk) in order to estimate the SOR value. For example, it is most conservative to use the year 0 radium-226 and year 1000 thorium-230, uranium-234 and uranium-238 values while calculating the SOR. This will assure that the limit will not be exceeded at any time within the 1000-year evaluation period.

The cancer risk due to a 25 mrem/year dose is approximately $4x10^{-4}$ per radionuclide for the subsistence farmer scenario. The ARAR (dose) based values presented in Table 3.A.8 are the selected Luckey site cleanup goals. However, based on USACE experience, it is anticipated that post-remediation residual concentrations of radionuclides are likely to be much lower than the cleanup goals stated in Table 3.A.8. Specifically, relatively low residual concentrations are anticipated due to conservative excavation practices (i.e., over-excavation) and USACE's adherence to the guidance in the Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) (DoD 2000).

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Table 3A.1. Exposure Unit 2. Future - RME - Surface Soil (0 - 2 ft) Risk for Subsistence Farmer Scenario - Child (Non-Radiologicals)

Constituent	EPC mg/kg	CANCER EFFECTS: Route-Specific Risk Oral	Dermal	Inhalation Dust	Inhalation VOCs	Plant Ingestion	Cancer Risk Total	Percent of Total	NON-CANCER EFFECTS: Route-Specific HQ Oral	Dermal	Inhalation Dust	Inhalation VOCs	Plant Ingestion	Non-Cancer HI Total	Percent of Total
Metals/Inorganics															
Beryllium	765	NA	NA	4.6E-08	NAP	NA	4.6E-08	100%	4.9E+00	NA	1.1E-02	NAP	9.48E-01	**5.8E+00**	100%
TOTAL		0.0E+00	0.0E+00	4.6E-08	0.0E+00	0.0E+00	4.6E-08	100%	4.9E+00	0.0E+00	1.1E-02	0.0E+00	9.5E-01	**5.8E+00**	100%

Bold	Indicates risk values that exceed criteria of 1.0E-06 for cancer or an HI of 1.0E+00 for non-cancer
EPC	Exposure point concentration
mg/kg	Milligram per kilogram.
NA	Not available; insufficient toxicity data.
NAP	Not applicable pathway; not a VOC.
NC	Not a suspected carcinogen.
RME	Reasonable maximum exposure.
SVOCs	Semi-volatile organic compounds.
VOCs	Volatile organic compounds.

Table 3A.2a. Reasonable Maximum Exposure Parameters for the Subsistence Farmer Using RESRAD Version 6.1

RESRAD Parameter	Units	RESRAD default	Subsistence Farmer	Source of Parameter
Area of contaminated zone	m^2	10,000	11,400	RI Report*
Thickness of contaminated zone	m	2	3	RI Report*
Length parallel to aquifer flow	m	100	100	RESRAD default
Time since placement of material	yr	0	0	RESRAD default
Cover depth	m	0	0	RESRAD default
Density of cover material	g/m^3	1.5	NU	N/A
Cover depth erosion rate	m/yr	0.001	NU	N/A
Density of contaminated zone	g/m^3	1.5	1.84	RI Report and consistent with groundwater model
Contaminated zone erosion rate	m/yr	0.001	0.001	RESRAD default
Contaminated zone total porosity	unitless	0.4	0.29	Consistent with groundwater model
Contaminated zone field capacity	unitless	0.2	0.2	RESRAD default
Contaminated zone hydraulic conductivity	m/yr	10	5.6	Consistent with groundwater model
Contaminated zone b parameter	unitless	5.3	8.52	Consistent with groundwater model
Humidity in air	g/m^3	8	NU	N/A
Average annual wind speed	m/sec	2	2	RESRAD default
Evapotranspiration coefficient	unitless	0.5	0.917	Consistent with groundwater model
Precipitation	m/yr	1	0.816	Based on 10 years SESOIL climate data
Irrigation	m/yr	0.2	0.2	RESRAD default
Irrigation mode	unitless	Overhead	Overhead	RESRAD default
Runoff coefficient	unitless	0.2	0.5	Consistent with groundwater model
Watershed area for nearby stream or pond	m^2	1.00E+06	1.00E+06	RESRAD default
Accuracy for water/soil computations	unitless	0.001	0.001	RESRAD default
Saturated zone density	g/m^3	1.5	1.84	RI Report and consistent with groundwater model
Saturated zone total porosity	unitless	0.4	0.29	Consistent with groundwater model
Saturated zone effective porosity	unitless	0.2	0.2	RESRAD default
Saturated zone field capacity	unitless	0.2	0.2	RESRAD default

Table 3A.2a. Reasonable Maximum Exposure Parameters for the Subsistence Farmer Using RESRAD Version 6.1

RESRAD Parameter	Units	RESRAD default	Subsistence Farmer	Source of Parameter
Saturated zone hydraulic conductivity	m/yr	100	167	Conservative value: between silty clay and sand/gravel
Saturated zone hydraulic gradient	unitless	0.02	0.02	Based upon observed water levels measured at the site
Saturated zone b parameter	unitless	5.3	8.5	Consistent with groundwater model
Water table drop rate	m/yr	0.001	0.001	RESRAD default
Well pump intake depth (m below water table)	m	10	20	Based on residential well data from the area
Model: Nondispersion (ND) or Mass-Balance (MB)	unitless	ND	ND	RESRAD default
Well pumping rate	m^3/yr	250	104	Based on residential well data from the area
Number of unsaturated zone strata	unitless	1	1	RESRAD default
Unsaturated zone thickness	m	4	0.3	Assumed minimum thickness
Unsaturated zone soil density	g/m^3	1.5	1.84	RI Report and consistent with groundwater model
Unsaturated zone total porosity	unitless	0.4	0.37	Measured site data and as reported in literature
Unsaturated zone effective porosity	unitless	0.2	0.05	Consistent with groundwater model
Unsaturated zone field capacity	unitless	0.2	0.2	RESRAD default
Unsaturated zone b parameter	unitless	5.3	8.5	Consistent with groundwater model
Unsaturated zone hydraulic conductivity	m/yr	10	5.6	Consistent with groundwater model
Distribution coefficient - actinium	cm^3/g	20	2400	RESRAD referenced value for clay
Distribution coefficient - protactinium	cm^3/g	50	2700	RESRAD referenced value for clay
Distribution coefficient - lead	cm^3/g	100	1830	Table 1 from Ohio EPA interoffice memo dated 07/27/01
Distribution coefficient - radium	cm^3/g	70	450	Consistent with dilution attenuation factor calculations
Distribution coefficient - thorium	cm^3/g	60,000	50,000	Table 1 from Ohio EPA interoffice memo dated 07/27/01
Distribution coefficient - uranium	cm^3/g	50	15	Modeled to allow uranium to reach groundwater
Inhalation rate	m^3/yr	8,400	4,745	RI Report*
Mass loading for inhalation	g/m^3	0.0001	0.0001	RESRAD default
Exposure duration	yr	30	30	RESRAD default
Shielding factor, inhalation	unitless	0.4	0.4	RESRAD default
Shielding factor, external gamma	unitless	0.7	0.4	OSWER Directive 9355.4-16

Table 3A.2a. Reasonable Maximum Exposure Parameters for the Subsistence Farmer Using RESRAD Version 6.1

RESRAD Parameter	Units	RESRAD default	Subsistence Farmer	Source of Parameter
Fraction of time spent indoors	unitless	0.5	0.50	RESRAD default
Fraction of time spent outdoors (on site)	unitless	0.25	0.25	RESRAD default
Shape factor flag, external gamma	unitless	1	1	RESRAD default
Fruits, vegetables and grain consumption	kg/yr	160	160	RESRAD default
Leafy vegetable consumption	kg/yr	14	14	RESRAD default
Milk consumption	L/yr	92	92	RESRAD default
Meat and poultry consumption	kg/yr	63	63	RESRAD default
Fish consumption	kg/yr	5.4	5.4	RESRAD default
Other seafood consumption	kg/yr	0.9	0.9	RESRAD default
Soil ingestion rate	g/yr	36.5	36.5	RI Report*
Drinking water intake	L/yr	510	839.5	RI Report*
Contamination fraction of drinking water	unitless	1	1	RESRAD default
Contamination fraction of household water	unitless	1	NU	N/A
Contamination fraction of livestock water	unitless	1	1	RESRAD default
Contamination fraction of irrigation water	unitless	1	1	RESRAD default
Contamination fraction of aquatic food	unitless	0.5	0.5	RESRAD default
Contamination fraction of plant food	unitless	-1	0.3	Table 13-71, USEPA 1997
Contamination fraction of meat	unitless	-1	-1	RESRAD default
Contamination fraction of milk	unitless	-1	-1	RESRAD default
Livestock fodder intake for meat	kg/day	68	68	RESRAD default
Livestock fodder intake for milk	kg/day	55	55	RESRAD default
Livestock water intake for meat	L/day	50	50	RESRAD default
Livestock water intake for milk	L/day	160	160	RESRAD default
Livestock soil intake	kg/day	0.5	0.5	RESRAD default
Mass loading for foliar deposition	g/m^3	0.0001	0.0001	RESRAD default
Depth of soil mixing layer	m	0.15	0.15	RESRAD default

Table 3A.2a. Reasonable Maximum Exposure Parameters for the Subsistence Farmer Using RESRAD Version 6.1

RESRAD Parameter	Units	RESRAD default	Subsistence Farmer	Source of Parameter
Depth of roots	m	0.9	0.9	RESRAD default
Drinking water fraction from ground water	unitless	1	1	RESRAD default
Household water fraction from ground water	unitless	1	NU	N/A
Livestock water fraction from ground water	unitless	1	1	RESRAD default
Irrigation fraction from ground water	unitless	1	1	RESRAD default
Wet weight crop yield for non-leafy	kg/m^2	0.7	0.7	RESRAD default
Wet weight crop yield for leafy	kg/m^2	1.5	1.5	RESRAD default
Wet weight crop yield for fodder	kg/m^2	1.1	1.1	RESRAD default
Growing season for non-leafy	years	0.17	0.17	RESRAD default
Growing season for leafy	years	0.25	0.25	RESRAD default
Growing season for fodder	years	0.08	0.08	RESRAD default
Translocation factor for non-leafy	unitless	0.1	0.1	RESRAD default
Translocation factor for leafy	unitless	1.0	1.0	RESRAD default
Translocation factor for fodder	unitless	1.0	1.0	RESRAD default
Dry foliar interception fraction for non-leafy	unitless	0.25	0.25	RESRAD default
Dry foliar interception fraction for leafy	unitless	0.25	0.25	RESRAD default
Dry foliar interception fraction for fodder	unitless	0.25	0.25	RESRAD default
Wet foliar interception fraction for non-leafy	unitless	0.25	0.25	RESRAD default
Wet foliar interception fraction for leafy	unitless	0.25	0.25	RESRAD default
Wet foliar interception fraction for fodder	unitless	0.25	0.25	RESRAD default
Weathering removal constant for vegetation	unitless	20	20	RESRAD default
Storage time: fruits, non-leafy vegetables, and grain	days	14	14	RESRAD default
Storage time: leafy vegetables	days	1	1	RESRAD default
Storage time: milk	days	1	1	RESRAD default
Storage time: meat and poultry	days	20	20	RESRAD default
Storage time: fish	days	7	7	RESRAD default

Table 3A.2a. Reasonable Maximum Exposure Parameters for the Subsistence Farmer Using RESRAD Version 6.1

RESRAD Parameter	Units	RESRAD default	Subsistence Farmer	Source of Parameter
Storage time: crustacea and mollusks	days	7	7	RESRAD default
Storage time: well water	days	1	1	RESRAD default
Storage time: surface water	days	1	1	RESRAD default
Storage time: livestock fodder	days	45	45	RESRAD default
Thickness of building foundation	m	0.15	NU	N/A
Bulk density of building foundation	g/cm^3	2.4	NU	N/A
Total porosity of the cover material	unitless	0.4	NU	N/A
Total porosity of the building foundation	unitless	0.1	NU	N/A
Volumetric water constant of the cover material	unitless	0.05	NU	N/A
Volumetric water constant of the foundation	unitless	0.03	NU	N/A
Diffusion coef. for radon gas in cover material	m/sec	2.00E-06	NU	N/A
Diffusion coef. for radon gas in foundation material	m/sec	3.00E-07	NU	N/A
Diffusion coef. for radon gas in contaminated zone soil	m/sec	2.00E-06	NU	N/A
Radon vertical dimension of mixing	m	2	NU	N/A
Average building air exchange rate	1/hour	0.5	NU	N/A
Height of the building (room)	m	2.5	NU	N/A
Building interior area factor	unitless	0	NU	N/A
Building depth below ground surface	m	-1	NU	N/A
Emanating power of Rn-222 gas	unitless	0.25	NU	N/A
Emanating power of Rn-220 gas	unitless	0.15	NU	N/A
Pathway – external gamma	unitless	active	active	RI Report*
Pathway – inhalation (w/o radon)	unitless	active	active	RI Report*
Pathway – plant ingestion	unitless	active	active	Assumed active for subsistence farmer scenario
Pathway – meat ingestion	unitless	active	active	Assumed active for subsistence farmer scenario
Pathway – milk ingestion	unitless	active	active	Assumed active for subsistence farmer scenario
Pathway – aquatic foods	unitless	active	inactive	Insufficient contaminant for subsistence fishing

Table 3A.2a. Reasonable Maximum Exposure Parameters for the Subsistence Farmer Using RESRAD Version 6.1

RESRAD Parameter	Units	RESRAD default	Subsistence Farmer	Source of Parameter
Pathway – drinking water	unitless	active	active	Assumed active for subsistence farmer scenario
Pathway – soil ingestion	unitless	active	active	RI Report*
Pathway – radon	unitless	active	inactive	RI Report*

* RI Report includes the Baseline Risk Assessment that was conducted as part of the Remedial Investigation (RI) for the Luckey FUSRAP project. See Tables 6.29 and 6.8 of the September 2000 Luckey RI Report additional parameter selection documentation. RESRAD uses radiological dose conversion factors and radiogenic cancer morbidity coefficients from FGR Reports 11, 12, and 13.
NU = not used; N/A = not applicable.

Table 3A.2b. Reasonable Maximum Exposure Parameters for the Revised Industrial Worker Using RESRAD Version 6.1

RESRAD Parameter	Units	RESRAD default	RI Industrial Worker	FS Industrial Worker	Source of Revised (FS) Industrial Worker Parameter
Area of contaminated zone	m^2	10,000	10,000	11,400	RI Report*
Thickness of contaminated zone	m	2	2	3	RI Report*
Length parallel to aquifer flow	m	100	100	100	RESRAD default
Time since placement of material	yr	0	0	0	RESRAD default
Cover depth	m	0	0	0	RESRAD default
Density of cover material	g/m^3	1.5	NU	NU	N/A
Cover depth erosion rate	m/yr	0.001	NU	NU	N/A
Density of contaminated zone	g/m^3	1.5	1.5	1.84	RI Report and consistent with groundwater model
Contaminated zone erosion rate	m/yr	0.001	0.001	0.00006	Industrial worker erosion rate for a site with 2% slope that is unsuitable for agriculture (DCH, page 78)
Contaminated zone total porosity	unitless	0.4	0.4	0.29	Consistent with groundwater model
Contaminated zone field capacity	unitless	0.2	0.2	0.2	RESRAD default
Contaminated zone hydraulic conductivity	m/yr	10	10	5.6	Consistent with groundwater model
Contaminated zone b parameter	unitless	5.3	5.3	8.52	Consistent with groundwater model
Humidity in air	g/m^3	8	NU	NU	N/A
Average annual wind speed	m/sec	2	2	2	RESRAD default
Evapotranspiration coefficient	unitless	0.5	0.5	0.917	Consistent with groundwater model
Precipitation	m/yr	1	1	0.816	Based on 10 years SESOIL climate data
Irrigation	m/yr	0.2	0.2	0.2	RESRAD default
Irrigation mode	unitless	Overhead	Overhead	Overhead	RESRAD default
Runoff coefficient	unitless	0.2	0.2	0.5	Consistent with groundwater model
Watershed area for nearby stream or pond	m^2	1.00E+06	1.00E+06	1.00E+06	RESRAD default
Accuracy for water/soil computations	unitless	0.001	0.001	0.001	RESRAD default
Saturated zone density	g/m^3	1.5	1.5	1.84	RI Report and consistent with groundwater model
Saturated zone total porosity	unitless	0.4	0.4	0.29	Consistent with groundwater model
Saturated zone effective porosity	unitless	0.2	0.2	0.2	RESRAD default
Saturated zone field capacity	unitless	0.2	0.2	0.2	RESRAD default
Saturated zone hydraulic conductivity	m/yr	100	100	167	Conservative value: between silty clay and sand/gravel
Saturated zone hydraulic gradient	unitless	0.02	0.02	0.02	Based upon observed water levels measured at the site
Saturated zone b parameter	unitless	5.3	5.3	8.5	Consistent with groundwater model

Table 3A.2b. Reasonable Maximum Exposure Parameters for the Revised Industrial Worker Using RESRAD Version 6.1

RESRAD Parameter	Units	RESRAD default	RI Industrial Worker	FS Industrial Worker	Source of Revised (FS) Industrial Worker Parameter
Water table drop rate	m/yr	0.001	0.001	0.001	RESRAD default
Well pump intake depth (m below water table)	m	10	11	20	Based on residential well data from the area
Model: Nondispersion (ND) or Mass-Balance (MB)	unitless	ND	ND	ND	RESRAD default
Well pumping rate	m^3/yr	250	250	104	Based on residential well data from the area
Number of unsaturated zone strata	unitless	1	1	1	RESRAD default
Unsaturated zone thickness	m	4	4	0.3	Assumed minimum thickness
Unsaturated zone soil density	g/m^3	1.5	1.5	1.84	RI Report and consistent with groundwater model
Unsaturated zone total porosity	unitless	0.4	0.4	0.37	Measured site data and as reported in literature
Unsaturated zone effective porosity	unitless	0.2	0.2	0.05	Consistent with groundwater model
Unsaturated zone field capacity	unitless	0.2	0.2	0.2	RESRAD default
Unsaturated zone b parameter	unitless	5.3	5.3	8.5	Consistent with groundwater model
Unsaturated zone hydraulic conductivity	m/yr	10	10	5.6	Consistent with groundwater model
Distribution coefficient - actinium	cm^3/g	20	20	2400	RESRAD referenced value for clay
Distribution coefficient - protactinium	cm^3/g	50	50	2700	RESRAD referenced value for clay
Distribution coefficient - lead	cm^3/g	100	100	1830	Table 1 from Ohio EPA interoffice memo dated 07/27/01
Distribution coefficient - radium	cm^3/g	70	70	450	Consistent with dilution attenuation factor calculations
Distribution coefficient - thorium	cm^3/g	60,000	60,000	50,000	Table 1 from Ohio EPA interoffice memo dated 07/27/01
Distribution coefficient - uranium	cm^3/g	50	50	15	Modeled to allow uranium to reach groundwater
Inhalation rate	m^3/yr	8,400	4,745	4,745	RI Report* (13 m^3/day)
Mass loading for inhalation	g/m^3	0.0001	0.0001	0.0001	RESRAD default
Exposure duration	yr	30	6.6	6.6	RI Report*
Shielding factor, inhalation	unitless	0.4	0.4	0.4	RESRAD default
Shielding factor, external gamma	unitless	0.7	0.8	0.4	OSWER Directive 9355.4-16 (60% shielding)
Fraction of time spent indoors	unitless	0.5	0.20	0.20	RI Report* (7 hours/day inside, on-site)
Fraction of time spent outdoors (on site)	unitless	0.25	0.0285	0.0285	RI Report* (1 hour/day outside, on-site)
Shape factor flag, external gamma	unitless	1	1	1	RESRAD default
Fruits, vegetables and grain consumption	kg/yr	160	NU	NU	N/A
Leafy vegetable consumption	kg/yr	14	NU	NU	N/A
Milk consumption	L/yr	92	NU	NU	N/A
Meat and poultry consumption	kg/yr	63	NU	NU	N/A

Table 3A.2b. Reasonable Maximum Exposure Parameters for the Revised Industrial Worker Using RESRAD Version 6.1

RESRAD Parameter	Units	RESRAD default	RI Industrial Worker	FS Industrial Worker	Source of Revised (FS) Industrial Worker Parameter
Fish consumption	kg/yr	5.4	NU	NU	N/A
Other seafood consumption	kg/yr	0.9	NU	NU	N/A
Soil ingestion rate	g/yr	36.5	18.25	18.25	RI Report*
Drinking water intake	L/yr	510	300	300	RI Report* (1.2 L/day for 250 days/year)
Contamination fraction of drinking water	unitless	1	1	1	RESRAD default
Contamination fraction of household water	unitless	1	NU	NU	N/A
Contamination fraction of livestock water	unitless	1	NU	NU	N/A
Contamination fraction of irrigation water	unitless	1	NU	NU	N/A
Contamination fraction of aquatic food	unitless	0.5	NU	NU	N/A
Contamination fraction of plant food	unitless	-1	NU	NU	N/A
Contamination fraction of meat	unitless	-1	NU	NU	N/A
Contamination fraction of milk	unitless	-1	NU	NU	N/A
Livestock fodder intake for meat	kg/day	68	NU	NU	N/A
Livestock fodder intake for milk	kg/day	55	NU	NU	N/A
Livestock water intake for meat	L/day	50	NU	NU	N/A
Livestock water intake for milk	L/day	160	NU	NU	N/A
Livestock soil intake	kg/day	0.5	NU	NU	N/A
Mass loading for foliar deposition	g/m^3	0.0001	NU	NU	N/A
Depth of soil mixing layer	m	0.15	0.15	0.0	No mixing assumed for industrial scenario
Depth of roots	m	0.9	NU	NU	N/A
Drinking water fraction from ground water	unitless	1	1	1	RESRAD default
Household water fraction from ground water	unitless	1	NU	NU	N/A
Livestock water fraction from ground water	unitless	1	NU	NU	N/A
Irrigation fraction from ground water	unitless	1	NU	NU	N/A
Wet weight crop yield for non-leafy	kg/m^2	0.7	NU	NU	N/A
Wet weight crop yield for leafy	kg/m^2	1.5	NU	NU	N/A
Wet weight crop yield for fodder	kg/m^2	1.1	NU	NU	N/A
Growing season for non-leafy	years	0.17	NU	NU	N/A
Growing season for leafy	years	0.25	NU	NU	N/A
Growing season for fodder	years	0.08	NU	NU	N/A

Table 3A.2b. Reasonable Maximum Exposure Parameters for the Revised Industrial Worker Using RESRAD Version 6.1

RESRAD Parameter	Units	RESRAD default	RI Industrial Worker	FS Industrial Worker	Source of Revised (FS) Industrial Worker Parameter
Translocation factor for non-leafy	unitless	0.1	NU	NU	N/A
Translocation factor for leafy	unitless	1.0	NU	NU	N/A
Translocation factor for fodder	unitless	1.0	NU	NU	N/A
Dry foliar interception fraction for non-leafy	unitless	0.25	NU	NU	N/A
Dry foliar interception fraction for leafy	unitless	0.25	NU	NU	N/A
Dry foliar interception fraction for fodder	unitless	0.25	NU	NU	N/A
Wet foliar interception fraction for non-leafy	unitless	0.25	NU	NU	N/A
Wet foliar interception fraction for leafy	unitless	0.25	NU	NU	N/A
Wet foliar interception fraction for fodder	unitless	0.25	NU	NU	N/A
Weathering removal constant for vegetation	unitless	20	NU	NU	N/A
Storage time: fruits, non-leafy vegetables, and grain	days	14	NU	NU	N/A
Storage time: leafy vegetables	days	1	NU	NU	N/A
Storage time: milk	days	1	NU	NU	N/A
Storage time: meat and poultry	days	20	NU	NU	N/A
Storage time: fish	days	7	NU	NU	N/A
Storage time: crustacea and mollusks	days	7	NU	NU	N/A
Storage time: well water	days	1	NU	NU	N/A
Storage time: surface water	days	1	NU	NU	N/A
Storage time: livestock fodder	days	45	NU	NU	N/A
Thickness of building foundation	m	0.15	NU	NU	N/A
Bulk density of building foundation	g/cm^3	2.4	NU	NU	N/A
Total porosity of the cover material	unitless	0.4	NU	NU	N/A
Total porosity of the building foundation	unitless	0.1	NU	NU	N/A
Volumetric water constant of the cover material	unitless	0.05	NU	NU	N/A
Volumetric water constant of the foundation	unitless	0.03	NU	NU	N/A
Diffusion coef. for radon gas in cover material	m/sec	2.00E-06	NU	NU	N/A
Diffusion coef. for radon gas in foundation material	m/sec	3.00E-07	NU	NU	N/A
Diffusion coef. for radon gas in contaminated zone soil	m/sec	2.00E-06	NU	NU	N/A
Radon vertical dimension of mixing	m	2	NU	NU	N/A
Average building air exchange rate	1/hour	0.5	NU	NU	N/A

Table 3A.2b. Reasonable Maximum Exposure Parameters for the Revised Industrial Worker Using RESRAD Version 6.1

RESRAD Parameter	Units	RESRAD default	RI Industrial Worker	FS Industrial Worker	Source of Revised (FS) Industrial Worker Parameter
Height of the building (room)	m	2.5	NU	NU	N/A
Building interior area factor	unitless	0	NU	NU	N/A
Building depth below ground surface	m	-1	NU	NU	N/A
Emanating power of Rn-222 gas	unitless	0.25	NU	NU	N/A
Emanating power of Rn-220 gas	unitless	0.15	NU	NU	N/A
Pathway – external gamma	unitless	active	active	active	RI Report*
Pathway – inhalation (w/o radon)	unitless	active	active	active	RI Report*
Pathway – plant ingestion	unitless	active	inactive	inactive	Assumed inactive for industrial worker scenario
Pathway – meat ingestion	unitless	active	inactive	inactive	Assumed inactive for industrial worker scenario
Pathway – milk ingestion	unitless	active	inactive	inactive	Assumed inactive for industrial worker scenario
Pathway – aquatic foods	unitless	active	inactive	inactive	Assumed inactive for industrial worker scenario
Pathway – drinking water	unitless	active	active	active	RI Report*
Pathway – soil ingestion	unitless	active	active	active	RI Report*
Pathway – radon	unitless	active	inactive	inactive	RI Report*

* RI Report includes the Baseline Risk Assessment that was conducted as part of the Remedial Investigation (RI) for the Luckey FUSRAP project. See Tables 6.29 and 6.8 of the September 2000 Luckey RI Report additional parameter selection documentation.

DCH = Yu, C., Loureiro, C., Cheng, J.-J., Jones, L.G., Wang, Y.Y., Chia, Y.P., and Faillace, E., 1993. *Data Collection Handbook to Support Modeling the Impacts of Radioactive Material in Soil* , ANL/EAIS-8, Environmental Assessment and Information Sciences Division, Argonne, Illinois, April.

NU = not used; N/A = not applicable.

Table 3A.3a. Risk-to-Source Ratios and Dose-to-Source Ratios for the Luckey, Ohio Subsistence Farmer Scenario

		RSR: Water Independent Pathways (pCi/g)$^{-1}$							RSR: Water Dependent Pathways (pCi/g)$^{-1}$						RSR
Radionuclide*	**Year**	Ground	Inhalation	Radon	Plant	Meat	Milk	Soil	Water	Fish	Radon	Plant	Meat	Milk	**Total**
Actinium-227	0	1.21E-05	1.48E-07	0.00E+00	1.65E-06	6.08E-09	8.44E-09	6.14E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.45E-05
Protactinium-231	0	8.48E-06	1.32E-07	0.00E+00	4.46E-06	1.45E-06	6.56E-09	6.46E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.52E-05
Radium-226	0	1.07E-04	2.75E-08	0.00E+00	8.60E-05	5.31E-06	3.89E-06	2.76E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.05E-04
Radium-228	0	4.18E-05	4.33E-08	0.00E+00	2.49E-05	1.38E-06	1.67E-06	6.82E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.04E-05
Thorium-228	0	9.10E-06	1.45E-08	0.00E+00	6.09E-08	2.38E-09	1.70E-10	6.11E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.24E-06
Thorium-230	0	7.10E-07	3.14E-08	0.00E+00	4.83E-07	2.46E-08	1.74E-08	1.73E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.44E-06
Thorium-232	0	1.06E-04	1.53E-07	0.00E+00	6.73E-05	3.66E-06	4.46E-06	1.99E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.83E-04
Uranium-234	0	3.34E-09	1.24E-08	0.00E+00	3.71E-07	2.32E-08	5.70E-08	1.29E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.95E-07
Uranium-235	0	6.93E-06	1.10E-08	0.00E+00	3.80E-07	2.42E-08	5.82E-08	1.33E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.53E-06
Uranium-238	0	1.44E-06	1.02E-08	0.00E+00	4.70E-07	2.94E-08	7.22E-08	1.71E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.19E-06
Actinium-227	1000	1.80E-19	2.20E-21	0.00E+00	2.45E-20	9.04E-23	1.26E-22	9.13E-21	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.16E-19
Protactinium-231	1000	2.01E-05	2.73E-07	0.00E+00	5.96E-06	1.42E-06	1.46E-08	1.23E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.90E-05
Radium-226	1000	6.82E-05	1.76E-08	0.00E+00	5.50E-05	3.39E-06	2.48E-06	1.77E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.31E-04
Radium-228	1000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Thorium-228	1000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Thorium-230	1000	3.79E-05	4.06E-08	0.00E+00	3.00E-05	1.84E-06	1.35E-06	1.11E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.22E-05
Thorium-232	1000	1.57E-04	2.11E-07	0.00E+00	9.22E-05	5.04E-06	6.13E-06	2.73E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.63E-04
Uranium-234	1000	1.54E-07	7.02E-09	0.00E+00	3.21E-07	2.00E-08	3.64E-08	7.49E-08	6.61E-06	0.00E+00	0.00E+00	2.50E-07	2.25E-08	8.69E-08	7.58E-06
Uranium-235	1000	4.10E-06	1.04E-08	0.00E+00	3.03E-07	3.60E-08	3.21E-08	9.21E-08	6.73E-06	0.00E+00	0.00E+00	2.57E-07	2.31E-08	8.91E-08	1.17E-05
Uranium-238	1000	7.87E-07	5.58E-09	0.00E+00	2.57E-07	1.61E-08	3.95E-08	9.36E-08	8.19E-06	0.00E+00	0.00E+00	3.19E-07	2.87E-08	1.11E-07	9.84E-06

		DSR: Water Independent Pathways (mrem/yr per pCi/g)							RSR: Water Dependent Pathways (mrem/yr per pCi/g)						DSR
Radionuclide*	**Year**	Ground	Inhalation	Radon	Plant	Meat	Milk	Soil	Water	Fish	Radon	Plant	Meat	Milk	**Total**
Actinium-227	0	8.44E-01	2.42E-01	0.00E+00	1.90E+00	7.01E-03	9.74E-03	3.99E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.40E+00
Protactinium-231	0	9.53E-02	5.08E-02	0.00E+00	5.57E+00	2.25E+00	3.10E-03	2.97E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.27E+00
Radium-226	0	4.75E+00	1.17E-03	0.00E+00	6.58E+00	4.03E-01	3.09E-01	2.35E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.23E+01
Radium-228	0	3.06E+00	2.13E-03	0.00E+00	2.86E+00	1.59E-01	1.92E-01	4.06E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.31E+00
Thorium-228	0	3.63E+00	1.06E-02	0.00E+00	3.54E-02	1.38E-03	9.87E-05	1.86E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.70E+00
Thorium-230	0	1.55E-03	1.19E-02	0.00E+00	2.92E-02	1.14E-03	1.14E-04	1.50E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.90E-02
Thorium-232	0	1.75E-01	6.02E-02	0.00E+00	3.08E-01	1.27E-02	1.01E-02	7.72E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.43E-01
Uranium-234	0	1.76E-04	4.84E-03	0.00E+00	3.69E-02	2.32E-03	5.68E-03	7.75E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.77E-02
Uranium-235	0	3.25E-01	4.51E-03	0.00E+00	3.49E-02	2.20E-03	5.36E-03	7.31E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.79E-01
Uranium-238	0	5.82E-02	4.32E-03	0.00E+00	3.51E-02	2.20E-03	5.40E-03	7.36E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.13E-01
Actinium-227	1000	1.26E-14	3.61E-15	0.00E+00	2.83E-14	1.04E-16	1.45E-16	5.93E-15	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.06E-14
Protactinium-231	1000	9.17E-01	2.86E-01	0.00E+00	7.29E+00	2.20E+00	1.25E-02	6.79E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.14E+01
Radium-226	1000	3.02E+00	7.48E-04	0.00E+00	4.22E+00	2.58E-01	1.98E-01	1.51E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.85E+00
Radium-228	1000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Thorium-228	1000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Thorium-230	1000	1.65E+00	1.22E-02	0.00E+00	2.28E+00	1.39E-01	1.06E-01	9.47E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.28E+00
Thorium-232	1000	6.87E+00	7.29E-02	0.00E+00	3.20E+00	1.73E-01	2.02E-01	1.36E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.06E+01
Uranium-234	1000	6.65E-03	2.72E-03	0.00E+00	2.91E-02	1.81E-03	3.51E-03	4.63E-03	8.90E-01	0.00E+00	0.00E+00	2.50E-02	2.24E-03	8.66E-03	9.74E-01
Uranium-235	1000	1.92E-01	6.97E-03	0.00E+00	1.36E-01	3.66E-02	3.12E-03	1.47E-02	8.45E-01	0.00E+00	0.00E+00	2.37E-02	2.18E-03	8.20E-03	1.27E+00
Uranium-238	1000	3.18E-02	2.37E-03	0.00E+00	1.93E-02	1.21E-03	2.96E-03	4.04E-03	8.51E-01	0.00E+00	0.00E+00	2.39E-02	2.15E-03	8.28E-03	9.46E-01

* Radium-226 RSR and DSR values include lead-210 at equilibrium concentrations.

Generated using RESRAD Version 6.1 and default cancer slope factor and dose factor libraries.

Confirmatory RESRAD 'runs' were executed to demonstrate risk results did not peak between years 0.0 and 1,000. Thus, risk estimated using year 0.0 and year 1,000 RSRs are assured to represent maximums for the evaluation period.

Table 3A.3b. Risk-to-Source Ratios and Dose-to-Source Ratios for the Luckey, Ohio Revised Industrial Worker Scenario

		RSR: Water Independent Pathways (pCi/g)$^{-1}$							RSR: Water Dependent Pathways (pCi/g)$^{-1}$						RSR
Radionuclide*	**Year**	Ground	Inhalation	Radon	Plant	Meat	Milk	Soil	Water	Fish	Radon	Plant	Meat	Milk	**Total**
Actinium-227	0	9.00E-07	1.10E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.88E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.40E-07
Protactinium-231	0	1.93E-07	3.85E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.34E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.10E-07
Radium-226	0	5.73E-06	1.47E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.26E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.82E-06
Radium-228	0	4.54E-06	4.08E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.38E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.60E-06
Thorium-228	0	1.99E-06	3.17E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.46E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-06
Thorium-230	0	8.75E-09	1.66E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.60E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.60E-08
Thorium-232	0	1.77E-06	3.92E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.94E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-06
Uranium-234	0	1.75E-10	6.63E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.34E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.18E-09
Uranium-235	0	3.70E-07	5.88E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.48E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.75E-07
Uranium-238	0	7.69E-08	5.44E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.77E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.33E-08
Actinium-227	1000	1.34E-20	1.64E-22	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.28E-22	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.40E-20
Protactinium-231	1000	1.07E-06	1.45E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.12E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.12E-06
Radium-226	1000	3.64E-06	9.38E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.95E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.70E-06
Radium-228	1000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Thorium-228	1000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Thorium-230	1000	1.99E-06	2.15E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.71E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.03E-06
Thorium-232	1000	8.30E-06	1.12E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.16E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.40E-06
Uranium-234	1000	8.04E-09	3.75E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.53E-09	5.77E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.88E-07
Uranium-235	1000	2.19E-07	5.50E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.10E-09	5.88E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.10E-07
Uranium-238	1000	4.20E-08	2.98E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.16E-09	7.15E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.60E-07

		DSR: Water Independent Pathways (mrem/yr per pCi/g)							RSR: Water Dependent Pathways (mrem/yr per pCi/g)						DSR
Radionuclide*	**Year**	Ground	Inhalation	Radon	Plant	Meat	Milk	Soil	Water	Fish	Radon	Plant	Meat	Milk	**Total**
Actinium-227	0	2.04E-01	5.84E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.08E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.23E-01
Protactinium-231	0	2.30E-02	1.22E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.52E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.04E-02
Radium-226	0	1.15E+00	2.81E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.59E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.18E+00
Radium-228	0	7.38E-01	5.14E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.18E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.44E-01
Thorium-228	0	8.76E-01	2.56E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.83E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.82E-01
Thorium-230	0	3.74E-04	2.88E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.29E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.54E-03
Thorium-232	0	4.22E-02	1.45E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.18E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.85E-02
Uranium-234	0	4.23E-05	1.17E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.18E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.39E-03
Uranium-235	0	7.83E-02	1.09E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.11E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.05E-02
Uranium-238	0	1.40E-02	1.04E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.12E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.62E-02
Actinium-227	1000	3.03E-15	8.69E-16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.04E-16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.80E-15
Protactinium-231	1000	2.21E-01	6.90E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.03E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.93E-01
Radium-226	1000	7.28E-01	1.80E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.31E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.52E-01
Radium-228	1000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Thorium-228	1000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Thorium-230	1000	3.98E-01	2.95E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.44E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.15E-01
Thorium-232	1000	1.66E+00	1.76E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.08E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.69E+00
Uranium-234	1000	1.60E-03	6.55E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.05E-04	3.50E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.53E-01
Uranium-235	1000	4.62E-02	1.68E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.25E-03	3.33E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.83E-01
Uranium-238	1000	7.67E-03	5.71E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.15E-04	3.35E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.44E-01

* Radium-226 RSR and DSR values include lead-210 at equilibrium concentrations.

Generated using RESRAD Version 6.1 and default cancer slope factor and dose factor libraries.

Confirmatory RESRAD 'runs' were executed to demonstrate risk results did not peak between years 0.0 and 1,000. Thus, risk estimated using year 0.0 and year 1,000 RSRs are assured to represent maximums for the evaluation period.

Table 3A.4a. Subsistence Farmer Risk Estimates for the Luckey FUSRAP Site (0-10 ft)

Medium	Location	Year	Parameter	Gross EPC	BKG UTL	BKG AVG	Net EPC	RSR $(pCi/g)^{-1}$	Risk Estimate
0-10 ft Soil	EU 1	0	Actinium-227	0.297	1.76	0.304	0	1.45E-05	
0-10 ft Soil	EU 1	0	Protactinium-231	-0.138	0	0.0	0	1.52E-05	
0-10 ft Soil	EU 1	0	Radium-226	5.95	2.97	1.75	4.2	2.05E-04	**8.6E-04**
0-10 ft Soil	EU 1	0	Radium-228	0.879	1.48	1.10	0	7.04E-05	
0-10 ft Soil	EU 1	0	Thorium-228	1.08	1.6	1.15	0	9.24E-06	
0-10 ft Soil	EU 1	0	Thorium-230	5.63	3.2	2.11	3.5	1.44E-06	5.0E-06
0-10 ft Soil	EU 1	0	Thorium-232	0.842	1.48	1.03	0	1.83E-04	
0-10 ft Soil	EU 1	0	Uranium-234	4.65	2.36	1.48	3.2	5.95E-07	1.9E-06
0-10 ft Soil	EU 1	0	Uranium-235	0.202	0.26	0.09	0	7.53E-06	
0-10 ft Soil	EU 1	0	Uranium-238	4.69	2.63	1.63	3.1	2.19E-06	6.8E-06
									8.8E-04
0-10 ft Soil	EU 1	1000	Actinium-227	0.297	1.76	0.304	0	2.16E-19	
0-10 ft Soil	EU 1	1000	Protactinium-231	-0.138	0	0.0	0	2.90E-05	
0-10 ft Soil	EU 1	1000	Radium-226	5.95	2.97	1.75	4.2	1.31E-04	**5.5E-04**
0-10 ft Soil	EU 1	1000	Radium-228	0.879	1.48	1.10	0	0.00E+00	
0-10 ft Soil	EU 1	1000	Thorium-228	1.08	1.6	1.15	0	0.00E+00	
0-10 ft Soil	EU 1	1000	Thorium-230	5.63	3.2	2.11	3.5	7.22E-05	**2.5E-04**
0-10 ft Soil	EU 1	1000	Thorium-232	0.842	1.48	1.03	0	2.63E-04	
0-10 ft Soil	EU 1	1000	Uranium-234	4.65	2.36	1.48	3.2	7.58E-06	**2.4E-05**
0-10 ft Soil	EU 1	1000	Uranium-235	0.202	0.26	0.09	0	1.17E-05	
0-10 ft Soil	EU 1	1000	Uranium-238	4.69	2.63	1.63	3.1	9.84E-06	**3.1E-05**
									8.6E-04

Notes:
Radium-226 RSR includes contributions from lead-210 assuming equilibrium conditions.
Contaminants of concern shown in **bold**; identified for radionuclides with risk > 1E-5 when total risk > 1E-4.
Net EPC values rounded to the tenth decimal.

Gross EPC = exposure point concentration (includes background) (pCi/g)
BKG UTL = background upper tolerance level on the mean (pCi/g)
BKG AVG = average background concentration (pCi/g)
Net EPC = exposure point concentration (average background subtracted) (pCi/g)
RSR = risk-to-source ratio for all pathways combined $(pCi/g)^{-1}$
EU = Exposure Unit

Table 3A.4a. Subsistence Farmer Risk Estimates for the Luckey FUSRAP Site (0-10 ft)

Medium	Location	Year	Parameter	Gross EPC	BKG UTL	BKG AVG	Net EPC	RSR $(pCi/g)^{-1}$	Risk Estimate
0-10 ft Soil	EU 2	0	Actinium-227	0.335	1.76	0.304	0	1.45E-05	
0-10 ft Soil	EU 2	0	Protactinium-231	-0.285	0	0.0	0	1.52E-05	
0-10 ft Soil	EU 2	0	Radium-226	7.02	2.97	1.75	5.3	2.05E-04	**1.1E-03**
0-10 ft Soil	EU 2	0	Radium-228	0.925	1.48	1.10	0	7.04E-05	
0-10 ft Soil	EU 2	0	Thorium-228	1.02	1.6	1.15	0	9.24E-06	
0-10 ft Soil	EU 2	0	Thorium-230	6.85	3.2	2.11	4.7	1.44E-06	6.8E-06
0-10 ft Soil	EU 2	0	Thorium-232	0.8	1.48	1.03	0	1.83E-04	
0-10 ft Soil	EU 2	0	Uranium-234	4.37	2.36	1.48	2.9	5.95E-07	1.7E-06
0-10 ft Soil	EU 2	0	Uranium-235	0.219	0.26	0.09	0.0	7.53E-06	
0-10 ft Soil	EU 2	0	Uranium-238	4.4	2.63	1.63	2.8	2.19E-06	6.1E-06
									1.1E-03
0-10 ft Soil	EU 2	1000	Actinium-227	0.335	1.76	0.304	0	2.16E-19	
0-10 ft Soil	EU 2	1000	Protactinium-231	-0.285	0	0.0	0	2.90E-05	
0-10 ft Soil	EU 2	1000	Radium-226	7.02	2.97	1.75	5.3	1.31E-04	**6.9E-04**
0-10 ft Soil	EU 2	1000	Radium-228	0.925	1.48	1.10	0	0.00E+00	
0-10 ft Soil	EU 2	1000	Thorium-228	1.02	1.6	1.15	0	0.00E+00	
0-10 ft Soil	EU 2	1000	Thorium-230	6.85	3.2	2.11	4.7	7.22E-05	**3.4E-04**
0-10 ft Soil	EU 2	1000	Thorium-232	0.8	1.48	1.03	0	2.63E-04	
0-10 ft Soil	EU 2	1000	Uranium-234	4.37	2.36	1.48	2.9	7.58E-06	**2.2E-05**
0-10 ft Soil	EU 2	1000	Uranium-235	0.219	0.26	0.09	0	1.17E-05	
0-10 ft Soil	EU 2	1000	Uranium-238	4.4	2.63	1.63	2.8	9.84E-06	**2.8E-05**
									1.1E-03

Notes:
Radium-226 RSR includes contributions from lead-210 assuming equilibrium conditions.
Contaminants of concern shown in **bold**; identified for radionuclides with risk > 1E-5 when total risk > 1E-4.
Net EPC values rounded to the tenth decimal.

Gross EPC = exposure point concentration (includes background) (pCi/g)
BKG UTL = background upper tolerance level on the mean (pCi/g)
BKG AVG = average background concentration (pCi/g)
Net EPC = exposure point concentration (average background subtracted) (pCi/g)
RSR = risk-to-source ratio for all pathways combined $(pCi/g)^{-1}$
EU = Exposure Unit

Table 3A.4a. Subsistence Farmer Risk Estimates for the Luckey FUSRAP Site (0-10 ft)

Medium	Location	Year	Parameter	Gross EPC	BKG UTL	BKG AVG	Net EPC	RSR $(pCi/g)^{-1}$	Risk Estimate
0-10 ft Soil	EU 3	0	Actinium-227	0.165	1.76	0.304	0	1.45E-05	
0-10 ft Soil	EU 3	0	Protactinium-231	0.193	0	0.0	0.2	1.52E-05	3.0E-06
0-10 ft Soil	EU 3	0	Radium-226	3.27	2.97	1.75	1.5	2.05E-04	**3.1E-04**
0-10 ft Soil	EU 3	0	Radium-228	1.1	1.48	1.10	0	7.04E-05	
0-10 ft Soil	EU 3	0	Thorium-228	1.2	1.6	1.15	0	9.24E-06	
0-10 ft Soil	EU 3	0	Thorium-230	3.01	3.2	2.11	0	1.44E-06	
0-10 ft Soil	EU 3	0	Thorium-232	0.961	1.48	1.03	0	1.83E-04	
0-10 ft Soil	EU 3	0	Uranium-234	2.58	2.36	1.48	1.1	5.95E-07	6.5E-07
0-10 ft Soil	EU 3	0	Uranium-235	0.15	0.26	0.09	0	7.53E-06	
0-10 ft Soil	EU 3	0	Uranium-238	2.49	2.63	1.63	0	2.19E-06	
									3.1E-04
0-10 ft Soil	EU 3	1000	Actinium-227	0.165	1.76	0.304	0	2.16E-19	
0-10 ft Soil	EU 3	1000	Protactinium-231	0.193	0	0.0	0.2	2.90E-05	5.8E-06
0-10 ft Soil	EU 3	1000	Radium-226	3.27	2.97	1.75	1.5	1.31E-04	**2.0E-04**
0-10 ft Soil	EU 3	1000	Radium-228	1.1	1.48	1.10	0	0.00E+00	
0-10 ft Soil	EU 3	1000	Thorium-228	1.2	1.6	1.15	0	0.00E+00	
0-10 ft Soil	EU 3	1000	Thorium-230	3.01	3.2	2.11	0	7.22E-05	
0-10 ft Soil	EU 3	1000	Thorium-232	0.961	1.48	1.03	0	2.63E-04	
0-10 ft Soil	EU 3	1000	Uranium-234	2.58	2.36	1.48	1.1	7.58E-06	8.3E-06
0-10 ft Soil	EU 3	1000	Uranium-235	0.15	0.26	0.09	0	1.17E-05	
0-10 ft Soil	EU 3	1000	Uranium-238	2.49	2.63	1.63	0	9.84E-06	
									2.1E-04

Notes:
Radium-226 RSR includes contributions from lead-210 assuming equilibrium conditions.
Contaminants of concern shown in **bold**; identified for and radionuclide with risk > 1E-5 when total risk > 1E-4.
Net EPC values rounded to the tenth decimal.

Gross EPC = exposure point concentration (includes background) (pCi/g)
BKG UTL = background upper tolerance level on the mean (pCi/g)
BKG AVG = average background concentration (pCi/g)
Net EPC = exposure point concentration (average background subtracted) (pCi/g)
RSR = risk-to-source ratio for all pathways combined $(pCi/g)^{-1}$
EU = Exposure Unit

Table 3A.4b. Industrial Worker Risk Estimates for the Luckey FUSRAP Site (0-10 ft)

Medium	Location	Year	Parameter	Gross EPC	BKG UTL	BKG AVG	Net EPC	RSR $(pCi/g)^{-1}$	Risk Estimate
0-10 ft Soil	EU 1	0	Actinium-227	0.297	1.76	0.304	0	9.40E-07	
0-10 ft Soil	EU 1	0	Protactinium-231	-0.138	0	0.0	0	2.10E-07	
0-10 ft Soil	EU 1	0	Radium-226	5.95	2.97	1.75	4.2	5.82E-06	2.4E-05
0-10 ft Soil	EU 1	0	Radium-228	0.879	1.48	1.10	0	4.60E-06	
0-10 ft Soil	EU 1	0	Thorium-228	1.08	1.6	1.15	0	2.00E-06	
0-10 ft Soil	EU 1	0	Thorium-230	5.63	3.2	2.11	3.5	1.60E-08	5.6E-08
0-10 ft Soil	EU 1	0	Thorium-232	0.842	1.48	1.03	0	1.80E-06	
0-10 ft Soil	EU 1	0	Uranium-234	4.65	2.36	1.48	3.2	5.18E-09	1.7E-08
0-10 ft Soil	EU 1	0	Uranium-235	0.202	0.26	0.09	0	3.75E-07	
0-10 ft Soil	EU 1	0	Uranium-238	4.69	2.63	1.63	3.1	8.33E-08	2.6E-07
									2.5E-05
0-10 ft Soil	EU 1	1000	Actinium-227	0.297	1.76	0.304	0	1.40E-20	
0-10 ft Soil	EU 1	1000	Protactinium-231	-0.138	0	0.0	0	1.12E-06	
0-10 ft Soil	EU 1	1000	Radium-226	5.95	2.97	1.75	4.2	3.70E-06	1.6E-05
0-10 ft Soil	EU 1	1000	Radium-228	0.879	1.48	1.10	0	0.00E+00	
0-10 ft Soil	EU 1	1000	Thorium-228	1.08	1.6	1.15	0	0.00E+00	
0-10 ft Soil	EU 1	1000	Thorium-230	5.63	3.2	2.11	3.5	2.03E-06	7.1E-06
0-10 ft Soil	EU 1	1000	Thorium-232	0.842	1.48	1.03	0	8.40E-06	
0-10 ft Soil	EU 1	1000	Uranium-234	4.65	2.36	1.48	3.2	5.88E-07	1.9E-06
0-10 ft Soil	EU 1	1000	Uranium-235	0.202	0.26	0.09	0	8.10E-07	
0-10 ft Soil	EU 1	1000	Uranium-238	4.69	2.63	1.63	3.1	7.60E-07	2.4E-06
									2.7E-05

Notes:
Radium-226 RSR includes contributions from lead-210 assuming equilibrium conditions.
Contaminants of concern shown in **bold**; identified for radionuclides with risk > 1E-5 when total risk > 1E-4.
Net EPC values rounded to the tenth decimal.

Gross EPC = exposure point concentration (includes background) (pCi/g)
BKG UTL = background upper tolerance level on the mean (pCi/g)
BKG AVG = average background concentration (pCi/g)
Net EPC = exposure point concentration (average background subtracted) (pCi/g)
RSR = risk-to-source ratio for all pathways combined $(pCi/g)^{-1}$
EU = Exposure Unit

Table 3A.4b. Industrial Worker Risk Estimates for the Luckey FUSRAP Site (0-10 ft)

Medium	Location	Year	Parameter	Gross EPC	BKG UTL	BKG AVG	Net EPC	RSR $(pCi/g)^{-1}$	Risk Estimate
0-10 ft Soil	EU 2	0	Actinium-227	0.335	1.76	0.304	0	9.40E-07	
0-10 ft Soil	EU 2	0	Protactinium-231	-0.285	0	0.0	0	2.10E-07	
0-10 ft Soil	EU 2	0	Radium-226	7.02	2.97	1.75	5.3	5.82E-06	3.1E-05
0-10 ft Soil	EU 2	0	Radium-228	0.925	1.48	1.10	0	4.60E-06	
0-10 ft Soil	EU 2	0	Thorium-228	1.02	1.6	1.15	0	2.00E-06	
0-10 ft Soil	EU 2	0	Thorium-230	6.85	3.2	2.11	4.7	1.60E-08	7.5E-08
0-10 ft Soil	EU 2	0	Thorium-232	0.8	1.48	1.03	0	1.80E-06	
0-10 ft Soil	EU 2	0	Uranium-234	4.37	2.36	1.48	2.9	5.18E-09	1.5E-08
0-10 ft Soil	EU 2	0	Uranium-235	0.219	0.26	0.09	0.0	3.75E-07	
0-10 ft Soil	EU 2	0	Uranium-238	4.4	2.63	1.63	2.8	8.33E-08	2.3E-07
									3.1E-05
0-10 ft Soil	EU 2	1000	Actinium-227	0.335	1.76	0.304	0	1.40E-20	
0-10 ft Soil	EU 2	1000	Protactinium-231	-0.285	0	0.0	0	1.12E-06	
0-10 ft Soil	EU 2	1000	Radium-226	7.02	2.97	1.75	5.3	3.70E-06	2.0E-05
0-10 ft Soil	EU 2	1000	Radium-228	0.925	1.48	1.10	0	0.00E+00	
0-10 ft Soil	EU 2	1000	Thorium-228	1.02	1.6	1.15	0	0.00E+00	
0-10 ft Soil	EU 2	1000	Thorium-230	6.85	3.2	2.11	4.7	2.03E-06	9.6E-06
0-10 ft Soil	EU 2	1000	Thorium-232	0.8	1.48	1.03	0	8.40E-06	
0-10 ft Soil	EU 2	1000	Uranium-234	4.37	2.36	1.48	2.9	5.88E-07	1.7E-06
0-10 ft Soil	EU 2	1000	Uranium-235	0.219	0.26	0.09	0	8.10E-07	
0-10 ft Soil	EU 2	1000	Uranium-238	4.4	2.63	1.63	2.8	7.60E-07	2.1E-06
									3.3E-05

Notes:
Radium-226 RSR includes contributions from lead-210 assuming equilibrium conditions.
Contaminants of concern shown in **bold**; identified for radionuclides with risk > 1E-5 when total risk > 1E-4.
Net EPC values rounded to the tenth decimal.

Gross EPC = exposure point concentration (includes background) (pCi/g)
BKG UTL = background upper tolerance level on the mean (pCi/g)
BKG AVG = average background concentration (pCi/g)
Net EPC = exposure point concentration (average background subtracted) (pCi/g)
RSR = risk-to-source ratio for all pathways combined $(pCi/g)^{-1}$
EU = Exposure Unit

Table 3A.4b. Industrial Worker Risk Estimates for the Luckey FUSRAP Site (0-10 ft)

Medium	Location	Year	Parameter	Gross EPC	BKG UTL	BKG AVG	Net EPC	RSR $(pCi/g)^{-1}$	Risk Estimate
0-10 ft Soil	EU 3	0	Actinium-227	0.165	1.76	0.304	0	9.40E-07	
0-10 ft Soil	EU 3	0	Protactinium-231	0.193	0	0.0	0.2	2.10E-07	4.2E-08
0-10 ft Soil	EU 3	0	Radium-226	3.27	2.97	1.75	1.5	5.82E-06	8.7E-06
0-10 ft Soil	EU 3	0	Radium-228	1.1	1.48	1.10	0	4.60E-06	
0-10 ft Soil	EU 3	0	Thorium-228	1.2	1.6	1.15	0	2.00E-06	
0-10 ft Soil	EU 3	0	Thorium-230	3.01	3.2	2.11	0	1.60E-08	
0-10 ft Soil	EU 3	0	Thorium-232	0.961	1.48	1.03	0	1.80E-06	
0-10 ft Soil	EU 3	0	Uranium-234	2.58	2.36	1.48	1.1	5.18E-09	5.7E-09
0-10 ft Soil	EU 3	0	Uranium-235	0.15	0.26	0.09	0	3.75E-07	
0-10 ft Soil	EU 3	0	Uranium-238	2.49	2.63	1.63	0	8.33E-08	
									8.8E-06
0-10 ft Soil	EU 3	1000	Actinium-227	0.165	1.76	0.304	0	1.40E-20	
0-10 ft Soil	EU 3	1000	Protactinium-231	0.193	0	0.0	0.2	1.12E-06	2.2E-07
0-10 ft Soil	EU 3	1000	Radium-226	3.27	2.97	1.75	1.5	3.70E-06	5.5E-06
0-10 ft Soil	EU 3	1000	Radium-228	1.1	1.48	1.10	0	0.00E+00	
0-10 ft Soil	EU 3	1000	Thorium-228	1.2	1.6	1.15	0	0.00E+00	
0-10 ft Soil	EU 3	1000	Thorium-230	3.01	3.2	2.11	0	2.03E-06	
0-10 ft Soil	EU 3	1000	Thorium-232	0.961	1.48	1.03	0	8.40E-06	
0-10 ft Soil	EU 3	1000	Uranium-234	2.58	2.36	1.48	1.1	5.88E-07	6.5E-07
0-10 ft Soil	EU 3	1000	Uranium-235	0.15	0.26	0.09	0	8.10E-07	
0-10 ft Soil	EU 3	1000	Uranium-238	2.49	2.63	1.63	0	7.60E-07	
									6.4E-06

Notes:
Radium-226 RSR includes contributions from lead-210 assuming equilibrium conditions.
Contaminants of concern shown in **bold**; identified for and radionuclide with risk > 1E-5 when total risk > 1E-4.
Net EPC values rounded to the tenth decimal.

Gross EPC = exposure point concentration (includes background) (pCi/g)
BKG UTL = background upper tolerance level on the mean (pCi/g)
BKG AVG = average background concentration (pCi/g)
Net EPC = exposure point concentration (average background subtracted) (pCi/g)
RSR = risk-to-source ratio for all pathways combined $(pCi/g)^{-1}$
EU = Exposure Unit

Table 3A.5a. Subsistence Farmer Risk Estimates for the Luckey FUSRAP Site (0-2 ft)

Medium	Location	Year	Parameter	Gross EPC	BKG UTL	BKG AVG	Net EPC	RSR $(pCi/g)^{-1}$	Risk Estimate
0-2 ft Soil	EU 1	0	Actinium-227	0.547	1.76	0.304	0	1.45E-05	
0-2 ft Soil	EU 1	0	Protactinium-231	-0.328	0	0.0	0	1.52E-05	
0-2 ft Soil	EU 1	0	Radium-226	11.4	2.97	1.75	9.7	2.05E-04	**1.99E-03**
0-2 ft Soil	EU 1	0	Radium-228	0.893	1.48	1.10	0	7.04E-05	
0-2 ft Soil	EU 1	0	Thorium-228	1.04	1.6	1.15	0	9.24E-06	
0-2 ft Soil	EU 1	0	Thorium-230	10.5	3.2	2.11	8.4	1.44E-06	**1.21E-05**
0-2 ft Soil	EU 1	0	Thorium-232	0.833	1.48	1.03	0	1.83E-04	
0-2 ft Soil	EU 1	0	Uranium-234	8.87	2.36	1.48	7.4	5.95E-07	4.40E-06
0-2 ft Soil	EU 1	0	Uranium-235	0.359	0.26	0.09	0.3	7.53E-06	2.26E-06
0-2 ft Soil	EU 1	0	Uranium-238	8.95	2.63	1.63	7.3	2.19E-06	**1.60E-05**
									2.0E-03
0-2 ft Soil	EU 1	1000	Actinium-227	0.547	1.76	0.304	0	2.16E-19	
0-2 ft Soil	EU 1	1000	Protactinium-231	-0.328	0	0.0	0	2.90E-05	
0-2 ft Soil	EU 1	1000	Radium-226	11.4	2.97	1.75	9.7	1.31E-04	**1.27E-03**
0-2 ft Soil	EU 1	1000	Radium-228	0.893	1.48	1.10	0	0.00E+00	
0-2 ft Soil	EU 1	1000	Thorium-228	1.04	1.6	1.15	0	0.00E+00	
0-2 ft Soil	EU 1	1000	Thorium-230	10.5	3.2	2.11	8.4	7.22E-05	**6.07E-04**
0-2 ft Soil	EU 1	1000	Thorium-232	0.833	1.48	1.03	0	2.63E-04	
0-2 ft Soil	EU 1	1000	Uranium-234	8.87	2.36	1.48	7.4	7.58E-06	**5.61E-05**
0-2 ft Soil	EU 1	1000	Uranium-235	0.359	0.26	0.09	0.3	1.17E-05	3.50E-06
0-2 ft Soil	EU 1	1000	Uranium-238	8.95	2.63	1.63	7.3	9.84E-06	**7.18E-05**
									2.0E-03

Notes:
Radium-226 RSR includes contributions from lead-210 assuming equilibrium conditions.
Contaminants of concern shown in **bold**; identified for radionuclides with risk > 1E-5 when total risk > 1E-4.
Net EPC values rounded to the tenth decimal.

Gross EPC = exposure point concentration (includes background) (pCi/g)
BKG UTL = background upper tolerance level on the mean (pCi/g)
BKG AVG = average background concentration (pCi/g)
Net EPC = exposure point concentration (average background subtracted) (pCi/g)
RSR = risk-to-source ratio for all pathways combined $(pCi/g)^{-1}$
EU = Exposure Unit

Table 3A.5a. Subsistence Farmer Risk Estimates for the Luckey FUSRAP Site (0-2 ft)

Medium	Location	Year	Parameter	Gross EPC	BKG UTL	BKG AVG	Net EPC	RSR $(pCi/g)^{-1}$	Risk Estimate
0-2 ft Soil	EU 2	0	Actinium-227	0.502	1.76	0.304	0	1.45E-05	
0-2 ft Soil	EU 2	0	Protactinium-231	-0.51	0	0.0	0	1.52E-05	
0-2 ft Soil	EU 2	0	Radium-226	8.28	2.97	1.75	6.5	2.05E-04	**1.34E-03**
0-2 ft Soil	EU 2	0	Radium-228	0.868	1.48	1.10	0	7.04E-05	
0-2 ft Soil	EU 2	0	Thorium-228	0.944	1.6	1.15	0	9.24E-06	
0-2 ft Soil	EU 2	0	Thorium-230	12.3	3.2	2.11	10.2	1.44E-06	**1.47E-05**
0-2 ft Soil	EU 2	0	Thorium-232	0.774	1.48	1.03	0	1.83E-04	
0-2 ft Soil	EU 2	0	Uranium-234	6.71	2.36	1.48	5.2	5.95E-07	3.10E-06
0-2 ft Soil	EU 2	0	Uranium-235	0.379	0.26	0.09	0.3	7.53E-06	2.26E-06
0-2 ft Soil	EU 2	0	Uranium-238	6.67	2.63	1.63	5.0	2.19E-06	**1.10E-05**
									1.4E-03
0-2 ft Soil	EU 2	1000	Actinium-227	0.502	1.76	0.304	0	2.16E-19	
0-2 ft Soil	EU 2	1000	Protactinium-231	-0.51	0	0.0	0	2.90E-05	
0-2 ft Soil	EU 2	1000	Radium-226	8.28	2.97	1.75	6.5	1.31E-04	**8.51E-04**
0-2 ft Soil	EU 2	1000	Radium-228	0.868	1.48	1.10	0	0.00E+00	
0-2 ft Soil	EU 2	1000	Thorium-228	0.944	1.6	1.15	0	0.00E+00	
0-2 ft Soil	EU 2	1000	Thorium-230	12.3	3.2	2.11	10.2	7.22E-05	**7.37E-04**
0-2 ft Soil	EU 2	1000	Thorium-232	0.774	1.48	1.03	0	2.63E-04	
0-2 ft Soil	EU 2	1000	Uranium-234	6.71	2.36	1.48	5.2	7.58E-06	**3.94E-05**
0-2 ft Soil	EU 2	1000	Uranium-235	0.379	0.26	0.09	0.3	1.17E-05	3.50E-06
0-2 ft Soil	EU 2	1000	Uranium-238	6.67	2.63	1.63	5.0	9.84E-06	**4.92E-05**
									1.7E-03

Notes:
Radium-226 RSR includes contributions from lead-210 assuming equilibrium conditions.
Contaminants of concern shown in **bold**; identified for radionuclides with risk > 1E-5 when total risk > 1E-4.
Net EPC values rounded to the tenth decimal.

Gross EPC = exposure point concentration (includes background) (pCi/g)
BKG UTL = background upper tolerance level on the mean (pCi/g)
BKG AVG = average background concentration (pCi/g)
Net EPC = exposure point concentration (average background subtracted) (pCi/g)
RSR = risk-to-source ratio for all pathways combined $(pCi/g)^{-1}$
EU = Exposure Unit

Table 3A.5a. Subsistence Farmer Risk Estimates for the Luckey FUSRAP Site (0-2 ft)

Medium	Location	Year	Parameter	Gross EPC	BKG UTL	BKG AVG	Net EPC	RSR $(pCi/g)^{-1}$	Risk Estimate
0-2 ft Soil	EU 3	0	Actinium-227	0.166	1.76	0.304	0	1.45E-05	
0-2 ft Soil	EU 3	0	Protactinium-231	0.204	0	0.0	0.2	1.52E-05	3.03E-06
0-2 ft Soil	EU 3	0	Radium-226	3.32	2.97	1.75	1.6	2.05E-04	**3.29E-04**
0-2 ft Soil	EU 3	0	Radium-228	1.11	1.48	1.10	0	7.04E-05	
0-2 ft Soil	EU 3	0	Thorium-228	1.2	1.6	1.15	0	9.24E-06	
0-2 ft Soil	EU 3	0	Thorium-230	3.02	3.2	2.11	0	1.44E-06	
0-2 ft Soil	EU 3	0	Thorium-232	0.941	1.48	1.03	0	1.83E-04	
0-2 ft Soil	EU 3	0	Uranium-234	2.61	2.36	1.48	1.1	5.95E-07	6.55E-07
0-2 ft Soil	EU 3	0	Uranium-235	0.155	0.26	0.09	0	7.53E-06	
0-2 ft Soil	EU 3	0	Uranium-238	2.51	2.63	1.63	0	2.19E-06	
									3.3E-04
0-2 ft Soil	EU 3	1000	Actinium-227	0.166	1.76	0.304	0	2.16E-19	
0-2 ft Soil	EU 3	1000	Protactinium-231	0.204	0	0.0	0.2	2.90E-05	5.80E-06
0-2 ft Soil	EU 3	1000	Radium-226	3.32	2.97	1.75	1.6	1.31E-04	**2.09E-04**
0-2 ft Soil	EU 3	1000	Radium-228	1.11	1.48	1.10	0	0.00E+00	
0-2 ft Soil	EU 3	1000	Thorium-228	1.2	1.6	1.15	0	0.00E+00	
0-2 ft Soil	EU 3	1000	Thorium-230	3.02	3.2	2.11	0	7.22E-05	
0-2 ft Soil	EU 3	1000	Thorium-232	0.941	1.48	1.03	0	2.63E-04	
0-2 ft Soil	EU 3	1000	Uranium-234	2.61	2.36	1.48	1.1	7.58E-06	8.34E-06
0-2 ft Soil	EU 3	1000	Uranium-235	0.155	0.26	0.09	0	1.17E-05	
0-2 ft Soil	EU 3	1000	Uranium-238	2.51	2.63	1.63	0	9.84E-06	
									2.2E-04

Notes:
Radium-226 RSR includes contributions from lead-210 assuming equilibrium conditions.
Contaminants of concern shown in **bold**; identified for and radionuclide with risk > 1E-5 when total risk > 1E-4.
Net EPC values rounded to the tenth decimal.

Gross EPC = exposure point concentration (includes background) (pCi/g)
BKG UTL = background upper tolerance level on the mean (pCi/g)
BKG AVG = average background concentration (pCi/g)
Net EPC = exposure point concentration (average background subtracted) (pCi/g)
RSR = risk-to-source ratio for all pathways combined $(pCi/g)^{-1}$
EU = Exposure Unit

Table 3A.5b. Industrial Worker Risk Estimates for the Luckey FUSRAP Site (0-2 ft)

Medium	Location	Year	Parameter	Gross EPC	BKG UTL	BKG AVG	Net EPC	RSR $(pCi/g)^{-1}$	Risk Estimate
0-2 ft Soil	EU 1	0	Actinium-227	0.547	1.76	0.304	0	9.40E-07	
0-2 ft Soil	EU 1	0	Protactinium-231	-0.328	0	0.0	0	2.10E-07	
0-2 ft Soil	EU 1	0	Radium-226	11.4	2.97	1.75	9.7	5.82E-06	5.65E-05
0-2 ft Soil	EU 1	0	Radium-228	0.893	1.48	1.10	0	4.60E-06	
0-2 ft Soil	EU 1	0	Thorium-228	1.04	1.6	1.15	0	2.00E-06	
0-2 ft Soil	EU 1	0	Thorium-230	10.5	3.2	2.11	8.4	1.60E-08	1.34E-07
0-2 ft Soil	EU 1	0	Thorium-232	0.833	1.48	1.03	0	1.80E-06	
0-2 ft Soil	EU 1	0	Uranium-234	8.87	2.36	1.48	7.4	5.18E-09	3.83E-08
0-2 ft Soil	EU 1	0	Uranium-235	0.359	0.26	0.09	0.3	3.75E-07	1.12E-07
0-2 ft Soil	EU 1	0	Uranium-238	8.95	2.63	1.63	7.3	8.33E-08	6.08E-07
									5.7E-05
0-2 ft Soil	EU 1	1000	Actinium-227	0.547	1.76	0.304	0	1.40E-20	
0-2 ft Soil	EU 1	1000	Protactinium-231	-0.328	0	0.0	0	1.12E-06	
0-2 ft Soil	EU 1	1000	Radium-226	11.4	2.97	1.75	9.7	3.70E-06	3.59E-05
0-2 ft Soil	EU 1	1000	Radium-228	0.893	1.48	1.10	0	0.00E+00	
0-2 ft Soil	EU 1	1000	Thorium-228	1.04	1.6	1.15	0	0.00E+00	
0-2 ft Soil	EU 1	1000	Thorium-230	10.5	3.2	2.11	8.4	2.03E-06	1.71E-05
0-2 ft Soil	EU 1	1000	Thorium-232	0.833	1.48	1.03	0	8.40E-06	
0-2 ft Soil	EU 1	1000	Uranium-234	8.87	2.36	1.48	7.4	5.88E-07	4.35E-06
0-2 ft Soil	EU 1	1000	Uranium-235	0.359	0.26	0.09	0.3	8.10E-07	2.43E-07
0-2 ft Soil	EU 1	1000	Uranium-238	8.95	2.63	1.63	7.3	7.60E-07	5.55E-06
									6.3E-05

Notes:
Radium-226 RSR includes contributions from lead-210 assuming equilibrium conditions.
Contaminants of concern shown in **bold**; identified for radionuclides with risk > 1E-5 when total risk > 1E-4.
Net EPC values rounded to the tenth decimal.

Gross EPC = exposure point concentration (includes background) (pCi/g)
BKG UTL = background upper tolerance level on the mean (pCi/g)
BKG AVG = average background concentration (pCi/g)
Net EPC = exposure point concentration (average background subtracted) (pCi/g)
RSR = risk-to-source ratio for all pathways combined $(pCi/g)^{-1}$
EU = Exposure Unit

Table 3A.5b. Industrial Worker Risk Estimates for the Luckey FUSRAP Site (0-2 ft)

Medium	Location	Year	Parameter	Gross EPC	BKG UTL	BKG AVG	Net EPC	RSR $(pCi/g)^{-1}$	Risk Estimate
0-2 ft Soil	EU 2	0	Actinium-227	0.502	1.76	0.304	0	9.40E-07	
0-2 ft Soil	EU 2	0	Protactinium-231	-0.51	0	0.0	0	2.10E-07	
0-2 ft Soil	EU 2	0	Radium-226	8.28	2.97	1.75	6.5	5.82E-06	3.78E-05
0-2 ft Soil	EU 2	0	Radium-228	0.868	1.48	1.10	0	4.60E-06	
0-2 ft Soil	EU 2	0	Thorium-228	0.944	1.6	1.15	0	2.00E-06	
0-2 ft Soil	EU 2	0	Thorium-230	12.3	3.2	2.11	10.2	1.60E-08	1.63E-07
0-2 ft Soil	EU 2	0	Thorium-232	0.774	1.48	1.03	0	1.80E-06	
0-2 ft Soil	EU 2	0	Uranium-234	6.71	2.36	1.48	5.2	5.18E-09	2.69E-08
0-2 ft Soil	EU 2	0	Uranium-235	0.379	0.26	0.09	0.3	3.75E-07	1.12E-07
0-2 ft Soil	EU 2	0	Uranium-238	6.67	2.63	1.63	5.0	8.33E-08	4.16E-07
									3.9E-05
0-2 ft Soil	EU 2	1000	Actinium-227	0.502	1.76	0.304	0	1.40E-20	
0-2 ft Soil	EU 2	1000	Protactinium-231	-0.51	0	0.0	0	1.12E-06	
0-2 ft Soil	EU 2	1000	Radium-226	8.28	2.97	1.75	6.5	3.70E-06	2.40E-05
0-2 ft Soil	EU 2	1000	Radium-228	0.868	1.48	1.10	0	0.00E+00	
0-2 ft Soil	EU 2	1000	Thorium-228	0.944	1.6	1.15	0	0.00E+00	
0-2 ft Soil	EU 2	1000	Thorium-230	12.3	3.2	2.11	10.2	2.03E-06	2.07E-05
0-2 ft Soil	EU 2	1000	Thorium-232	0.774	1.48	1.03	0	8.40E-06	
0-2 ft Soil	EU 2	1000	Uranium-234	6.71	2.36	1.48	5.2	5.88E-07	3.06E-06
0-2 ft Soil	EU 2	1000	Uranium-235	0.379	0.26	0.09	0.3	8.10E-07	2.43E-07
0-2 ft Soil	EU 2	1000	Uranium-238	6.67	2.63	1.63	5.0	7.60E-07	3.80E-06
									5.2E-05

Notes:
Radium-226 RSR includes contributions from lead-210 assuming equilibrium conditions.
Contaminants of concern shown in **bold**; identified for radionuclides with risk > 1E-5 when total risk > 1E-4.
Net EPC values rounded to the tenth decimal.

Gross EPC = exposure point concentration (includes background) (pCi/g)
BKG UTL = background upper tolerance level on the mean (pCi/g)
BKG AVG = average background concentration (pCi/g)
Net EPC = exposure point concentration (average background subtracted) (pCi/g)
RSR = risk-to-source ratio for all pathways combined $(pCi/g)^{-1}$
EU = Exposure Unit

Table 3A.5b. Industrial Worker Risk Estimates for the Luckey FUSRAP Site (0-2 ft)

Medium	Location	Year	Parameter	Gross EPC	BKG UTL	BKG AVG	Net EPC	RSR $(pCi/g)^{-1}$	Risk Estimate
0-2 ft Soil	EU 3	0	Actinium-227	0.166	1.76	0.304	0	9.40E-07	
0-2 ft Soil	EU 3	0	Protactinium-231	0.204	0	0.0	0.2	2.10E-07	4.20E-08
0-2 ft Soil	EU 3	0	Radium-226	3.32	2.97	1.75	1.6	5.82E-06	9.31E-06
0-2 ft Soil	EU 3	0	Radium-228	1.11	1.48	1.10	0	4.60E-06	
0-2 ft Soil	EU 3	0	Thorium-228	1.2	1.6	1.15	0	2.00E-06	
0-2 ft Soil	EU 3	0	Thorium-230	3.02	3.2	2.11	0	1.60E-08	
0-2 ft Soil	EU 3	0	Thorium-232	0.941	1.48	1.03	0	1.80E-06	
0-2 ft Soil	EU 3	0	Uranium-234	2.61	2.36	1.48	1.1	5.18E-09	5.70E-09
0-2 ft Soil	EU 3	0	Uranium-235	0.155	0.26	0.09	0	3.75E-07	
0-2 ft Soil	EU 3	0	Uranium-238	2.51	2.63	1.63	0	8.33E-08	
									9.4E-06
0-2 ft Soil	EU 3	1000	Actinium-227	0.166	1.76	0.304	0	1.40E-20	
0-2 ft Soil	EU 3	1000	Protactinium-231	0.204	0	0.0	0.2	1.12E-06	2.25E-07
0-2 ft Soil	EU 3	1000	Radium-226	3.32	2.97	1.75	1.6	3.70E-06	5.92E-06
0-2 ft Soil	EU 3	1000	Radium-228	1.11	1.48	1.10	0	0.00E+00	
0-2 ft Soil	EU 3	1000	Thorium-228	1.2	1.6	1.15	0	0.00E+00	
0-2 ft Soil	EU 3	1000	Thorium-230	3.02	3.2	2.11	0	2.03E-06	
0-2 ft Soil	EU 3	1000	Thorium-232	0.941	1.48	1.03	0	8.40E-06	
0-2 ft Soil	EU 3	1000	Uranium-234	2.61	2.36	1.48	1.1	5.88E-07	6.47E-07
0-2 ft Soil	EU 3	1000	Uranium-235	0.155	0.26	0.09	0	8.10E-07	
0-2 ft Soil	EU 3	1000	Uranium-238	2.51	2.63	1.63	0	7.60E-07	
									6.8E-06

Notes:
Radium-226 RSR includes contributions from lead-210 assuming equilibrium conditions.
Contaminants of concern shown in **bold**; identified for and radionuclide with risk > 1E-5 when total risk > 1E-4.
Net EPC values rounded to the tenth decimal.

Gross EPC = exposure point concentration (includes background) (pCi/g)
BKG UTL = background upper tolerance level on the mean (pCi/g)
BKG AVG = average background concentration (pCi/g)
Net EPC = exposure point concentration (average background subtracted) (pCi/g)
RSR = risk-to-source ratio for all pathways combined $(pCi/g)^{-1}$
EU = Exposure Unit

Table 3A.6a. Subsistence Farmer Radiological Dose Estimates for the Luckey FUSRAP Site (0-10 ft)

Medium	Location	Year	Parameter	Gross EPC	BKG UTL	BKG AVG	Net EPC	DSR	Dose (mrem/yr)
0-10 ft Soil	EU 1	0	Actinium-227	0.297	1.76	0.304	0	3.40E+00	
0-10 ft Soil	EU 1	0	Protactinium-231	-0.138	0	0.0	0	8.27E+00	
0-10 ft Soil	EU 1	0	Radium-226	5.95	2.97	1.75	4.2	1.23E+01	5.2E+01
0-10 ft Soil	EU 1	0	Radium-228	0.879	1.48	1.10	0	6.31E+00	
0-10 ft Soil	EU 1	0	Thorium-228	1.08	1.6	1.15	0	3.70E+00	
0-10 ft Soil	EU 1	0	Thorium-230	5.63	3.2	2.11	3.5	5.90E-02	2.1E-01
0-10 ft Soil	EU 1	0	Thorium-232	0.842	1.48	1.03	0	6.43E-01	
0-10 ft Soil	EU 1	0	Uranium-234	4.65	2.36	1.48	3.2	5.77E-02	1.8E-01
0-10 ft Soil	EU 1	0	Uranium-235	0.202	0.26	0.09	0	3.79E-01	
0-10 ft Soil	EU 1	0	Uranium-238	4.69	2.63	1.63	3.1	1.13E-01	3.5E-01
									5.2E+01
0-10 ft Soil	EU 1	1000	Actinium-227	0.297	1.76	0.304	0	5.06E-14	
0-10 ft Soil	EU 1	1000	Protactinium-231	-0.138	0	0.0	0	1.14E+01	
0-10 ft Soil	EU 1	1000	Radium-226	5.95	2.97	1.75	4.2	7.85E+00	3.3E+01
0-10 ft Soil	EU 1	1000	Radium-228	0.879	1.48	1.10	0	0.00E+00	
0-10 ft Soil	EU 1	1000	Thorium-228	1.08	1.6	1.15	0	0.00E+00	
0-10 ft Soil	EU 1	1000	Thorium-230	5.63	3.2	2.11	3.5	4.28E+00	1.5E+01
0-10 ft Soil	EU 1	1000	Thorium-232	0.842	1.48	1.03	0	1.06E+01	
0-10 ft Soil	EU 1	1000	Uranium-234	4.65	2.36	1.48	3.2	9.74E-01	3.1E+00
0-10 ft Soil	EU 1	1000	Uranium-235	0.202	0.26	0.09	0	1.27E+00	
0-10 ft Soil	EU 1	1000	Uranium-238	4.69	2.63	1.63	3.1	9.46E-01	2.9E+00
									5.4E+01

Notes:
Radium-226 DSR includes contributions from lead-210 assuming equilibrium conditions.
Total dose estimates > 25 mrem/yr **bolded.**
Net EPC values rounded to the tenth decimal.

Gross EPC = exposure point concentration (includes background) (pCi/g)
BKG UTL = background upper tolerance level on the mean (pCi/g)
BKG AVG = average background concentration (pCi/g)
Net EPC = exposure point concentration (average background subtracted) (pCi/g)
DSR = dose-to-source ratio for all pathways combined (mrem/yr per pCi/g)
EU = Exposure Unit

Table 3A.6a. Subsistence Farmer Radiological Dose Estimates for the Luckey FUSRAP Site (0-10 ft)

Medium	Location	Year	Parameter	Gross EPC	BKG UTL	BKG AVG	Net EPC	DSR	Dose (mrem/yr)
0-10 ft Soil	EU 2	0	Actinium-227	0.335	1.76	0.304	0	3.40E+00	
0-10 ft Soil	EU 2	0	Protactinium-231	-0.285	0	0.0	0	8.27E+00	
0-10 ft Soil	EU 2	0	Radium-226	7.02	2.97	1.75	5.3	1.23E+01	6.5E+01
0-10 ft Soil	EU 2	0	Radium-228	0.925	1.48	1.10	0	6.31E+00	
0-10 ft Soil	EU 2	0	Thorium-228	1.02	1.6	1.15	0	3.70E+00	
0-10 ft Soil	EU 2	0	Thorium-230	6.85	3.2	2.11	4.7	5.90E-02	2.8E-01
0-10 ft Soil	EU 2	0	Thorium-232	0.8	1.48	1.03	0	6.43E-01	
0-10 ft Soil	EU 2	0	Uranium-234	4.37	2.36	1.48	2.9	5.77E-02	1.7E-01
0-10 ft Soil	EU 2	0	Uranium-235	0.219	0.26	0.09	0.0	3.79E-01	
0-10 ft Soil	EU 2	0	Uranium-238	4.4	2.63	1.63	2.8	1.13E-01	3.2E-01
									6.6E+01
0-10 ft Soil	EU 2	1000	Actinium-227	0.335	1.76	0.304	0	5.06E-14	
0-10 ft Soil	EU 2	1000	Protactinium-231	-0.285	0	0.0	0	1.14E+01	
0-10 ft Soil	EU 2	1000	Radium-226	7.02	2.97	1.75	5.3	7.85E+00	4.2E+01
0-10 ft Soil	EU 2	1000	Radium-228	0.925	1.48	1.10	0	0.00E+00	
0-10 ft Soil	EU 2	1000	Thorium-228	1.02	1.6	1.15	0	0.00E+00	
0-10 ft Soil	EU 2	1000	Thorium-230	6.85	3.2	2.11	4.7	4.28E+00	2.0E+01
0-10 ft Soil	EU 2	1000	Thorium-232	0.8	1.48	1.03	0	1.06E+01	
0-10 ft Soil	EU 2	1000	Uranium-234	4.37	2.36	1.48	2.9	9.74E-01	2.8E+00
0-10 ft Soil	EU 2	1000	Uranium-235	0.219	0.26	0.09	0	1.27E+00	
0-10 ft Soil	EU 2	1000	Uranium-238	4.4	2.63	1.63	2.8	9.46E-01	2.6E+00
									6.7E+01

Notes:
Radium-226 DSR includes contributions from lead-210 assuming equilibrium conditions.
Total dose estimates > 25 mrem/yr **bolded.**
Net EPC values rounded to the tenth decimal.

Gross EPC = exposure point concentration (includes background) (pCi/g)
BKG UTL = background upper tolerance level on the mean (pCi/g)
BKG AVG = average background concentration (pCi/g)
Net EPC = exposure point concentration (average background subtracted) (pCi/g)
DSR = dose-to-source ratio for all pathways combined (mrem/yr per pCi/g)
EU = Exposure Unit

Table 3A.6a. Subsistence Farmer Radiological Dose Estimates for the Luckey FUSRAP Site (0-10 ft)

Medium	Location	Year	Parameter	Gross EPC	BKG UTL	BKG AVG	Net EPC	DSR	Dose (mrem/yr)
0-10 ft Soil	EU 3	0	Actinium-227	0.165	1.76	0.304	0	3.40E+00	
0-10 ft Soil	EU 3	0	Protactinium-231	0.193	0	0.0	0.2	8.27E+00	1.7E+00
0-10 ft Soil	EU 3	0	Radium-226	3.27	2.97	1.75	1.5	1.23E+01	1.8E+01
0-10 ft Soil	EU 3	0	Radium-228	1.1	1.48	1.10	0	6.31E+00	
0-10 ft Soil	EU 3	0	Thorium-228	1.2	1.6	1.15	0	3.70E+00	
0-10 ft Soil	EU 3	0	Thorium-230	3.01	3.2	2.11	0	5.90E-02	
0-10 ft Soil	EU 3	0	Thorium-232	0.961	1.48	1.03	0	6.43E-01	
0-10 ft Soil	EU 3	0	Uranium-234	2.58	2.36	1.48	1.1	5.77E-02	6.3E-02
0-10 ft Soil	EU 3	0	Uranium-235	0.15	0.26	0.09	0	3.79E-01	
0-10 ft Soil	EU 3	0	Uranium-238	2.49	2.63	1.63	0	1.13E-01	
									2.0E+01
0-10 ft Soil	EU 3	1000	Actinium-227	0.165	1.76	0.304	0	5.06E-14	
0-10 ft Soil	EU 3	1000	Protactinium-231	0.193	0	0.0	0.2	1.14E+01	2.3E+00
0-10 ft Soil	EU 3	1000	Radium-226	3.27	2.97	1.75	1.5	7.85E+00	1.2E+01
0-10 ft Soil	EU 3	1000	Radium-228	1.1	1.48	1.10	0	0.00E+00	
0-10 ft Soil	EU 3	1000	Thorium-228	1.2	1.6	1.15	0	0.00E+00	
0-10 ft Soil	EU 3	1000	Thorium-230	3.01	3.2	2.11	0	4.28E+00	
0-10 ft Soil	EU 3	1000	Thorium-232	0.961	1.48	1.03	0	1.06E+01	
0-10 ft Soil	EU 3	1000	Uranium-234	2.58	2.36	1.48	1.1	9.74E-01	1.1E+00
0-10 ft Soil	EU 3	1000	Uranium-235	0.15	0.26	0.09	0	1.27E+00	
0-10 ft Soil	EU 3	1000	Uranium-238	2.49	2.63	1.63	0	9.46E-01	
									1.5E+01

Notes:
Radium-226 DSR includes contributions from lead-210 assuming equilibrium conditions.
Total dose estimates > 25 mrem/yr **bolded.**
Net EPC values rounded to the tenth decimal.

Gross EPC = exposure point concentration (includes background) (pCi/g)
BKG UTL = background upper tolerance level on the mean (pCi/g)
BKG AVG = average background concentration (pCi/g)
Net EPC = exposure point concentration (average background subtracted) (pCi/g)
DSR = dose-to-source ratio for all pathways combined (mrem/yr per pCi/g)
EU = Exposure Unit

Table 3A.6b. Industrial Worker Radiological Dose Estimates for the Luckey FUSRAP Site (0-10 ft)

Medium	Location	Year	Parameter	Gross EPC	BKG UTL	BKG AVG	Net EPC	DSR	Dose (mrem/yr)
0-10 ft Soil	EU 1	0	Actinium-227	0.297	1.76	0.304	0	3.23E-01	
0-10 ft Soil	EU 1	0	Protactinium-231	-0.138	0	0.0	0	8.04E-02	
0-10 ft Soil	EU 1	0	Radium-226	5.95	2.97	1.75	4.2	1.18E+00	5.0E+00
0-10 ft Soil	EU 1	0	Radium-228	0.879	1.48	1.10	0	7.44E-01	
0-10 ft Soil	EU 1	0	Thorium-228	1.08	1.6	1.15	0	8.82E-01	
0-10 ft Soil	EU 1	0	Thorium-230	5.63	3.2	2.11	3.5	5.54E-03	1.9E-02
0-10 ft Soil	EU 1	0	Thorium-232	0.842	1.48	1.03	0	6.85E-02	
0-10 ft Soil	EU 1	0	Uranium-234	4.65	2.36	1.48	3.2	2.39E-03	7.6E-03
0-10 ft Soil	EU 1	0	Uranium-235	0.202	0.26	0.09	0	8.05E-02	
0-10 ft Soil	EU 1	0	Uranium-238	4.69	2.63	1.63	3.1	1.62E-02	5.0E-02
									5.0E+00
0-10 ft Soil	EU 1	1000	Actinium-227	0.297	1.76	0.304	0	4.80E-15	
0-10 ft Soil	EU 1	1000	Protactinium-231	-0.138	0	0.0	0	3.93E-01	
0-10 ft Soil	EU 1	1000	Radium-226	5.95	2.97	1.75	4.2	7.52E-01	3.2E+00
0-10 ft Soil	EU 1	1000	Radium-228	0.879	1.48	1.10	0	0.00E+00	
0-10 ft Soil	EU 1	1000	Thorium-228	1.08	1.6	1.15	0	0.00E+00	
0-10 ft Soil	EU 1	1000	Thorium-230	5.63	3.2	2.11	3.5	4.15E-01	1.5E+00
0-10 ft Soil	EU 1	1000	Thorium-232	0.842	1.48	1.03	0	1.69E+00	
0-10 ft Soil	EU 1	1000	Uranium-234	4.65	2.36	1.48	3.2	3.53E-01	1.1E+00
0-10 ft Soil	EU 1	1000	Uranium-235	0.202	0.26	0.09	0	3.83E-01	
0-10 ft Soil	EU 1	1000	Uranium-238	4.69	2.63	1.63	3.1	3.44E-01	1.1E+00
									6.8E+00

Notes:
Radium-226 DSR includes contributions from lead-210 assuming equilibrium conditions.
Total dose estimates > 25 mrem/yr **bolded.**
Net EPC values rounded to the tenth decimal.

Gross EPC = exposure point concentration (includes background) (pCi/g)
BKG UTL = background upper tolerance level on the mean (pCi/g)
BKG AVG = average background concentration (pCi/g)
Net EPC = exposure point concentration (average background subtracted) (pCi/g)
DSR = dose-to-source ratio for all pathways combined (mrem/yr per pCi/g)
EU = Exposure Unit

Table 3A.6b. Industrial Worker Radiological Dose Estimates for the Luckey FUSRAP Site (0-10 ft)

Medium	Location	Year	Parameter	Gross EPC	BKG UTL	BKG AVG	Net EPC	DSR	Dose (mrem/yr)
0-10 ft Soil	EU 2	0	Actinium-227	0.335	1.76	0.304	0	3.23E-01	
0-10 ft Soil	EU 2	0	Protactinium-231	-0.285	0	0.0	0	8.04E-02	
0-10 ft Soil	EU 2	0	Radium-226	7.02	2.97	1.75	5.3	1.18E+00	6.3E+00
0-10 ft Soil	EU 2	0	Radium-228	0.925	1.48	1.10	0	7.44E-01	
0-10 ft Soil	EU 2	0	Thorium-228	1.02	1.6	1.15	0	8.82E-01	
0-10 ft Soil	EU 2	0	Thorium-230	6.85	3.2	2.11	4.7	5.54E-03	2.6E-02
0-10 ft Soil	EU 2	0	Thorium-232	0.8	1.48	1.03	0	6.85E-02	
0-10 ft Soil	EU 2	0	Uranium-234	4.37	2.36	1.48	2.9	2.39E-03	6.9E-03
0-10 ft Soil	EU 2	0	Uranium-235	0.219	0.26	0.09	0.0	8.05E-02	
0-10 ft Soil	EU 2	0	Uranium-238	4.4	2.63	1.63	2.8	1.62E-02	4.5E-02
									6.3E+00
0-10 ft Soil	EU 2	1000	Actinium-227	0.335	1.76	0.304	0	4.80E-15	
0-10 ft Soil	EU 2	1000	Protactinium-231	-0.285	0	0.0	0	3.93E-01	
0-10 ft Soil	EU 2	1000	Radium-226	7.02	2.97	1.75	5.3	7.52E-01	4.0E+00
0-10 ft Soil	EU 2	1000	Radium-228	0.925	1.48	1.10	0	0.00E+00	
0-10 ft Soil	EU 2	1000	Thorium-228	1.02	1.6	1.15	0	0.00E+00	
0-10 ft Soil	EU 2	1000	Thorium-230	6.85	3.2	2.11	4.7	4.15E-01	2.0E+00
0-10 ft Soil	EU 2	1000	Thorium-232	0.8	1.48	1.03	0	1.69E+00	
0-10 ft Soil	EU 2	1000	Uranium-234	4.37	2.36	1.48	2.9	3.53E-01	1.0E+00
0-10 ft Soil	EU 2	1000	Uranium-235	0.219	0.26	0.09	0	3.83E-01	
0-10 ft Soil	EU 2	1000	Uranium-238	4.4	2.63	1.63	2.8	3.44E-01	9.6E-01
									7.9E+00

Notes:
Radium-226 DSR includes contributions from lead-210 assuming equilibrium conditions.
Total dose estimates > 25 mrem/yr **bolded.**
Net EPC values rounded to the tenth decimal.

Gross EPC = exposure point concentration (includes background) (pCi/g)
BKG UTL = background upper tolerance level on the mean (pCi/g)
BKG AVG = average background concentration (pCi/g)
Net EPC = exposure point concentration (average background subtracted) (pCi/g)
DSR = dose-to-source ratio for all pathways combined (mrem/yr per pCi/g)
EU = Exposure Unit

Table 3A.6b. Industrial Worker Radiological Dose Estimates for the Luckey FUSRAP Site (0-10 ft)

Medium	Location	Year	Parameter	Gross EPC	BKG UTL	BKG AVG	Net EPC	DSR	Dose (mrem/yr)
0-10 ft Soil	EU 3	0	Actinium-227	0.165	1.76	0.304	0	3.23E-01	
0-10 ft Soil	EU 3	0	Protactinium-231	0.193	0	0.0	0.2	8.04E-02	1.6E-02
0-10 ft Soil	EU 3	0	Radium-226	3.27	2.97	1.75	1.5	1.18E+00	1.8E+00
0-10 ft Soil	EU 3	0	Radium-228	1.1	1.48	1.10	0	7.44E-01	
0-10 ft Soil	EU 3	0	Thorium-228	1.2	1.6	1.15	0	8.82E-01	
0-10 ft Soil	EU 3	0	Thorium-230	3.01	3.2	2.11	0	5.54E-03	
0-10 ft Soil	EU 3	0	Thorium-232	0.961	1.48	1.03	0	6.85E-02	
0-10 ft Soil	EU 3	0	Uranium-234	2.58	2.36	1.48	1.1	2.39E-03	2.6E-03
0-10 ft Soil	EU 3	0	Uranium-235	0.15	0.26	0.09	0	8.05E-02	
0-10 ft Soil	EU 3	0	Uranium-238	2.49	2.63	1.63	0	1.62E-02	
									1.8E+00
0-10 ft Soil	EU 3	1000	Actinium-227	0.165	1.76	0.304	0	4.80E-15	
0-10 ft Soil	EU 3	1000	Protactinium-231	0.193	0	0.0	0.2	3.93E-01	7.9E-02
0-10 ft Soil	EU 3	1000	Radium-226	3.27	2.97	1.75	1.5	7.52E-01	1.1E+00
0-10 ft Soil	EU 3	1000	Radium-228	1.1	1.48	1.10	0	0.00E+00	
0-10 ft Soil	EU 3	1000	Thorium-228	1.2	1.6	1.15	0	0.00E+00	
0-10 ft Soil	EU 3	1000	Thorium-230	3.01	3.2	2.11	0	4.15E-01	
0-10 ft Soil	EU 3	1000	Thorium-232	0.961	1.48	1.03	0	1.69E+00	
0-10 ft Soil	EU 3	1000	Uranium-234	2.58	2.36	1.48	1.1	3.53E-01	3.9E-01
0-10 ft Soil	EU 3	1000	Uranium-235	0.15	0.26	0.09	0	3.83E-01	
0-10 ft Soil	EU 3	1000	Uranium-238	2.49	2.63	1.63	0	3.44E-01	
									1.6E+00

Notes:
Radium-226 DSR includes contributions from lead-210 assuming equilibrium conditions.
Total dose estimates > 25 mrem/yr **bolded.**
Net EPC values rounded to the tenth decimal.

Gross EPC = exposure point concentration (includes background) (pCi/g)
BKG UTL = background upper tolerance level on the mean (pCi/g)
BKG AVG = average background concentration (pCi/g)
Net EPC = exposure point concentration (average background subtracted) (pCi/g)
DSR = dose-to-source ratio for all pathways combined (mrem/yr per pCi/g)
EU = Exposure Unit

Table 3A.7a. Subsistence Farmer Radiological Dose Estimates for the Luckey FUSRAP Site (0-2 ft)

Medium	Location	Year	Parameter	Gross EPC	BKG UTL	BKG AVG	Net EPC	DSR	Dose (mrem/yr)
0-2 ft Soil	EU 1	0	Actinium-227	0.547	1.76	0.304	0	3.40E+00	
0-2 ft Soil	EU 1	0	Protactinium-231	-0.328	0	0.0	0	8.27E+00	
0-2 ft Soil	EU 1	0	Radium-226	11.4	2.97	1.75	9.7	1.23E+01	1.19E+02
0-2 ft Soil	EU 1	0	Radium-228	0.893	1.48	1.10	0	6.31E+00	
0-2 ft Soil	EU 1	0	Thorium-228	1.04	1.6	1.15	0	3.70E+00	
0-2 ft Soil	EU 1	0	Thorium-230	10.5	3.2	2.11	8.4	5.90E-02	4.95E-01
0-2 ft Soil	EU 1	0	Thorium-232	0.833	1.48	1.03	0	6.43E-01	
0-2 ft Soil	EU 1	0	Uranium-234	8.87	2.36	1.48	7.4	5.77E-02	4.27E-01
0-2 ft Soil	EU 1	0	Uranium-235	0.359	0.26	0.09	0.3	3.79E-01	1.14E-01
0-2 ft Soil	EU 1	0	Uranium-238	8.95	2.63	1.63	7.3	1.13E-01	8.22E-01
									1.21E+02
0-2 ft Soil	EU 1	1000	Actinium-227	0.547	1.76	0.304	0	5.06E-14	
0-2 ft Soil	EU 1	1000	Protactinium-231	-0.328	0	0.0	0	1.14E+01	
0-2 ft Soil	EU 1	1000	Radium-226	11.4	2.97	1.75	9.7	7.85E+00	7.61E+01
0-2 ft Soil	EU 1	1000	Radium-228	0.893	1.48	1.10	0	0.00E+00	
0-2 ft Soil	EU 1	1000	Thorium-228	1.04	1.6	1.15	0	0.00E+00	
0-2 ft Soil	EU 1	1000	Thorium-230	10.5	3.2	2.11	8.4	4.28E+00	3.59E+01
0-2 ft Soil	EU 1	1000	Thorium-232	0.833	1.48	1.03	0	1.06E+01	
0-2 ft Soil	EU 1	1000	Uranium-234	8.87	2.36	1.48	7.4	9.74E-01	7.21E+00
0-2 ft Soil	EU 1	1000	Uranium-235	0.359	0.26	0.09	0.3	1.27E+00	3.80E-01
0-2 ft Soil	EU 1	1000	Uranium-238	8.95	2.63	1.63	7.3	9.46E-01	6.91E+00
									1.27E+02

Notes:
Radium-226 DSR includes contributions from lead-210 assuming equilibrium conditions.
Total dose estimates > 25 mrem/yr **bolded.**
Net EPC values rounded to the tenth decimal.

Gross EPC = exposure point concentration (includes background) (pCi/g)
BKG UTL = background upper tolerance level on the mean (pCi/g)
BKG AVG = average background concentration (pCi/g)
Net EPC = exposure point concentration (average background subtracted) (pCi/g)
DSR = dose-to-source ratio for all pathways combined (mrem/yr per pCi/g)
EU = Exposure Unit

Table 3A.7a. Subsistence Farmer Radiological Dose Estimates for the Luckey FUSRAP Site (0-2 ft)

Medium	Location	Year	Parameter	Gross EPC	BKG UTL	BKG AVG	Net EPC	DSR	Dose (mrem/yr)
0-2 ft Soil	EU 2	0	Actinium-227	0.502	1.76	0.304	0	3.40E+00	
0-2 ft Soil	EU 2	0	Protactinium-231	-0.51	0	0.0	0	8.27E+00	
0-2 ft Soil	EU 2	0	Radium-226	8.28	2.97	1.75	6.5	1.23E+01	7.99E+01
0-2 ft Soil	EU 2	0	Radium-228	0.868	1.48	1.10	0	6.31E+00	
0-2 ft Soil	EU 2	0	Thorium-228	0.944	1.6	1.15	0	3.70E+00	
0-2 ft Soil	EU 2	0	Thorium-230	12.3	3.2	2.11	10.2	5.90E-02	6.02E-01
0-2 ft Soil	EU 2	0	Thorium-232	0.774	1.48	1.03	0	6.43E-01	
0-2 ft Soil	EU 2	0	Uranium-234	6.71	2.36	1.48	5.2	5.77E-02	3.00E-01
0-2 ft Soil	EU 2	0	Uranium-235	0.379	0.26	0.09	0.3	3.79E-01	1.14E-01
0-2 ft Soil	EU 2	0	Uranium-238	6.67	2.63	1.63	5.0	1.13E-01	5.63E-01
									8.1E+01
0-2 ft Soil	EU 2	1000	Actinium-227	0.502	1.76	0.304	0	5.06E-14	
0-2 ft Soil	EU 2	1000	Protactinium-231	-0.51	0	0.0	0	1.14E+01	
0-2 ft Soil	EU 2	1000	Radium-226	8.28	2.97	1.75	6.5	7.85E+00	5.10E+01
0-2 ft Soil	EU 2	1000	Radium-228	0.868	1.48	1.10	0	0.00E+00	
0-2 ft Soil	EU 2	1000	Thorium-228	0.944	1.6	1.15	0	0.00E+00	
0-2 ft Soil	EU 2	1000	Thorium-230	12.3	3.2	2.11	10.2	4.28E+00	4.36E+01
0-2 ft Soil	EU 2	1000	Thorium-232	0.774	1.48	1.03	0	1.06E+01	
0-2 ft Soil	EU 2	1000	Uranium-234	6.71	2.36	1.48	5.2	9.74E-01	5.06E+00
0-2 ft Soil	EU 2	1000	Uranium-235	0.379	0.26	0.09	0.3	1.27E+00	3.80E-01
0-2 ft Soil	EU 2	1000	Uranium-238	6.67	2.63	1.63	5.0	9.46E-01	4.73E+00
									1.05E+02

Notes:
Radium-226 DSR includes contributions from lead-210 assuming equilibrium conditions.
Total dose estimates > 25 mrem/yr **bolded.**
Net EPC values rounded to the tenth decimal.

Gross EPC = exposure point concentration (includes background) (pCi/g)
BKG UTL = background upper tolerance level on the mean (pCi/g)
BKG AVG = average background concentration (pCi/g)
Net EPC = exposure point concentration (average background subtracted) (pCi/g)
DSR = dose-to-source ratio for all pathways combined (mrem/yr per pCi/g)
EU = Exposure Unit

Table 3A.7a. Subsistence Farmer Radiological Dose Estimates for the Luckey FUSRAP Site (0-2 ft)

Medium	Location	Year	Parameter	Gross EPC	BKG UTL	BKG AVG	Net EPC	DSR	Dose (mrem/yr)
0-2 ft Soil	EU 3	0	Actinium-227	0.166	1.76	0.304	0	3.40E+00	
0-2 ft Soil	EU 3	0	Protactinium-231	0.204	0	0.0	0.2	8.27E+00	1.65E+00
0-2 ft Soil	EU 3	0	Radium-226	3.32	2.97	1.75	1.6	1.23E+01	1.97E+01
0-2 ft Soil	EU 3	0	Radium-228	1.11	1.48	1.10	0	6.31E+00	
0-2 ft Soil	EU 3	0	Thorium-228	1.2	1.6	1.15	0	3.70E+00	
0-2 ft Soil	EU 3	0	Thorium-230	3.02	3.2	2.11	0	5.90E-02	
0-2 ft Soil	EU 3	0	Thorium-232	0.941	1.48	1.03	0	6.43E-01	
0-2 ft Soil	EU 3	0	Uranium-234	2.61	2.36	1.48	1.1	5.77E-02	6.35E-02
0-2 ft Soil	EU 3	0	Uranium-235	0.155	0.26	0.09	0	3.79E-01	
0-2 ft Soil	EU 3	0	Uranium-238	2.51	2.63	1.63	0	1.13E-01	
									2.1E+01
0-2 ft Soil	EU 3	1000	Actinium-227	0.166	1.76	0.304	0	5.06E-14	
0-2 ft Soil	EU 3	1000	Protactinium-231	0.204	0	0.0	0.2	1.14E+01	2.28E+00
0-2 ft Soil	EU 3	1000	Radium-226	3.32	2.97	1.75	1.6	7.85E+00	1.26E+01
0-2 ft Soil	EU 3	1000	Radium-228	1.11	1.48	1.10	0	0.00E+00	
0-2 ft Soil	EU 3	1000	Thorium-228	1.2	1.6	1.15	0	0.00E+00	
0-2 ft Soil	EU 3	1000	Thorium-230	3.02	3.2	2.11	0	4.28E+00	
0-2 ft Soil	EU 3	1000	Thorium-232	0.941	1.48	1.03	0	1.06E+01	
0-2 ft Soil	EU 3	1000	Uranium-234	2.61	2.36	1.48	1.1	9.74E-01	1.07E+00
0-2 ft Soil	EU 3	1000	Uranium-235	0.155	0.26	0.09	0	1.27E+00	
0-2 ft Soil	EU 3	1000	Uranium-238	2.51	2.63	1.63	0	9.46E-01	
									1.6E+01

Notes:
Radium-226 DSR includes contributions from lead-210 assuming equilibrium conditions.
Total dose estimates > 25 mrem/yr **bolded.**
Net EPC values rounded to the tenth decimal.

Gross EPC = exposure point concentration (includes background) (pCi/g)
BKG UTL = background upper tolerance level on the mean (pCi/g)
BKG AVG = average background concentration (pCi/g)
Net EPC = exposure point concentration (average background subtracted) (pCi/g)
DSR = dose-to-source ratio for all pathways combined (mrem/yr per pCi/g)
EU = Exposure Unit

Table 3A.7b. Industrial Worker Radiological Dose Estimates for the Luckey FUSRAP Site (0-2 ft)

Medium	Location	Year	Parameter	Gross EPC	BKG UTL	BKG AVG	Net EPC	DSR	Dose (mrem/yr)
0-2 ft Soil	EU 1	0	Actinium-227	0.547	1.76	0.304	0	3.23E-01	
0-2 ft Soil	EU 1	0	Protactinium-231	-0.328	0	0.0	0	8.04E-02	
0-2 ft Soil	EU 1	0	Radium-226	11.4	2.97	1.75	9.7	1.18E+00	1.15E+01
0-2 ft Soil	EU 1	0	Radium-228	0.893	1.48	1.10	0	7.44E-01	
0-2 ft Soil	EU 1	0	Thorium-228	1.04	1.6	1.15	0	8.82E-01	
0-2 ft Soil	EU 1	0	Thorium-230	10.5	3.2	2.11	8.4	5.54E-03	4.65E-02
0-2 ft Soil	EU 1	0	Thorium-232	0.833	1.48	1.03	0	6.85E-02	
0-2 ft Soil	EU 1	0	Uranium-234	8.87	2.36	1.48	7.4	2.39E-03	1.77E-02
0-2 ft Soil	EU 1	0	Uranium-235	0.359	0.26	0.09	0.3	8.05E-02	2.41E-02
0-2 ft Soil	EU 1	0	Uranium-238	8.95	2.63	1.63	7.3	1.62E-02	1.18E-01
									1.2E+01
0-2 ft Soil	EU 1	1000	Actinium-227	0.547	1.76	0.304	0	4.80E-15	
0-2 ft Soil	EU 1	1000	Protactinium-231	-0.328	0	0.0	0	3.93E-01	
0-2 ft Soil	EU 1	1000	Radium-226	11.4	2.97	1.75	9.7	7.52E-01	7.29E+00
0-2 ft Soil	EU 1	1000	Radium-228	0.893	1.48	1.10	0	0.00E+00	
0-2 ft Soil	EU 1	1000	Thorium-228	1.04	1.6	1.15	0	0.00E+00	
0-2 ft Soil	EU 1	1000	Thorium-230	10.5	3.2	2.11	8.4	4.15E-01	3.49E+00
0-2 ft Soil	EU 1	1000	Thorium-232	0.833	1.48	1.03	0	1.69E+00	
0-2 ft Soil	EU 1	1000	Uranium-234	8.87	2.36	1.48	7.4	3.53E-01	2.61E+00
0-2 ft Soil	EU 1	1000	Uranium-235	0.359	0.26	0.09	0.3	3.83E-01	1.15E-01
0-2 ft Soil	EU 1	1000	Uranium-238	8.95	2.63	1.63	7.3	3.44E-01	2.51E+00
									1.60E+01

Notes:
Radium-226 DSR includes contributions from lead-210 assuming equilibrium conditions.
Total dose estimates > 25 mrem/yr **bolded.**
Net EPC values rounded to the tenth decimal.

Gross EPC = exposure point concentration (includes background) (pCi/g)
BKG UTL = background upper tolerance level on the mean (pCi/g)
BKG AVG = average background concentration (pCi/g)
Net EPC = exposure point concentration (average background subtracted) (pCi/g)
DSR = dose-to-source ratio for all pathways combined (mrem/yr per pCi/g)
EU = Exposure Unit

Table 3A.7b. Industrial Worker Radiological Dose Estimates for the Luckey FUSRAP Site (0-2 ft)

Medium	Location	Year	Parameter	Gross EPC	BKG UTL	BKG AVG	Net EPC	DSR	Dose (mrem/yr)
0-2 ft Soil	EU 2	0	Actinium-227	0.502	1.76	0.304	0	3.23E-01	
0-2 ft Soil	EU 2	0	Protactinium-231	-0.51	0	0.0	0	8.04E-02	
0-2 ft Soil	EU 2	0	Radium-226	8.28	2.97	1.75	6.5	1.18E+00	7.69E+00
0-2 ft Soil	EU 2	0	Radium-228	0.868	1.48	1.10	0	7.44E-01	
0-2 ft Soil	EU 2	0	Thorium-228	0.944	1.6	1.15	0	8.82E-01	
0-2 ft Soil	EU 2	0	Thorium-230	12.3	3.2	2.11	10.2	5.54E-03	5.65E-02
0-2 ft Soil	EU 2	0	Thorium-232	0.774	1.48	1.03	0	6.85E-02	
0-2 ft Soil	EU 2	0	Uranium-234	6.71	2.36	1.48	5.2	2.39E-03	1.24E-02
0-2 ft Soil	EU 2	0	Uranium-235	0.379	0.26	0.09	0.3	8.05E-02	2.41E-02
0-2 ft Soil	EU 2	0	Uranium-238	6.67	2.63	1.63	5.0	1.62E-02	8.10E-02
									7.9E+00
0-2 ft Soil	EU 2	1000	Actinium-227	0.502	1.76	0.304	0	4.80E-15	
0-2 ft Soil	EU 2	1000	Protactinium-231	-0.51	0	0.0	0	3.93E-01	
0-2 ft Soil	EU 2	1000	Radium-226	8.28	2.97	1.75	6.5	7.52E-01	4.89E+00
0-2 ft Soil	EU 2	1000	Radium-228	0.868	1.48	1.10	0	0.00E+00	
0-2 ft Soil	EU 2	1000	Thorium-228	0.944	1.6	1.15	0	0.00E+00	
0-2 ft Soil	EU 2	1000	Thorium-230	12.3	3.2	2.11	10.2	4.15E-01	4.23E+00
0-2 ft Soil	EU 2	1000	Thorium-232	0.774	1.48	1.03	0	1.69E+00	
0-2 ft Soil	EU 2	1000	Uranium-234	6.71	2.36	1.48	5.2	3.53E-01	1.84E+00
0-2 ft Soil	EU 2	1000	Uranium-235	0.379	0.26	0.09	0.3	3.83E-01	1.15E-01
0-2 ft Soil	EU 2	1000	Uranium-238	6.67	2.63	1.63	5.0	3.44E-01	1.72E+00
									1.3E+01

Notes:
Radium-226 DSR includes contributions from lead-210 assuming equilibrium conditions.
Total dose estimates > 25 mrem/yr **bolded.**
Net EPC values rounded to the tenth decimal.

Gross EPC = exposure point concentration (includes background) (pCi/g)
BKG UTL = background upper tolerance level on the mean (pCi/g)
BKG AVG = average background concentration (pCi/g)
Net EPC = exposure point concentration (average background subtracted) (pCi/g)
DSR = dose-to-source ratio for all pathways combined (mrem/yr per pCi/g)
EU = Exposure Unit

Table 3A.7b. Industrial Worker Radiological Dose Estimates for the Luckey FUSRAP Site (0-2 ft)

Medium	Location	Year	Parameter	Gross EPC	BKG UTL	BKG AVG	Net EPC	DSR	Dose (mrem/yr)
0-2 ft Soil	EU 3	0	Actinium-227	0.166	1.76	0.304	0	3.23E-01	
0-2 ft Soil	EU 3	0	Protactinium-231	0.204	0	0.0	0.2	8.04E-02	1.61E-02
0-2 ft Soil	EU 3	0	Radium-226	3.32	2.97	1.75	1.6	1.18E+00	1.89E+00
0-2 ft Soil	EU 3	0	Radium-228	1.11	1.48	1.10	0	7.44E-01	
0-2 ft Soil	EU 3	0	Thorium-228	1.2	1.6	1.15	0	8.82E-01	
0-2 ft Soil	EU 3	0	Thorium-230	3.02	3.2	2.11	0	5.54E-03	
0-2 ft Soil	EU 3	0	Thorium-232	0.941	1.48	1.03	0	6.85E-02	
0-2 ft Soil	EU 3	0	Uranium-234	2.61	2.36	1.48	1.1	2.39E-03	2.63E-03
0-2 ft Soil	EU 3	0	Uranium-235	0.155	0.26	0.09	0	8.05E-02	
0-2 ft Soil	EU 3	0	Uranium-238	2.51	2.63	1.63	0	1.62E-02	
									1.9E+00
0-2 ft Soil	EU 3	1000	Actinium-227	0.166	1.76	0.304	0	4.80E-15	
0-2 ft Soil	EU 3	1000	Protactinium-231	0.204	0	0.0	0.2	3.93E-01	7.87E-02
0-2 ft Soil	EU 3	1000	Radium-226	3.32	2.97	1.75	1.6	7.52E-01	1.20E+00
0-2 ft Soil	EU 3	1000	Radium-228	1.11	1.48	1.10	0	0.00E+00	
0-2 ft Soil	EU 3	1000	Thorium-228	1.2	1.6	1.15	0	0.00E+00	
0-2 ft Soil	EU 3	1000	Thorium-230	3.02	3.2	2.11	0	4.15E-01	
0-2 ft Soil	EU 3	1000	Thorium-232	0.941	1.48	1.03	0	1.69E+00	
0-2 ft Soil	EU 3	1000	Uranium-234	2.61	2.36	1.48	1.1	3.53E-01	3.89E-01
0-2 ft Soil	EU 3	1000	Uranium-235	0.155	0.26	0.09	0	3.83E-01	
0-2 ft Soil	EU 3	1000	Uranium-238	2.51	2.63	1.63	0	3.44E-01	
									1.7E+00

Notes:
Radium-226 DSR includes contributions from lead-210 assuming equilibrium conditions.
Total dose estimates > 25 mrem/yr **bolded.**
Net EPC values rounded to the tenth decimal.

Gross EPC = exposure point concentration (includes background) (pCi/g)
BKG UTL = background upper tolerance level on the mean (pCi/g)
BKG AVG = average background concentration (pCi/g)
Net EPC = exposure point concentration (average background subtracted) (pCi/g)
DSR = dose-to-source ratio for all pathways combined (mrem/yr per pCi/g)
EU = Exposure Unit

Table 3A.8. Risk-Based Concentrations for Luckey Subsistence Farmer Constituents of Concern

COC	Year	DSR mrem-g/pCi-yr	Dose Limit mrem/yr	Cleanup Goal pCi/g
Radium-226	0.0	1.23E+01	25	**2.0E+00**
Thorium-230	0.0	5.90E-02	25	4.2E+02
Uranium-234	0.0	5.77E-02	25	4.3E+02
Uranium-238	0.0	1.13E-01	25	2.2E+02
Radium-226	1000	7.85E+00	25	3.2E+00
Thorium-230	1000	4.28E+00	25	**5.8E+00**
Uranium-234	1000	9.74E-01	25	**2.6E+01**
Uranium-238	1000	9.46E-01	25	**2.6E+01**

Notes:

Cleanup Goal = Limit/RSR for risk or Limit/DRS for dose; most limiting value **bolded.**

Radium-226 cleanup goal includes radium-226 and lead-210 in equilibrium.

These cleanup goals represent concentrations above site background concentrations.

COC = constituent of concern

RSR = risk-to-source ratio

DSR = dose-to-source ratio

Figure 3A.1. Intake Calculations for Home-grown Produce - Subsistence Farmer Child

Ingestion of Home-grown Fruits and Vegetables

Vegetative Parts (Leafy vegetables)

Intake (mg/kg-day) = (Be_v x IR x FI x EF x ED) / (BW x AT)

			Source
Be_v =	Beryllium concentration in plants, vegetative parts(mg/kg)	0.61	Calculated using EPCsoil = 765 mg/kg in Exposure Unit 2
IR =	Ingestion rate (kg/meal)	0.0128	= (14 kg/yr) * (1yr/365 days) * (1day/3 meals), Note: 14 kg/yr is RESRAD default
FI =	Fraction Ingested from Contaminated Source (unitless)	0.3	EFH (Table 13-71, USEPA 1997), "house holds who farm" - total vegetables = 30.8%
EF =	Exposure Frequency (meals/year)	1050	3 meals x 350 days/year
ED =	Exposure Duration (years)	6	RIR value
BW =	Body weight (kg)	15	RIR value
ATn =	Averaging Time - noncancer (days)	2190	=ED x 365 days/year
ATc =	Averaging Time - cancer (days)	25550	=70 years x 365 days/year

Intake (noncancer) =	4.51E-04	mg/kg-day
Intake (cancer) =	3.86E-05	mg/kg-day

Fruiting Parts (Fruits, vegetables, and grain)

Intake (mg/kg-day) = (Be_r x IR x FI x EF x ED) / (BW x AT)

			Source
Be_r =	Beryllium concentration in plants, fruiting parts (mg/kg)	0.17	Calculated using EPCsoil = 765 mg/kg in Exposure Unit 2
IR =	Ingestion rate (kg/meal)	0.146	= (160 kg/yr) * (1yr/365 days) * (1day/3 meals), Note: 160 kg/yr is RESRAD default
FI =	Fraction Ingested from Contaminated Source (unitless)	0.3	EFH (Table 13-71, USEPA 1997), "house holds who farm" - total vegetables = 30.8%
EF =	Exposure Frequency (meals/year)	1050	3 meals x 350 days/year
ED =	Exposure Duration (years)	6	RIR value
BW =	Body weight (kg)	15	RIR value
ATn =	Averaging Time - noncancer (days)	2190	=ED x 365 days/year
ATc =	Averaging Time - cancer (days)	25550	=70 years x 365 days/year

Intake (noncancer) =	1.45E-03	mg/kg-day
Intake (cancer) =	1.24E-04	mg/kg-day

Total Plant Intake = Intake (vegetative parts) + Intake (fruiting parts)

Total Plant Intake (noncancer) =	1.90E-03	mg/kg-day
Total Plant Intake (cancer) =	1.63E-04	mg/kg-day

APPENDIX 3B:
Volume Estimates

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APPENDIX 3B. VOLUME ESTIMATE

3B.1 INTRODUCTION

This appendix presents the methodology, data, and information used to estimate the volume of impacted soils at the Luckey site for unrestricted and industrial land use cleanup goals. The volume of impacted soils is based on the media-specific cleanup goals developed in Section 3 of this Feasibility Study (FS), as well as site and historical knowledge.

3B.2 ENVIRONMENTAL DATA

Several data sources were used in estimating impacted soil volumes for the Luckey site (Table 3B.1). These included analytical data, Laser Induced Breakdown Spectroscopy (LIBS) data, and gamma walkover survey data. Analytical data collected from samples at 21 locations by Oak Ridge National Laboratory (ORNL) in 1988 were supplemented in 1997, 1998, and 1999 with an additional 760 soil samples collected during implementation of the Luckey Remedial Investigation (RI) (USACE 2000a). All of these soil samples were analyzed for beryllium. Approximately 45% of soil samples also were analyzed for additional metals including arsenic, barium, and lead and radionuclides (consisting of radium, thorium, and uranium). A subset, approximately 10%, of soil samples were analyzed for TAL metals and organic constituents for evaluation in the baseline risk assessment.

In 1988, ORNL completed a limited gamma walkover survey of the site. In 1997, a comprehensive gamma walkover survey was conducted over the entire site. LIBS was used during field screening activities to define the lateral boundaries of beryllium in soils. Sampling consisted of collecting a surface reading or sample at 10- or 20-meter intervals over the entire site.

The LIBS data and the gamma walkover survey data are detailed in the Phase II Characterization Report (BNI 1998). Analytical data are presented in the RI Report (USACE 2000a) with summaries of the results of the LIBS and gamma walkover surveys.

3B.3 MODELING

Environmental data (i.e. analytical, LIBS, and gamma walkover survey data) were used to develop 3D models of Atomic Energy Commission (AEC)-related constituents of concern (COCs) in soils using EarthVision™ (Dynamic Graphics, Inc. 2001). The 3D modeling process can be viewed as expanding traditional 2D contouring programs into three dimensions. The environmental data at Luckey were collected at various locations and depths. To contour the data in three dimensions, a regularly spaced grid of values is needed. This grid is calculated from the environmental data using a function that minimizes the error between adjacent grid nodes and between the measured site data and the calculated grid. The EarthVision™ function employed for developing the 3D models is called minimum tension gridding. Once the grid is calculated, it is visually and quantitatively compared with the environmental data to ensure accurate representation of the environmental data. Concentrations are then contoured at user-specified levels in 3D space. Volumes of soils above cleanup goals are subsequently calculated from the model.

Conceptual site knowledge can be incorporated into the model to permit a more accurate representation of contaminant extent and volume estimates. Pertinent site features such as topography, water table elevations, top of bedrock elevations, etc., have been incorporated into the model to establish the upper and lower extents and to determine the volume of contaminated soils above and below the water table. The locations of the trenches and lagoons also are accounted for within the model.

3B.3.1 Assumptions Inherent in the Volume Calculations

There are a number of assumptions inherent in the development of the 3D models and the volume estimates of AEC-related COCs at the Luckey site. The assumptions include the following:

- Environmental data accurately represent the nature and extent of AEC-related COCs in soils at the site (i.e. all significant contamination was detected during RI sampling activities).
- Site knowledge (reported or observed) pertaining to the extent of the trenches and lagoons permits an accurate representation of these features in the 3D models.
- Contamination associated with the LIBS data extends to 0.5 feet below ground surface (bgs). (LIBS range is limited to the immediate surface. Beyond analytical data associated with site features, LIBS indicates extent due to areal deposition of smokestack emissions – correlated with analytical data.)
- The impact of over-excavation is equal to 20% of the calculated in situ volume.
- The impact of constructability is equal to 10% of the calculated in situ volume (inclusive of over-excavation).
- The increase in volume (swell factor) is equal to 20% of the calculated volume. One in place cubic yard is therefore equal to 1.2 cubic yards after excavation.

3B.3.2 Modeled Volumes

Volume estimates were developed for soils above unrestricted land use cleanup goals and soils above industrial land use cleanup goals. A data set for each AEC-related COC was entered into EarthVision™, a 3D grid was developed for each COC, and a volume was calculated from the modeled 3D grid. This analysis produced four volumes:

1) the volume of soils containing beryllium derived from LIBS,
2) the volume of soils containing beryllium derived from analytical data,
3) the volume of soils containing lead derived from analytical data, and
4) the volume of soils where the sum-of-ratios (SOR) for the radionuclides exceeds one (as prescribed by the cleanup goals, see FS Section 3.3.4).

These volumes were merged into an in situ volume that prevented "double counting" volumes where more than one COC exceeded a cleanup goal. This in situ volume is detailed according to zone, or investigation area (IA), and presented in the second column (Total Volume Modeled from Data) of Table 3B.2 (volume for unrestricted land use) and Table 3B.3 (volume for industrial land use). The IAs and associated site features are depicted in Figure 3B.1. The horizontal and vertical extent of modeled contamination above unrestricted land use cleanup goals is depicted in Figures 3B.2 through 3B.8. These figures present the areal extent at vertical slices ranging from ground surface to 12 ft bgs. The horizontal and vertical extent of modeled contamination above industrial land use cleanup goals is depicted in Figures 3B.10 through 3B.14. These figures present the areal extent at vertical slices ranging from ground surface to 8 ft bgs.

3B.3.2.1 Historical Information and Site Knowledge

Historical documents and interviews provided additional information regarding potential contaminant distribution which was not captured in analytical data sources. This information is incorporated into the impacted soils volume estimate and is presented in the third column (Potential Additional Volumes) of Tables 3B.2 and 3B.3.

Historical documents and site knowledge are susceptible to inaccuracies and error. For example, historical documents available for the site included a series of maps depicting the lagoons. These maps do not consistently portray the extent or configuration of the lagoons. In some maps, Lagoon B is depicted as a single entity while in others it consists of three parts divided by dikes. Historical maps of Lagoon C are similarly inconsistent. Maps exist depicting Lagoon C as a single entity and also as two parts. Some of the lagoon boundaries seem to simply be outlines indicating topographic expression of the tops of the dikes surrounding the lagoons. Other depicted boundaries appear to be actual configurations.

The susceptibility of inaccuracies and errors in historical documents is further illustrated by a construction plan presenting specifications to create a disposal area in the northeast corner of the site. This plan called for a boundary dike, drain tiles, and a sump to be installed. Portions of the dike exist and the sump has been constructed. However, the area is considerably smaller than the plan specified and there are no records indicating that construction was completed according to the plan.

Several interviews were conducted in 1990 with employees who worked at the Luckey site in the 1950s. The employees provided information on the number and distribution of trenches used to dispose of sludge material dredged from the lagoons. One interviewee also provided dimensions for the trenches. The information recalled was more than 30 years old and may not have been complete or accurate. Several pieces of information derived from interviews were not consistent with actual field conditions. For example, it was indicated during an interview that four feet of cover had been placed over the trenches. There was no evidence of cover over some of the trenches during RI field investigation activities.

Because of the discrepancies between historical documents and field verified information, information derived from historical sources is not considered as certain as analytical data. However, volumes attributable to information provided by historical documents and site knowledge are incorporated into the estimated in situ volume. Column 8 (Comments) in Tables 3B.2 and 3B.3, details the basis for these additional volumes. The additional volumes are minor where there is limited historical information (e.g. IA07) and significant in IA01 where historical descriptions of the configuration of the trenches are not confirmed by analytical data. Significant volumes also are added in IA02 where a limited number of samples in Lagoon C result in all potential sludges within the boundaries of Lagoon C to be considered impacted.

3B.3.3 Over-excavation and Constructability

Excavation will be performed in a conservative manner to ensure remedial action objectives (RAOs) are achieved. Experience in excavation has shown that this conservatism results in an over-excavation of roughly 20% of the estimated volume. Additional excavated volume to assure safe slopes on side walls and to address machinery limitations (i.e. constructability) is estimated at a 10% increase. The effects of over-excavation and constructability are incorporated into Tables 3B.2 and 3B.3 (Columns 5 and 6, respectively). Figures 3B.9 and 3B.15 illustrate the estimated extent of excavation for the unrestricted and industrial land uses at the Luckey site.

3B.3.4 Ex Situ Volume

The volumes presented to this point constitute “in place” or in situ volumes. The act of excavation results in an expansion of the material. This expanded volume is then transported and disposed. The volume expansion, or “swell”, experienced by soil when it is excavated averages approximately 20%. This additional volume is addressed in Column 7 of Tables 3B.2 and 3B.3.

3B.4 ESTIMATING WASTE STREAM VOLUMES

An assessment of the potential waste streams comprising the volume of soil above the unrestricted clean up goals was performed. The calculation of waste stream volumes is a complicated process. Characteristics of the contaminated soils affect the final disposition of soils and determine applicable waste stream categories. Beryllium-contaminated soil at the Luckey site, even with beryllium above the cleanup goal, is a solid waste. Lead-contaminated soil exceeding the cleanup goal may qualify as a Resource Conservation and Recovery Act (RCRA) hazardous waste. Radium, thorium, and uranium above cleanup goals constitute a Formerly Utilized Sites Remedial Action Program (FUSRAP) radioactive waste similar to 11(e)(2) as defined by the Atomic Energy Act. The final category of waste is mixed waste. The term "*mixed waste,*" as used throughout this appendix, is defined as: *RCRA hazardous waste with radioactive residuals that are not NRC regulated*. This includes 1) RCRA hazardous wastes containing radioactive residuals at activities acceptable for disposal at a RCRA permitted disposal facility, and 2) RCRA hazardous waste containing radioactive residuals at activities requiring disposal at a RCRA disposal facility that is both permitted and licensed."

In order to determine the volume of each potential waste stream, the original volumes of beryllium-contaminated soil, lead-contaminated soil, radionuclide-contaminated soil and LIBS-identified soil were evaluated to determine where soils contained multiple contaminants. Soil that was determined to be beryllium-contaminated, either by analytical data or by LIBS, was classified as solid waste if it contained no other contaminants. Soil that was lead-contaminated but contained no other contaminants was identified as potentially RCRA hazardous waste. Soil that was contaminated with radionuclides above the cleanup goals, did not contain lead contamination, but may or may not contain beryllium contamination, was identified as FUSRAP radioactive waste. Mixed waste was soil that contained radiologically-contaminated soil with RCRA hazardous waste. Table 3B.4 summarizes the volume and percentage of soil in each of the categories.

Solid Waste (64%): Solid waste represents the largest waste stream and is driven by beryllium. This waste stream volume was calculated using the EarthVision™ software by subtracting the volume of impacted soils containing contaminant other than beryllium from the total volume of impacted soil. This volume is relatively controlled in terms of uncertainty, with an approximated 15% high-end uncertainty. This uncertainty is due mostly to historical descriptions of the trenches not correlating with collected field data.

FUSRAP Radioactive Waste (28.9%): FUSRAP radioactive waste represents the second largest volume. It was calculated using EarthVision™, as described above. Soils above the radiological criteria were included in this waste designation as long as RCRA hazardous components were not present. This estimate is also relatively certain with only about a 15% high-end uncertainty. This uncertainty, like the solid waste estimate, is due mostly to the uncertainty in the configuration of the trenches.

RCRA Hazardous Waste (2.6%): Although some RCRA hazardous waste is present in the volume estimate, the actual likelihood of any material exhibiting the characteristics of hazardous waste is low. Compounds that have been detected on the site occurring on the F-list are not necessarily listed hazardous waste. United States Environmental Protection Agency (EPA) indicates that if a compound is on the F-list it must also have been used in the process specified on the list before being considered RCRA hazardous waste. It is permissible to assume it is not hazardous if a good faith effort has been made to identify the source of the compounds and to ascertain that the process by which they arrived in the soil is not the process defined in the hazardous waste regulations. At the Luckey site, RCRA waste, if present, could also contain beryllium as a complicating factor during handling and disposition. The uncertainty of this estimate is high. There is approximately 100% uncertainty associated with this volume

estimate (zero to double the amount currently estimated depending on how the soils are evaluated). If the material is not hazardous, a portion of it will likely be solid waste (i.e. beryllium-contaminated soils).

Mixed Waste (4.5%): Mixed waste has similar considerations to the RCRA Hazardous waste. It is unlikely that there is much material that meets the definition of "mixed waste." At the Luckey site, this material, if present, could also contain beryllium as a complicating factor during handling and disposition. This volume estimate has a high degree of uncertainty mostly due to the definition of "hazardous," as described above.

Table 3B.1. Summary of Data Sources

Source	Data Type	Comments
ORNL Designation survey	analytical	limited analytical suite
RI	analytical	beryllium and radiological analyses of most samples, limited full suite analyses
RI, Phase II characterization report	LIBS	beryllium screening data limited precision and accuracy 10-meter grid over most impacted areas
ORNL Designation Survey	gamma walkover	limited coverage
RI, Phase II characterization report	gamma walkover	complete coverage of the site, coverage of 50-meter of portions of the surrounding off-site fields and rail road bed
maps	historical, site	maps indicating the extent of lagoons, locations of “disposal areas”
personnel interviews	historical, site	Cline and Singleton interviews from 1990 - provided information on trenches, scrap metal storage areas

Table 3B.2. Estimated Volumes of Impacted Soils ~ Unrestricted Land Use

Zone	Total Volume Modeled from Data (yd^3)[1,2]	Potential Additional Volume (yd^3)	Most Likely Volume (yd^3)	Most Likely + 20% Overexcavation (yd^3)[3,3]	Constructability Volume (yd^3)	Volume With Swell Factor (yd^3)	Comments
	a	b	c = a + b	d = c * 1.2	e = d * 1.1	f = e * 1.2	
IA01	12,700	8,300	21,000	25,200	27,720	33,264	The volume estimated from the data consists of 11,900 yd^3 from analytical soil samples and about 800 yd^3 from LIBS data for a total of 12,700 yd^3. **Potential Additional Volume** The total volume of the trenches in IA01 is estimated to be as much as 13,000 yd^3. This is based on a combination of interpretation of boring logs from IA01, historical information about the trenches, and geophysical testing in IA01. The volume already included from the trenches in the 12,700 yd^3 estimate is 4,700 yd^3. Assuming the entire remainder of the trenches are contaminated adds about 8,300 yd^3 to the volume estimate in this area. An addition of approximately 1,400 yd^3 that has been modeled to exist between IA01 and the railroad tracks has been included in the "Off_Site" volume estimate below.
IA02							
Lagoon A	300	0	300	360	396	475	The volume estimated from the data consists of 250 yd^3 from analytical soil samples and about 50 yd^3 from LIBS data for a total of 300 yd^3. Contamination is fairly well bounded on all sides by sample locations that are below the cleanup criteria. As such, no potential additional volume has been added to the calculated volume.
Lagoon B	5,500	1,400	6,900	8,280	9,108	10,930	The volume estimated from the data consists of 5,200 yd^3 from analytical soil samples and about 300 yd^3 from LIBS data for a total of 5,500 yd^3. **Potential Additional Volume** Lagoon B has an area of 29,500 ft^2. This area includes the area of modeled contamination but extends further than the sample data. The thickness of the contaminated zone could potentially be 6 ft so that the additional area could contain a potential additional volume of 1,400 yd^3 within the lagoon. This has been added to the roughly 300 yd^3 of surface contamination identified by LIBS and the 5,200 yd^3 already modeled in the lagoon for a total of 6,900 yd^3.
Lagoon C	7,500	3,500	11,000	13,200	14,520	17,424	The volume estimated from the data consists of 4,850 yd^3 from analytical soil samples and about 2,650 yd^3 from LIBS data, for a total of 7,500 yd^3. **Potential Additional Volume** Total contamination in the first stage area in Lagoon C may cover the entire 31,000 ft^2 area to a depth of up to 4 ft for a total of 4,600 yd^3. The potentially contaminated area of the second stage of Lagoon C is about 115,000 ft^2 and may be as deep as 1.5 ft in this area, for a total of 6,400 yd^3. This gives a total potential volume of 11,000 yd^3. The 7,500 yd^3 calculated from the data exists within this 11,000 yd^3. This results in an actual potential additional volume of 3,500 yd^3.
IA03	2,300	0	2,300	2,760	3,036	3,643	The volume estimated from the data consists of 900 yd^3 from analytical soil samples and about 1,400 yd^3 from LIBS data yielding 2,300 yd^3 total. There is not any historic information that would indicate any extensive contamination in this area that has not been explicitly identified by the data.
IA04	700	0	700	840	924	1,109	The volume estimated from the data consists of 0 yd^3 from analytical soil samples and about 700 yd^3 from LIBS data yielding 700 yd^3 total. There is not any historic information that would indicate any extensive contamination in this area that has not been explicitly identified by the data.
IA05	4,350	0	4,350	5,220	5,742	6,890	The volume estimated from the data consists of 3,100 yd^3 from analytical soil samples and about 1,250 yd^3 from LIBS data yielding 4,350 yd^3 total. **Potential Additional Volume** The largest source of uncertainty in this area arises from the east-west running trench along this area's southern boundary. A pile of rubble has prevented characterization of this trench. Borings that have been sampled on the eastern end of this trench suggest extensive contamination may exist to at least 10 ft below ground surface through this trench. Assuming the trench is 15 ft wide by 300 ft long by 10 ft deep and full of contamination, this creates about 1,670 yd^3 of volume in this area. Extrapolation from data in this area has covered about 2,500 yd^3 of contaminated soil to account for the potential volume of soil in the trench. The remainder of hot data in IA05 is fairly well bounded by clean data. Therefore, no additional volume is expected from this area.
IA07	4,350	0	4,350	5,220	5,742	6,890	The volume estimated from the data consists of 3,650 yd^3 from analytical soil samples and about 700 yd^3 from LIBS data, for a total of 4,350 yd^3. Historically, little is known about this area. Some degree of activity obviously took place since a large area with very little vegetation has existed just east of the propane tanks reportedly for several decades. Analytical tests in this area have revealed most contaminants in IA07 are confined to this area "devoid of vegetation". "Hot" samples are fairly well bounded by samples below criteria in this area. Therefore, no additional volume is expected from this area.
IA08	100	0	100	120	132	158	The volume from the data consists of 0 yd^3 from analytical soil samples and about 100 yd^3 from LIBS data yielding 100 yd^3 total. From historic records, very little activity is believed to have taken place in this area, so no additional volume is expected from this area.
Off-Site	4,400	0	4,400	5,280	5,808	6,970	The volume estimated from the data consists of 4,100 yd^3 from analytical soil samples and about 300 yd^3 from LIBS data yielding 4,400 yd^3 total. **Potential Additional Volume** The largest source of uncertainty arises along the drainage ditch that runs from the western edge of the trench area north to Toussaint Creek. This ditch has been regularly dredged and the Be contaminated sediments have subsequently been mixed into the farm field along the eastern side of this ditch. Surface samples along the ditch have indicated beryllium is present along the entire length of the ditch's eastern bank in concentrations exceeding the cleanup criteria. Assuming the entire length of the ditch (1,200 ft from the site to Toussaint Creek) has contamination on the eastern bank that has been smeared out to 100 ft away from the bank by farming activities to a depth of 6 inches, gives a possible 2,200 yd^3 of contamination along the ditch. The earthVision model has about 3,000 yd3 of contamination modeled in this area. The majority of the remaining 1,400 yd3 of off-site volume lies between IA01 and the railroad bed on the east side of the site
Total	42,200	13,200	55,400	66,480	73,128	87,754	Most areas of the site have been fairly well defined by historic information and various sampling events. Much of the uncertainty should have been addressed in the above considerations. However, the recollections of some former employees from the time Brush Beryllium Company operated the plant have proven to be less than 100% reliable. Other instances such as the are "devoid of vegetation" in IA07 do not have any historic record of potentially harmful events taking place there further raise concern that unanticipated contamination may exist on site. As such, 59,000 yd^3 (70,800 accounting for 20% overexcavation) should be taken as a best guess of contamination that has been characterized either by sampling or historical records on and off site and does not account for areas that do not have historical records indicating possible contamination.

Notes:

1) The "Total Volume Modeled from Data" was calculated with a software package named EarthVision developed by Dynamic Graphics, Incorporated (www.dgi.com) using the Minimum Tension Gridding Algorithm along with engineering judgement to confine and shape the modeled extents.

2) The "Total Volume Modeled from Data" includes in situ volumes from beryllium analytical data, beryllium LIBS data, analytical data for U-238, U-234, Ra-226, and Th-230 combined as an SOR, and from analytical data for lead. It also incorporates information from gamma walkover surveys.

3) "Most Likely + 20% Overexcavation" accounts for overexcavation of the in-situ volumes based on mechanical and field screening limitations only.

4) All of the volumes reported in the above table except the Swell Factor volume are in units of cubic yards and represent the in situ volume.

5) Sludge from areas such as the trenches and possibly Lagoon B may need extra material added in order to absorb water trapped in it to fulfill landfill acceptance criteria. This may further increase the volume of material to be shipped to landfills.

6) The in situ volumes in this table were updated February 05, 2002, using action levels of 131 ppm for Be, 400 ppm for Pb, 5.06 pCi/g for Ra-226, 9.0 pCi/g for Th-230, 28.61 pCi/g for Uranium-234, and 28.63 pCi/g for Uranium-238.

Table 3B.3. Estimated Volumes of Impacted Soils ~ Industrial Land Use

Zone	Total Volume Modeled From Data (yd^3)[1,2]	Potential Additional Volume (yd3)	Most Likely Volume (yd^3)	Most Likely + 20% Overexcavation (yd^3)[3,3]	Constructability Volume (yd^3)	Volume With Swell Factor (yd^3)	Comments
	a	b	c = a + b	d = c * 1.2	e = d * 1.1	f = e * 1.2	
IA01	4,950	10,700	15,650	18,780	20,658	24,790	The volume estimated from the data consists entirely of 4,950 yd^3 from analytical soil samples of lead and rads. Of this volume, roughly 2,650 yd^3 is outside the trenches, and the remaining 2,300 yd^3 lies within the estimated trench extents. **Potential Additional Volume** The total volume of the trenches in IA01 is estimated to be as much as 13,000 yd^3. This is based on a combination of interpretation of boring logs from IA01, historical information about the trenches, and geophysical testing in IA01. According to the groundwater flow model developed for the site, the groundwater table will potentially rise up into the trenches if Uretech's production well is shut off. This could create a pathway for contaminants to enter the groundwater above acceptable levels, assuming contaminants are present deep in the trenches. Given the above volumes, the total excavation volume is 15,650 yd^3 (13,000 total trench volume + 2,650 modeled contamination outside trenches). For this reason, 10,700 yd^3 (15,650 - 4,950) has been added to the volume estimate in IA01 to account for the trenches.
IA02							
Lagoon_A	60	0	60	72	79	95	60 yd^3 of soil has been modeled to exceed the Industrial Worker criteria in Lagoon A. Extensive samples have been collected from the lagoon that bound the contaminated data with clean soil data. For this reason, no potential additional volume has been added for this lagoon.
Lagoon_B	1,750	4,910	6,660	7,992	8,791	10,549	The volume estimated from the data consists of 1,690 yd^3 in the lagoon itself, and an additional 60 yd^3 in the area immediately surrounding Lagoon B. **Potential Additional Volume** Lagoon B has an area of 29,500 ft^2 and a possible depth of 6 ft. This gives a potential total volume of contaminated soil in the lagoon of 6,600 yd^3. Since 1,690 yd^3 has already been predicted within the lagoon, this gives an additional volume of 4,910 yd^3 in the lagoon itself. Like the trenches, the groundwater table has the potential to rise above the bottom of Lagoon B, allowing potential contaminants in the lagoon to create groundwater concentrations that exceed acceptable levels.
Lagoon_C	500	0	500	600	660	792	The volume estimated from the data consists of 500 yd^3 of contaminated soil exceeding the industrial worker criteria. Construction records for the lagoon and borings through the lagoon indicate it was very shallow. Even with Uretech's production well shut down, it appears unlikely for the water table to rise above the bottom of this lagoon causing more contaminants to be released into the groundwater system.
IA03	80	2,800	2,880	3,456	3,802	4,562	The volume of contaminated soil exceeding the industrial worker criteria is estimated to be 80 yd^3. The groundwater may rise up into trench 7 allowing potential contaminants from that trench into the groundwater. This trench contains roughly 2,800 yd^3 of material which has been added to the estimate.
IA04	0	0	0	0	0	0	No lead above the acceptable level of 958 ppm has been found in IA04. Historic records and the site investigation indicate that IA04 does not have any trenches, lagoons, or other features that may cause contaminants to come into direct contact with groundwater.
IA05	150	3,100	3,250	3,900	4,290	5,148	The volume estimated from the data consists of 150 yd^3 from analytical soil samples in IA05. Of this volume, 100 yd^3 is located in the trenches, and the remaining 50 yd^3 is located outside of the estimated trench extents. **Potential Additional Volume** The largest source of uncertainty in this area arises from the east-west running trench along this area's southern boundary (trench 6). A pile of rubble has prevented characterization of this trench. Borings that have been sampled on the eastern end of the trench suggest extensive contamination may exist to at least 10 ft below ground surface through this trench. The trench was incorporated into the geologic model at roughly 15 ft wide by 300 ft long by 12 ft deep. Trenches 5 and 6 in IA05 account for approximately 3,200 yd^3 of volume. 100 yd^3 of contamination has already been modeled in the trenches in this area, so an additional volume of 3,100 yd^3 has been added to the estimate to account for the 3,200 yd^3 trench volumes. Both trench 5 and trench 6 show a potential for becoming fully saturated at least in the bottom few feet if Uretech's production well is shut off.
IA07	1,050	0	1,050	1,260	1,386	1,663	The volume estimated from the data consists of 1,050 yd^3 from analytical soil samples of lead and rads. Historically, little is known about this area. Some degree of activity obviously took place since a large area with very little vegetation has existed just east of the propane tanks reportedly for several decades. Analytical tests in this area have revealed most contaminants in IA07 are confined to this "dead spot". "Hot" samples are fairly well bounded by samples below criteria in this area.
IA08	0	0	0	0	0	0	No lead above the acceptable level of 958 ppm has been found in IA08. Historic records and the site investigation indicate that IA08 does not have any trenches, lagoons, or other features that may cause contaminants to come into direct contact with groundwater.
Off_Site	0	0	0	0	0	0	No lead above the acceptable level of 958 ppm has been found off-site.
Total	8,540	21,510	30,050	36,060	39,666	47,599	Most areas of the site have been fairly well defined by historic information and various sampling events. Much of the uncertainty should have been addressed in the above considerations. However, the recollections of some former employees from the time Brush Beryllium Company operated the plant have proven to be less than 100% reliable. Other instances such as the "dead spot" in IA07 that do not have any historic record of potentially harmful events taking place there further raise concern that unanticipated contamination may exist on site. As such, 23,270 yd^3 (28,000 accounting for 20% overexcavation) should be taken as a best guess of contamination that has been characterized either by sampling or historical records on and off site and does not account for areas that do not have historical records indicating possible contamination.

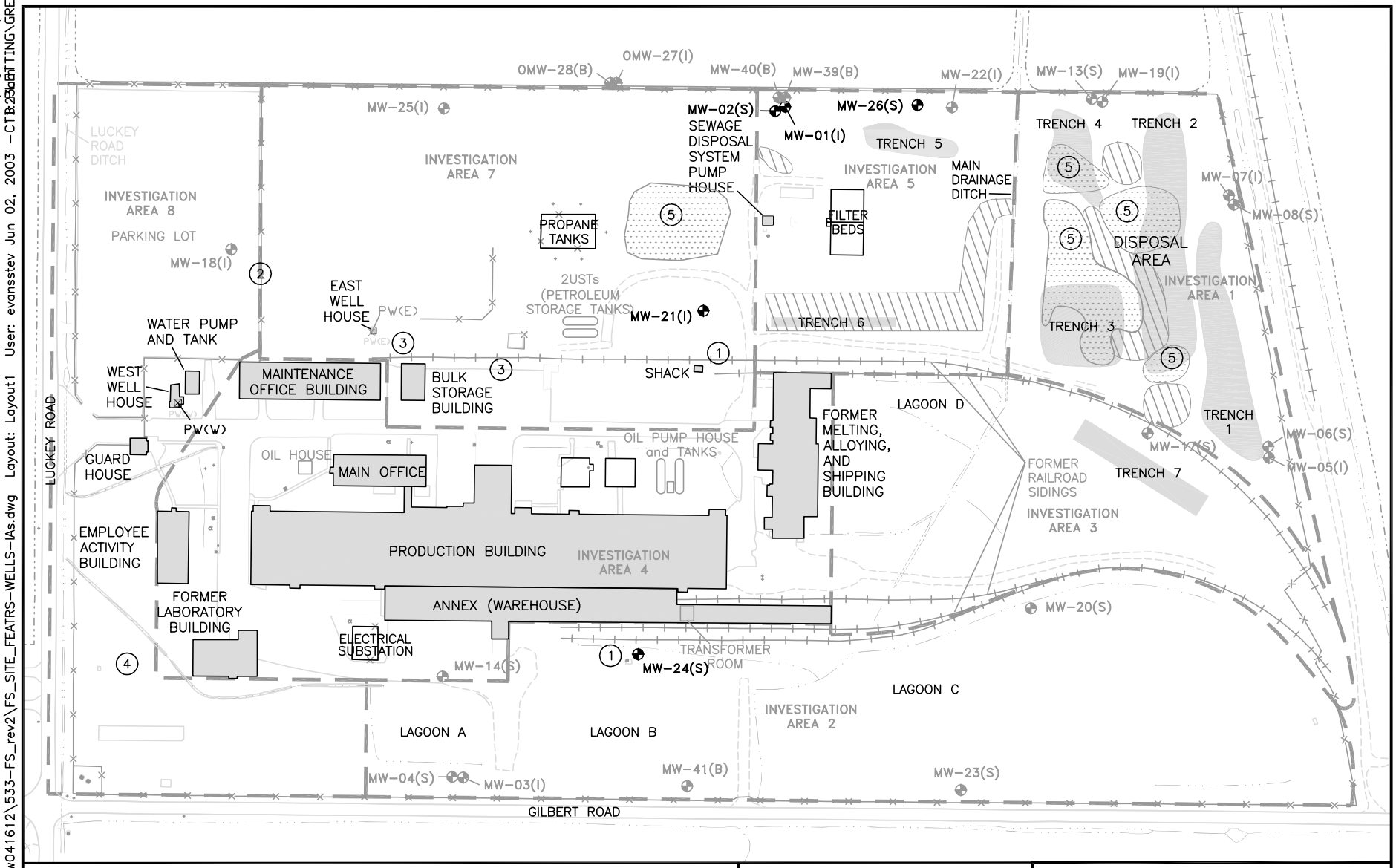
Notes:

1) **The "Total Volume Modeled From Data" was calculated with a software package named EarthVision developed by Dynamic Graphics, Incorporated (www.dgi.com) using the Minimum Tension Gridding Algorithm along with engineering judgement to confine and shape the modeled extents.**
2) **The "Total Volume Modeled From Data" includes in situ volumes from analytical data for lead.**
3) **"Most Likely + 20% Overexcavation" accounts for overexcavation of the in-situ volumes based on mechanical and field screening limitations only.**
4) **All of the volumes reported in the above table except the Swell Factor volume are in units of cubic yards and represent the in situ volume.**
5) **Sludge from areas such as the trenches and possibly Lagoon B may need extra material added in order to absorb water trapped in it to fulfill landfill acceptance criteria. This may further increase the volume of material to be shipped to landfills.**
6) **The in-situ volumes in this table were updated July 16, 2002, using a cleanup goal of 958 ppm for lead and the following radiological criteria: radium-226 = 11.07 pCi/g, thorium-230 = 26.2 pCi/g, uranium-234 = 73.61 pCi/g, and uranium-238 = 75.63 pCi/g.**

Table 3B.4. Summary of Waste Streams and Associated Volumes

Waste Stream	Contaminant(s)	Volume[1] (yd^3)	Percent of Total
Solid Waste	Beryllium	27,000	64.0
FUSRAP Radioactive Waste	Beryllium & Radiological	6,700	15.9
	Radiological	5,500	13.0
RCRA Hazardous Waste	Lead with and without Beryllium	1,100	2.6
Mixed Waste	Lead & Radiological	100	0.2
	Beryllium, Lead, & Radiological	1,800	4.3
Total		***42,200***	***100.0***

[1] Volumes noted are in situ volumes based on "Total Volume Modeled from Data" in Table 3B.2 associated with unrestricted land use and do not include potential additional volume, overexcavation, constructability, or expansion.
yd^3 – cubic yards



U.S. Army Corps of Engineers
Buffalo District

LUCKEY SITE
FS REPORT

Site Features and Investigation Areas

Science Applications International Corporation — Columbus, Ohio

DRAWN	DATE	SCALE	PROJECT NO.	FIGURE NO.
BJW	03-19-01	AS SHOWN	04-1612-503	3B.1

XREF Files: LUCKFEET DRIVES FENCE FIELDS IABOUNDS IAINFO MISC ROADS RR-RAIL STRUCT TOPO TREES UTILSTRC WATER IMAGE Files: Armylogoblk.bmp feet.tif 2
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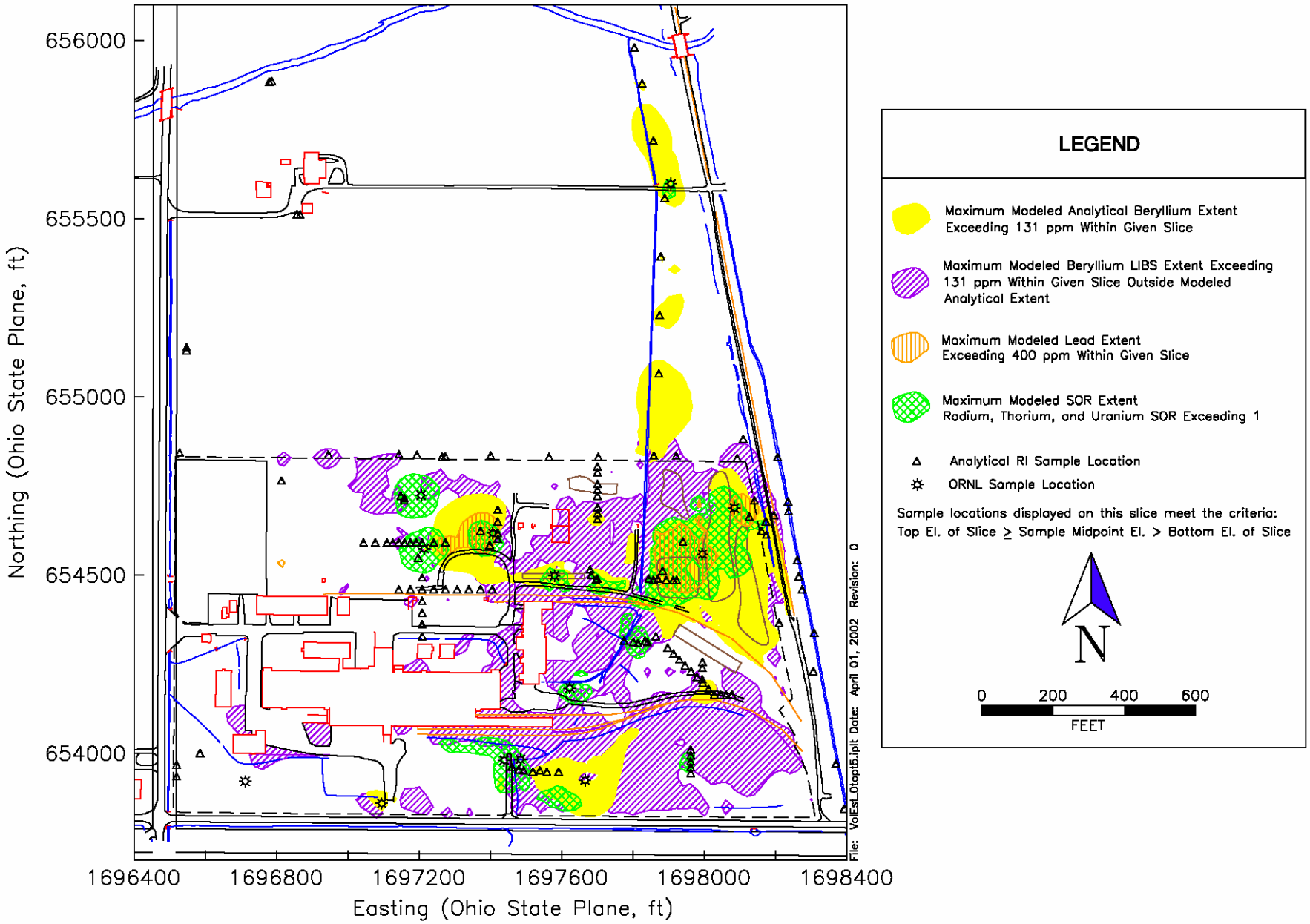


Figure 3B.2. Modeled Extent of Contaminants from Ground Surface to 0.5 feet bgs ~ Unrestricted Land Use

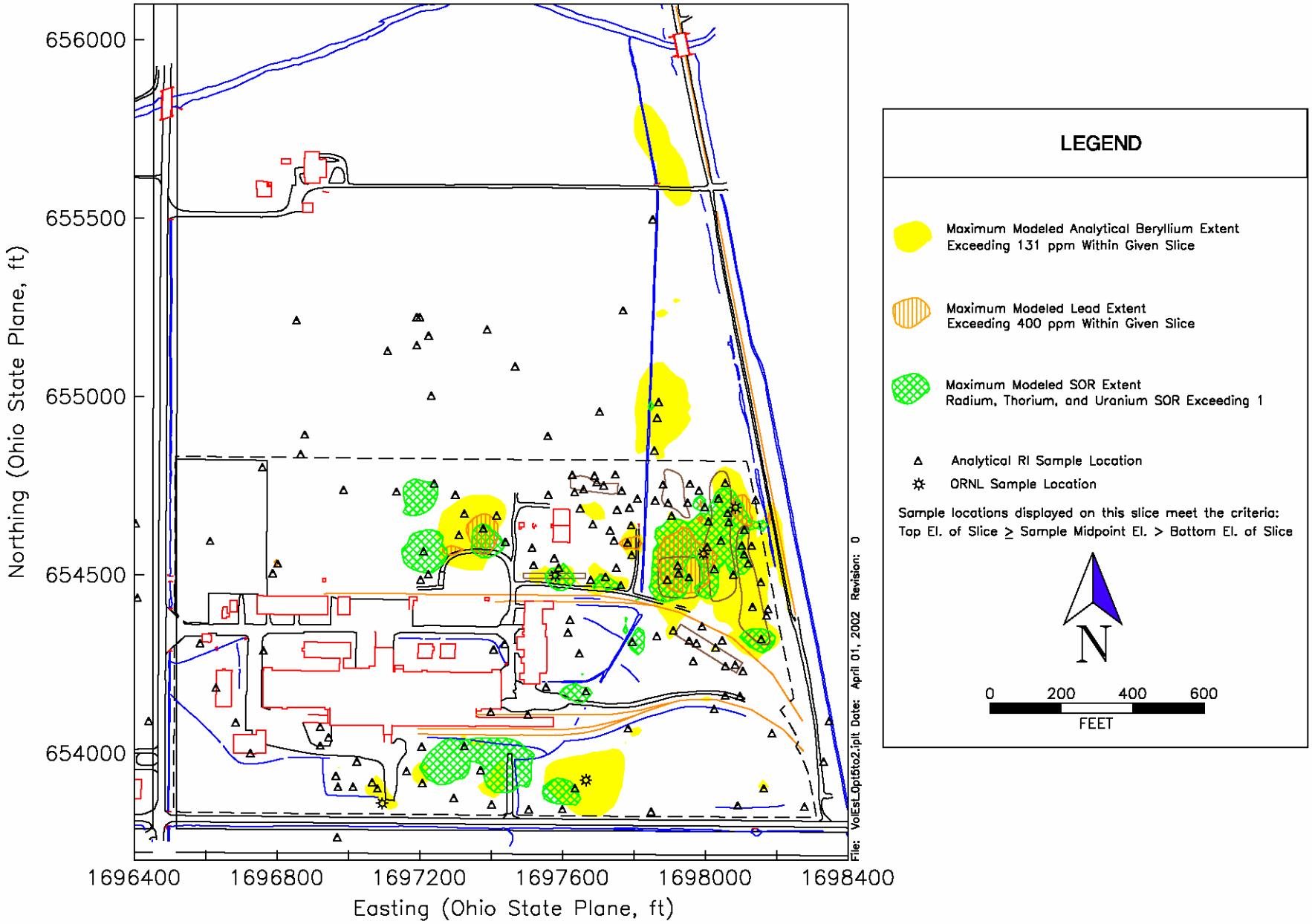


Figure 3B.3. Modeled Extent of Contaminants from 0.5 feet to 2 feet bgs ~ Unrestricted Land Use

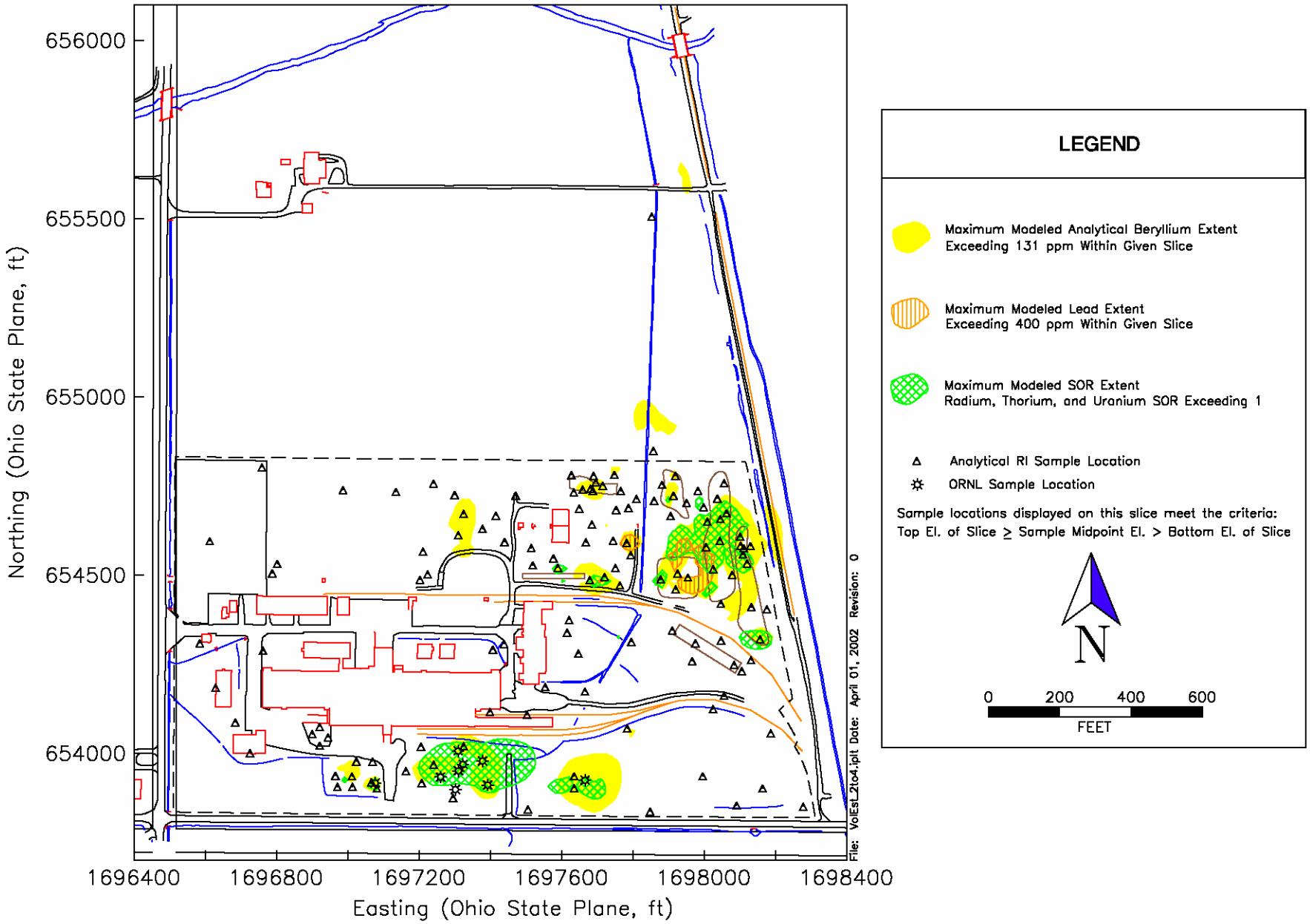


Figure 3B.4. Modeled Extent of Contaminants from 2 foot to 4 feet bgs ~ Unrestricted Land Use

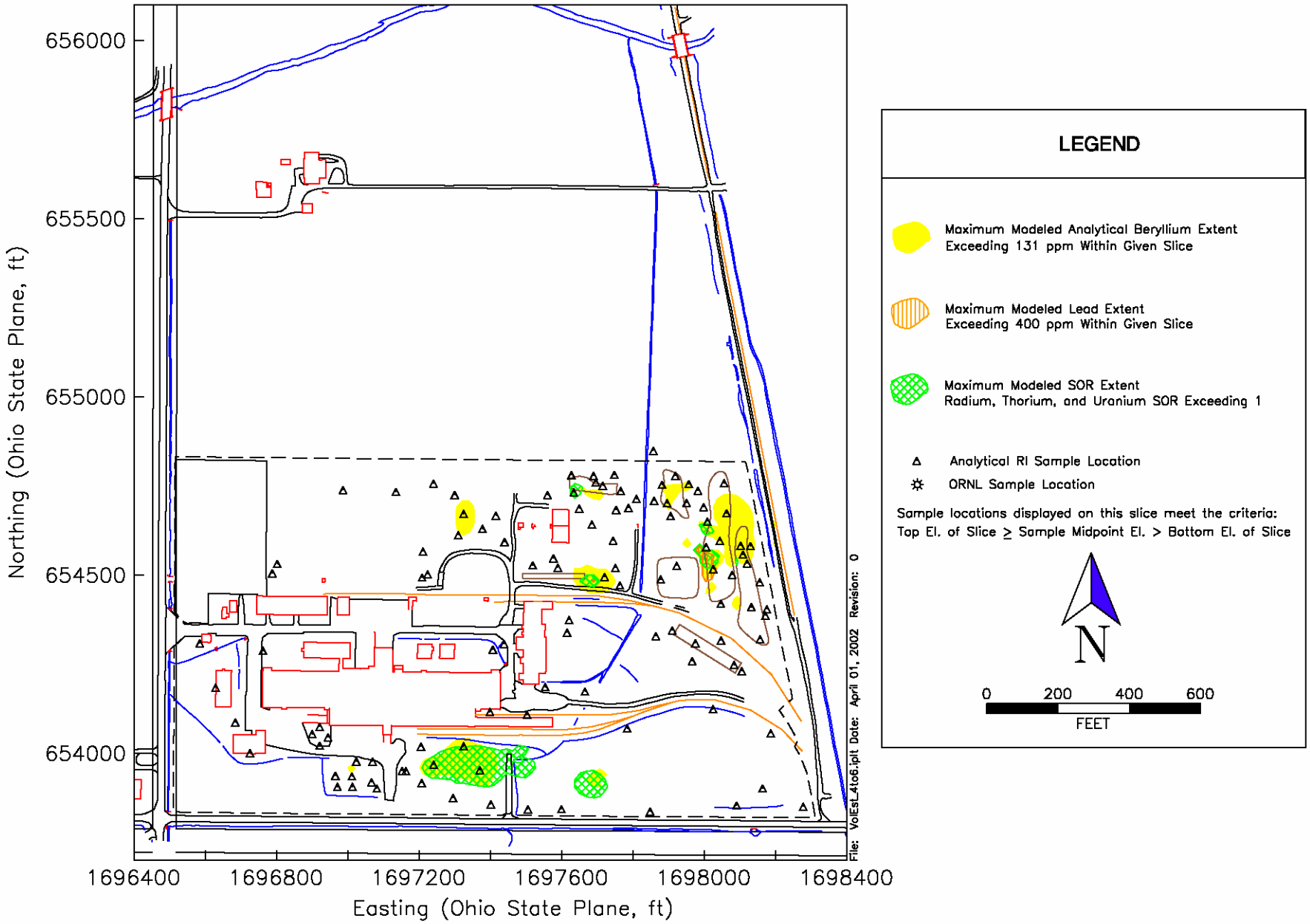


Figure 3B.5. Modeled Extent of Contaminants from 4 feet to 6 feet bgs ~ Unrestricted Land Use

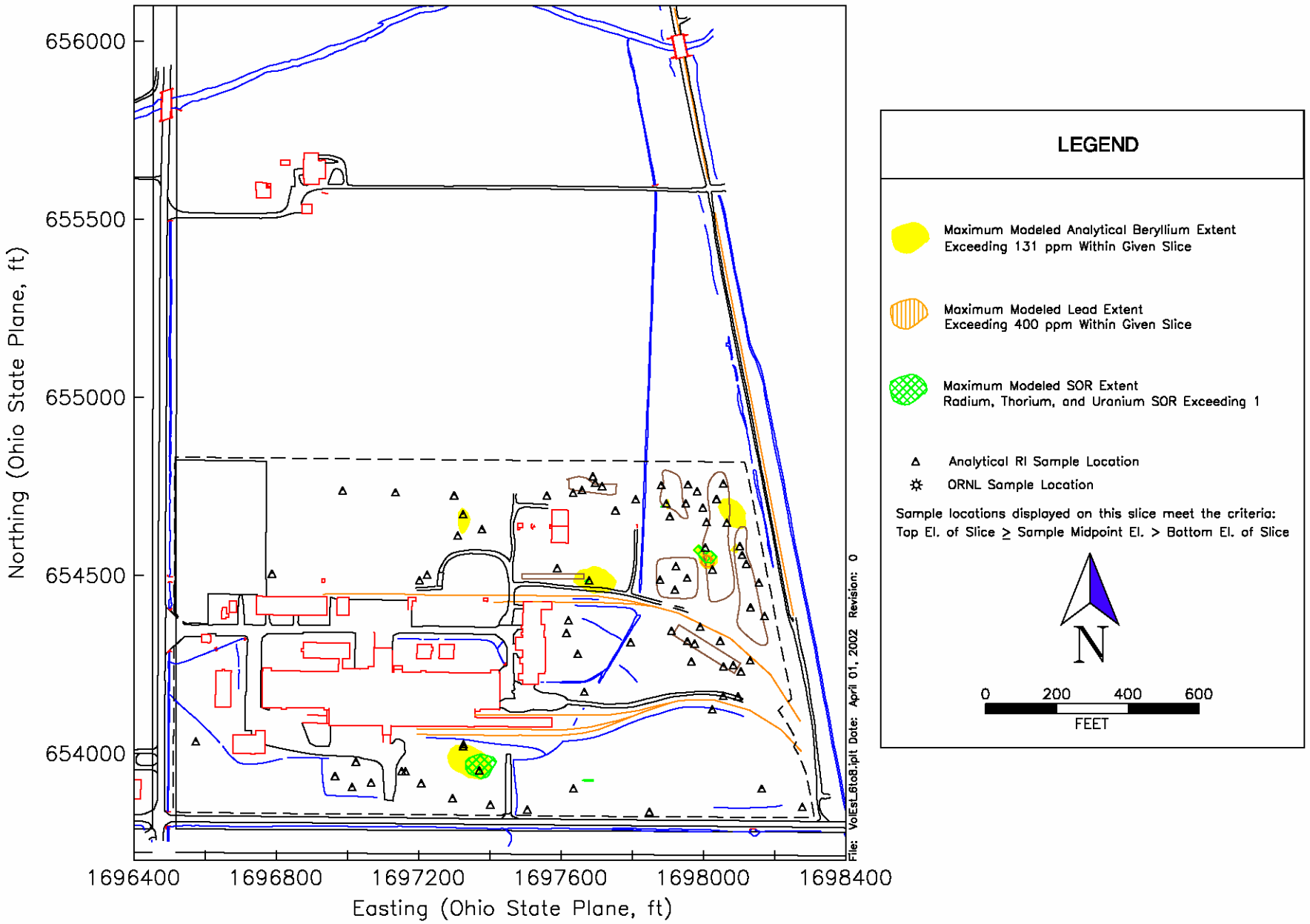


Figure 3B.6. Modeled Extent of Contaminants from 6 feet to 8 feet bgs ~ Unrestricted Land Use

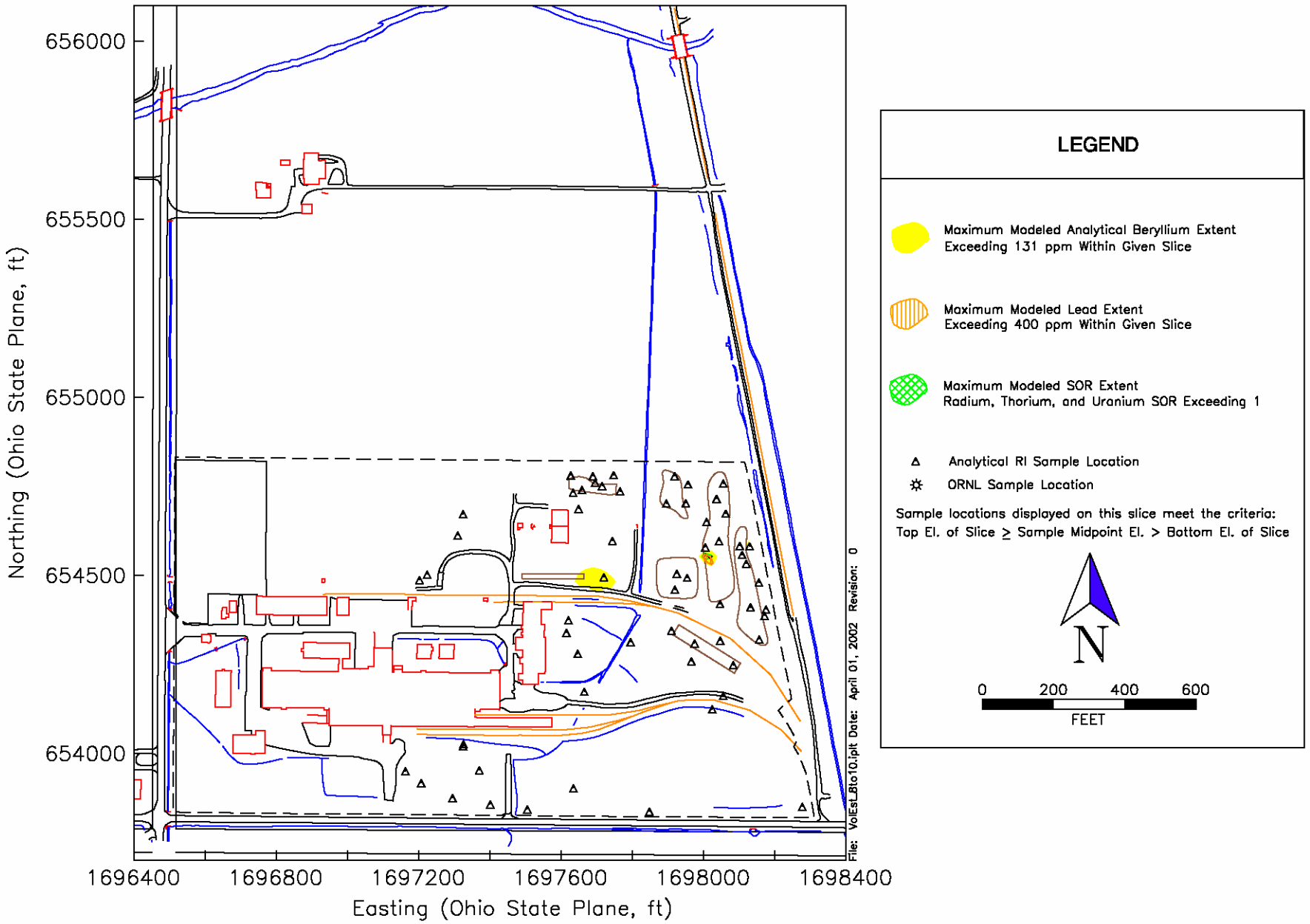


Figure 3B.7. Modeled Extent of Contaminants from 8 feet to 10 feet bgs ~ Unrestricted Land Use

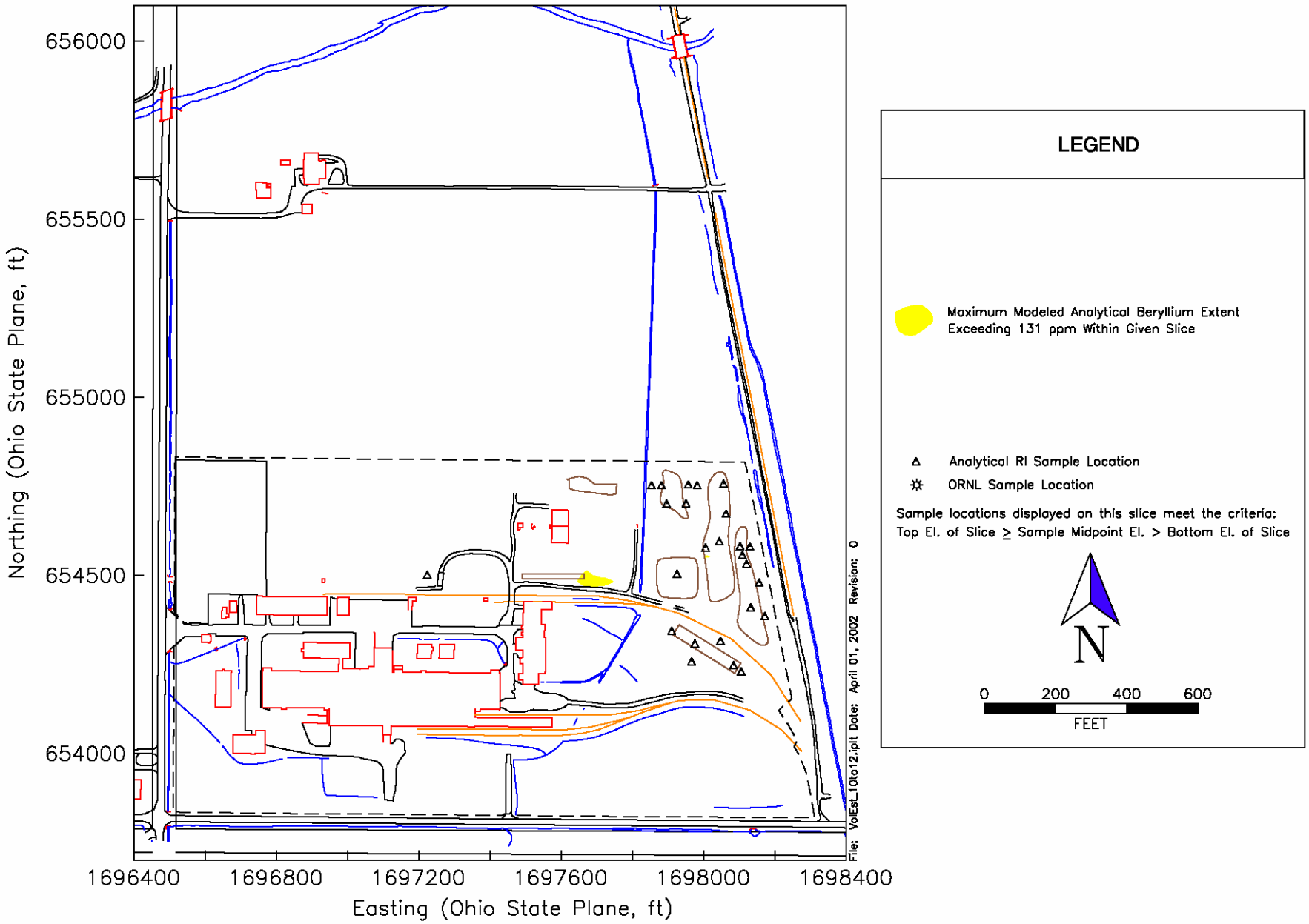
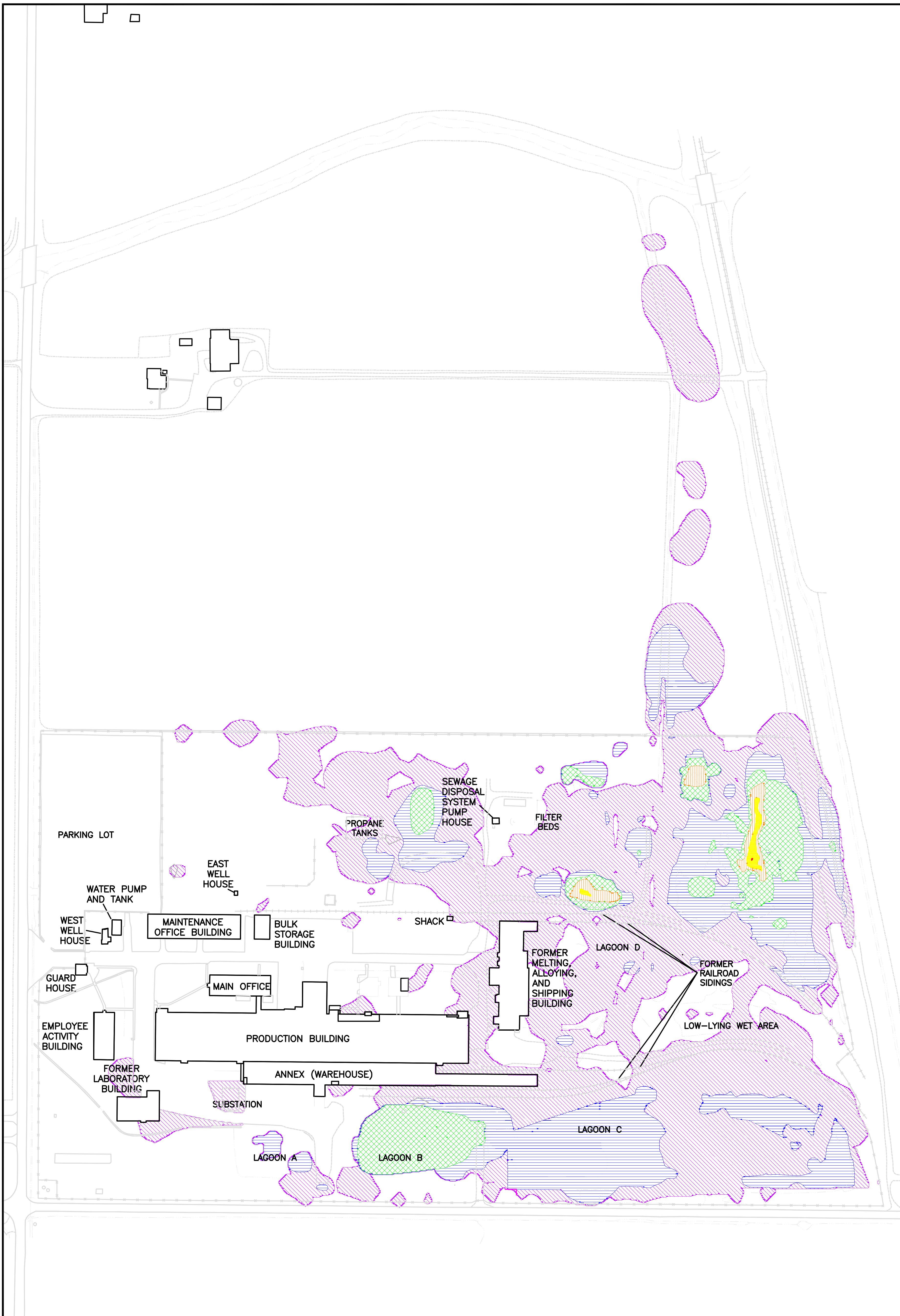


Figure 3B.8. Modeled Extent of Contaminants from 10 feet to 12 feet bgs ~ Unrestricted Land Use



BUILDING	0-2 FEET DEPTH
DITCH	2-5 FEET DEPTH
LOW-LYING WET AREAS	5-10 FEET DEPTH
FENCE LINE	10-15 FEET DEPTH
STREAMS & CREEKS	15-20 FEET DEPTH
ABANDONED RAILROAD GRADE	20+ FEET DEPTH

N
True North

100 0 100 200
FEET

31 0 31 62
METERS

U.S. Army Corps of Engineers
Buffalo District

LUCKEY SITE
FS REPORT

Extent of Impacted Soils
Unrestricted Land Use

SAIC. Science Applications International Corporation Columbus, Ohio

DRAWN	DATE	SCALE	PROJECT NO.	FIGURE NO.
BJW	03-19-01	AS SHOWN	04-1612-503	3B.9

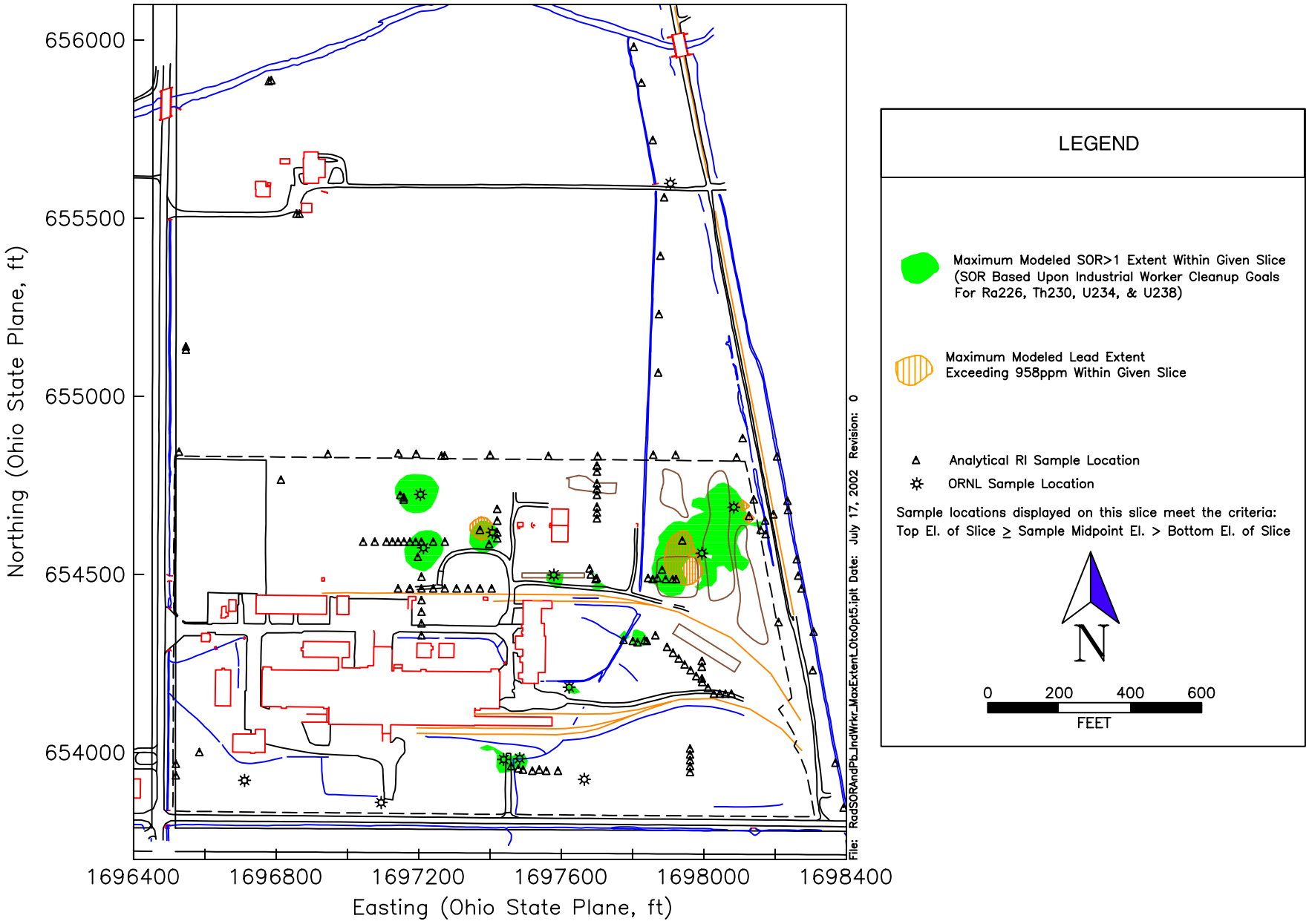


Figure 3B.10. Modeled Extent of Contaminants from Ground Surface to 0.5 feet bgs ~ Industrial Land Use

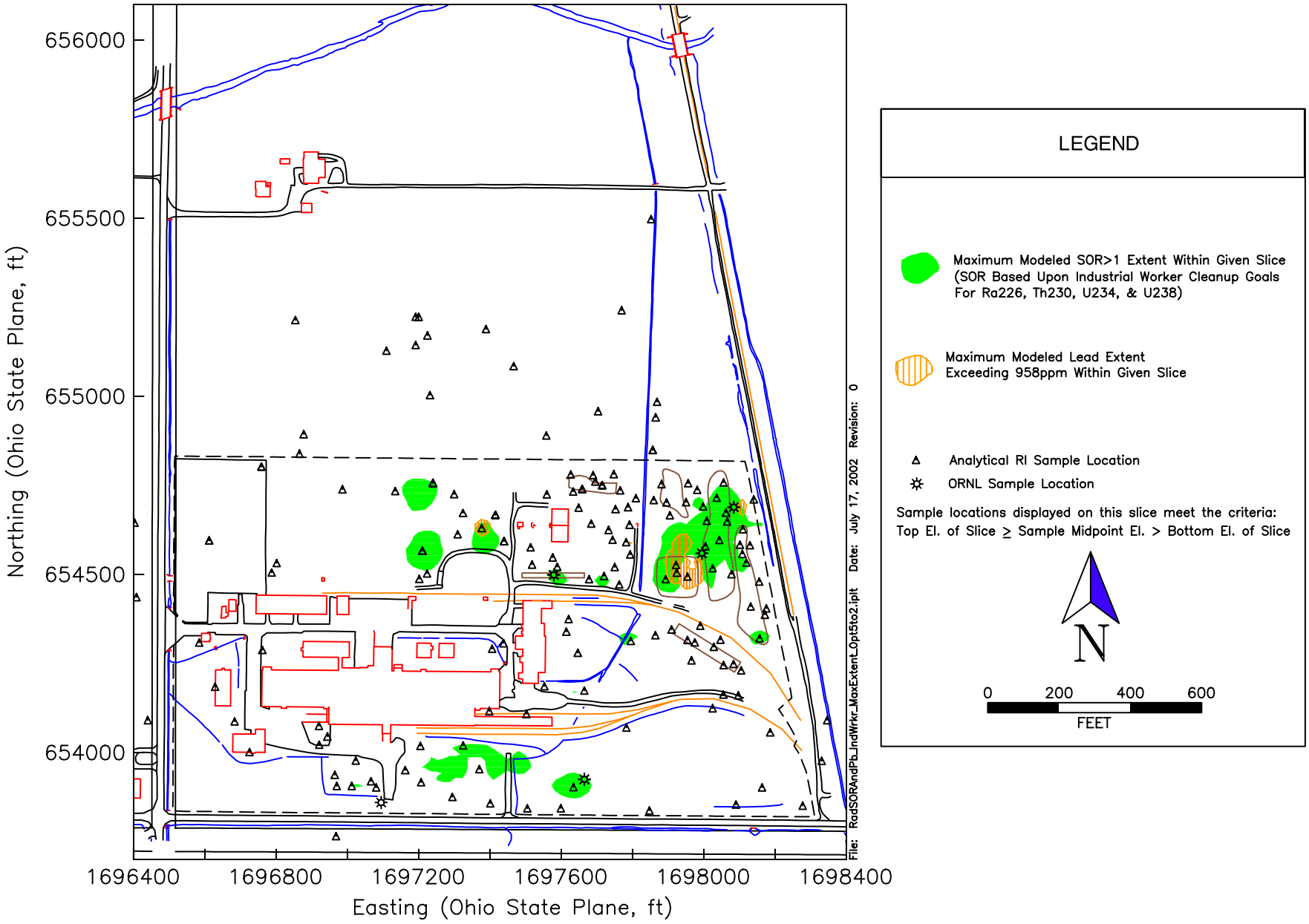


Figure 3B.11. Modeled Extent of Contaminants from 0.5 feet to 2 feet bgs ~ Industrial Land Use

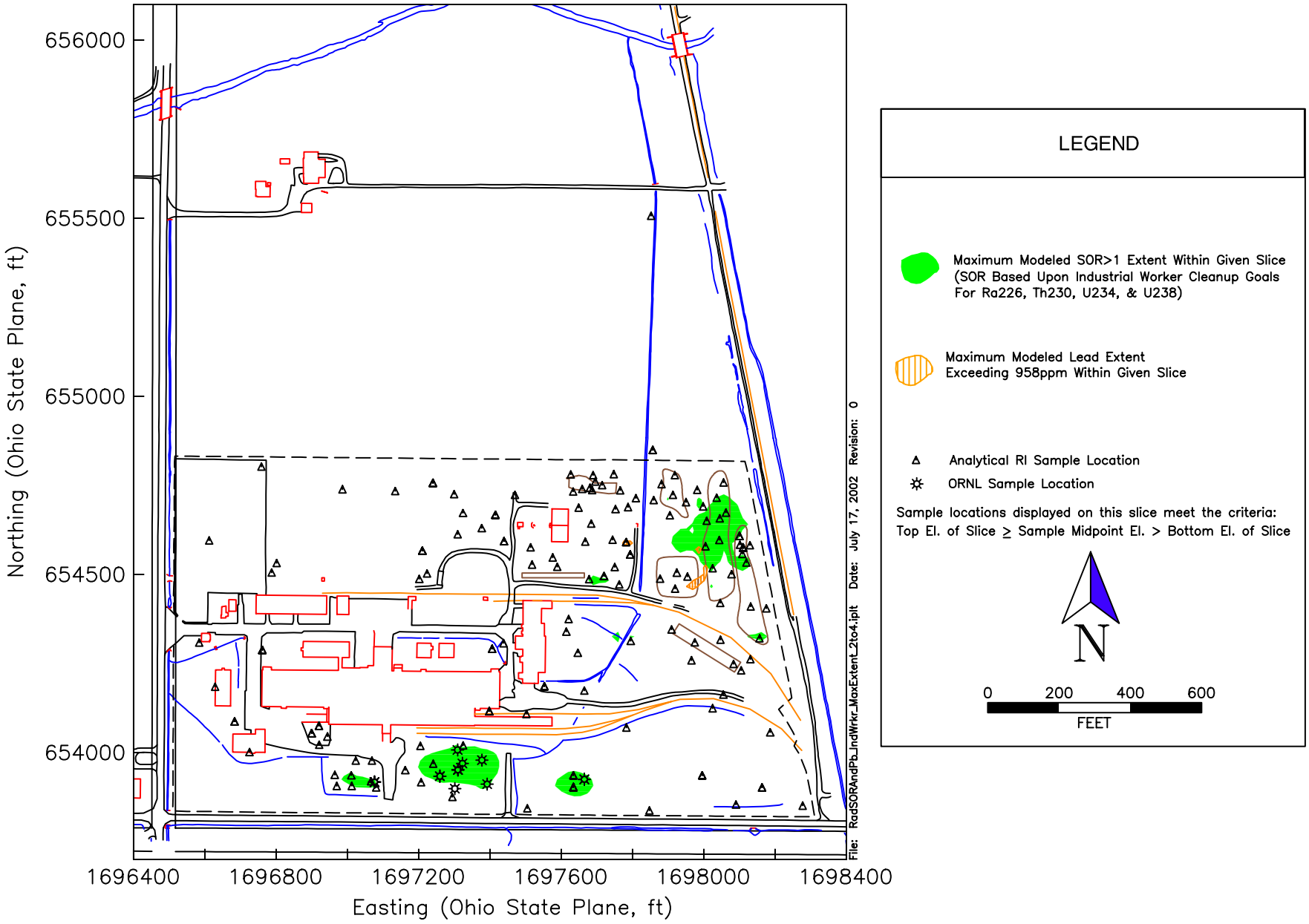


Figure 3B.12. Modeled Extent of Contaminants from 2 feet to 4 feet bgs ~ Industrial Land Use

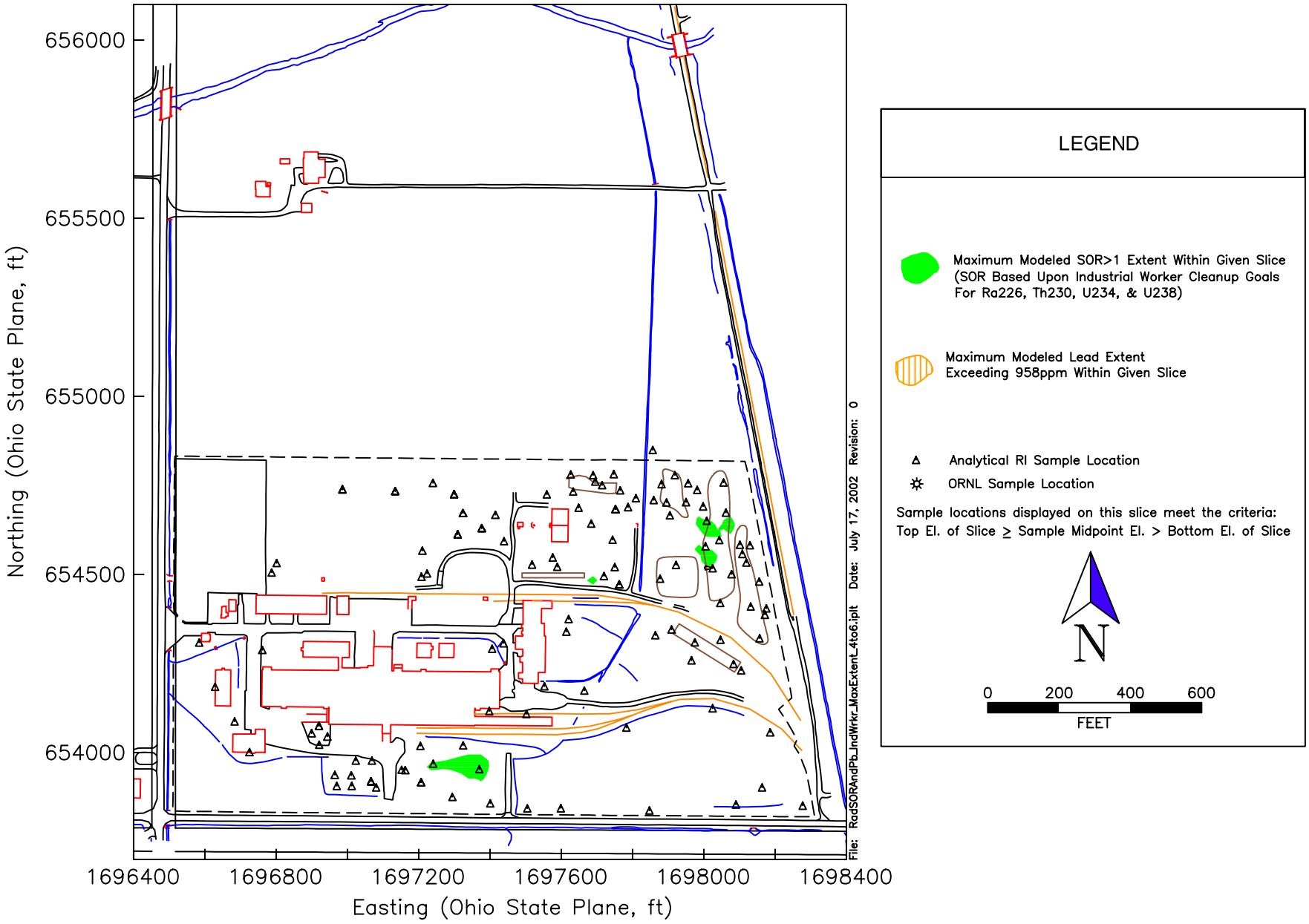


Figure 3B.13. Modeled Extent of Contaminants from 4 feet to 6 feet bgs ~ Industrial Land Use

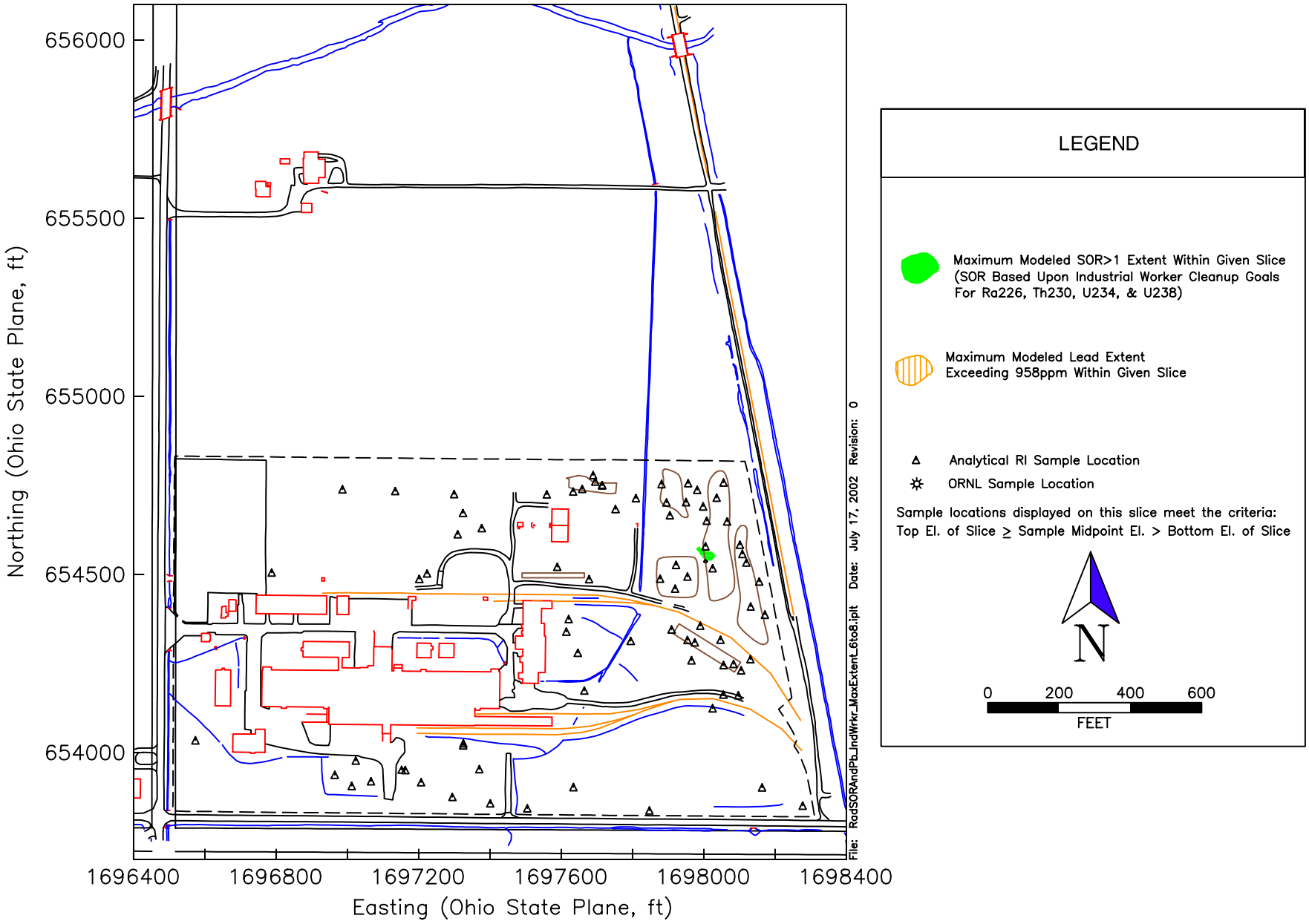
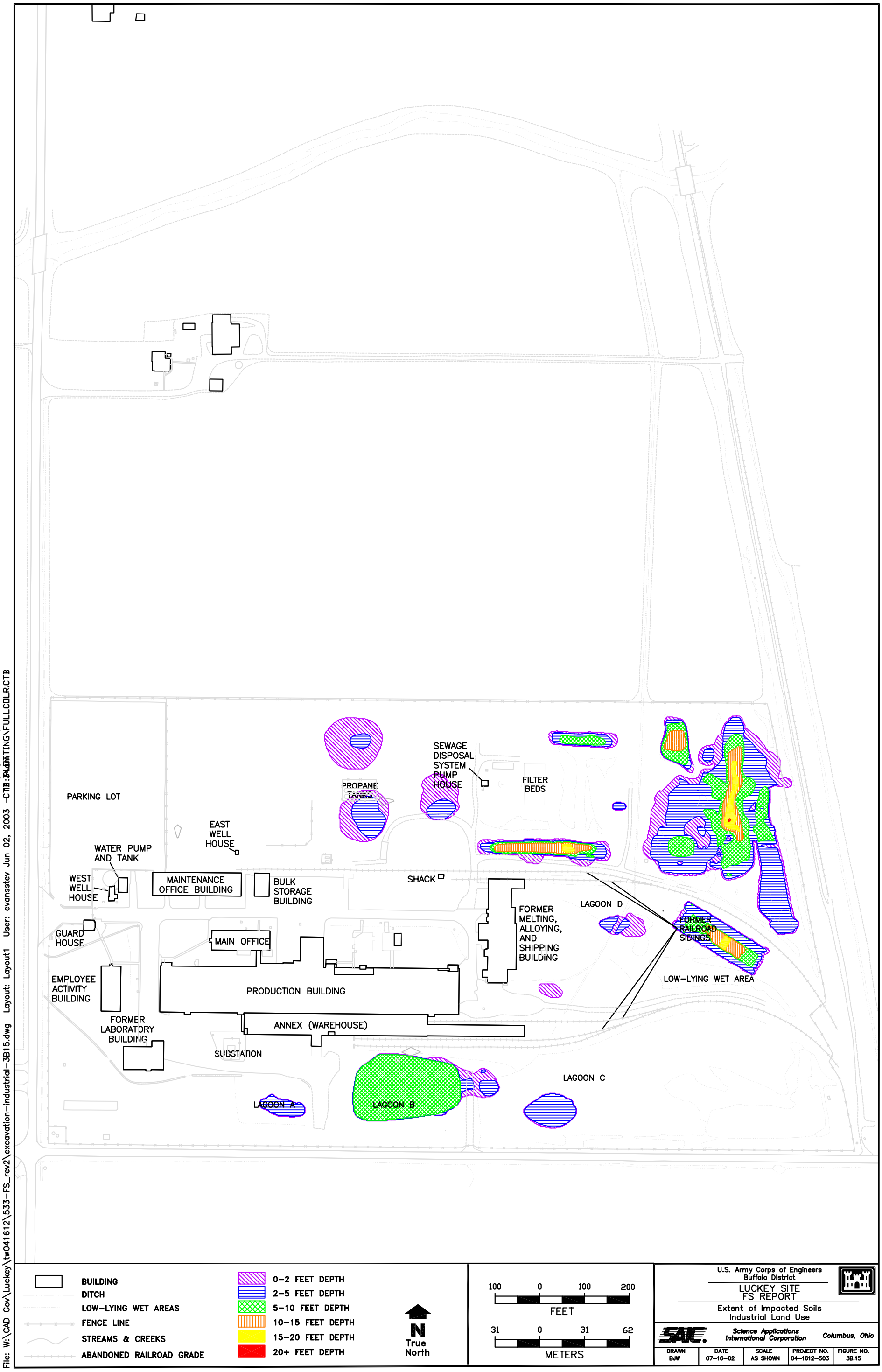


Figure 3B.14. Modeled Extent of Contaminants from 6 feet to 8 feet bgs ~ Industrial Land Use



U.S. Army Corps of Engineers
Buffalo District

LUCKEY SITE
FS REPORT

Extent of Impacted Soils
Industrial Land Use

Science Applications International Corporation — Columbus, Ohio

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BJW	07-16-02	AS SHOWN	04-1612-503	3B.15

XREF Files: luckfeet DRIVES FENCE FIELDS IABOUNDS IAINFO MISC ROADS RR-RAIL STRUCT TOPO TREES UTILSTRC WATER IMAGE Files: Armylogoblk.bmp feet.tif 2_foot.tif
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