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Pipeline Removal vs. Characterization Study

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Project Hanford Management Contractor for the
U.S. Department of Energy under Contract DE-AC06-96RL13200

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Richland, Washington

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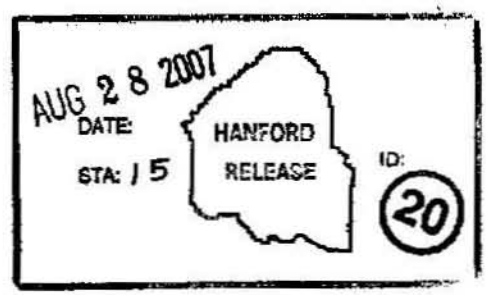

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Executive Summary

The purpose of this document is to provide a decision support tool for comparing pipe excavation/removal costs with the costs to characterize a pipeline. Characterizing a pipeline involves obtaining and analyzing the number of samples required at different confidence levels to determine if action levels for contaminants are not exceeded. The decision support tool can be used to help predict the break point at which one method exceeds the cost of the other method. Determining which method is more cost effective results in the potential for cost avoidance.

The first part of this activity provides a statistical evaluation of the number of samples to demonstrate, at several confidence intervals, that action levels for contaminants are not exceeded. A range of confidence intervals is used to allow for the potential for demonstrating ability to meet action levels (AL) at levels of varying statistical rigor, with resulting potential for cost avoidance. The confidence levels of 80, 85, 90, and 95 percent upper confidence level are used and summarized from section 2.8 below.

Confidence Level	Width of Gray region	Alpha	Beta	Number of Samples					
				1 sample *t*-test	1 sample Proportion	Wilcoxon Sign test	2 sample *t*-test	2 sample Proportion	Wilcoxon Rank Sum
80 %	5 % of AL	1 %	20 %	380	1041	245	255	1526	106
85 %	5 % of AL	1 %	15 %	428	1179	276	287	1719	119
90 %	5 % of AL	1 %	10 %	492	1366	318	330	1979	137
95 %	5 % of AL	1 %	5 %	596	1667	386	399	2398	166

The statistical evaluation provides an estimate for the number of samples and costs needed to enable the stated confidence levels. As an example, the cost for analyzing 403 samples is $4,608,305 (see Table 4 at a 95% confidence level).

The second part of this activity provides a cost estimate in dollars per linear foot for excavating pipeline types (materials of construction) and sizes and depths. Pipe materials include stainless and carbon steel, concrete and reinforced concrete, and vitrified clay pipe. Depths evaluated include 5, 10, 15, 20, and 25 feet below ground surface. For example, pipe excavation/removal costs range from $2,608 to $13,027 per foot ($38.24 to $8.49 per cubic foot) for vitrified clay pipe at different depths and diameters.

Pipe excavation/removal costs are compared to sampling and analysis costs. For the examples presented in this document, the cost to excavate vitrified clay pipe is compared to the cost for taking and analyzing a number of samples at various confidence levels. Excavation costs for the other pipe types, steel and concrete are similar to vitrified clay pipe. Based on the scenarios and examples presented in this document, the cost for sampling is more than the cost for excavation/removal. If the contaminated region is not known, the number of characterization samples required is independent of pipe length. This decision support tool can be used to help predict the break point at which the cost of sampling exceeds the cost for excavation.

The decision support tool is only as good as the inputs used in the Excel® spreadsheets. As described below the tool has limitations and areas for improvement. Further, the assumption that the contaminated volume is restricted to 2 pipe diameters from the pipe could be significantly different than actual conditions. This situation does not account for leaking pipelines and the possible need to chase or clean up the contaminated soil associated with a leak. Finally, the tool used for estimating the cost associated with the number of samples does not take into account the depth of the buried pipe, it only accounts for the contaminated region around the pipe. Samples taken at 25 foot depth are considerably more expensive than samples taken at a 5 foot depth. In some cases it might be necessary to exhume much of the waste site just to obtain the required samples. Finally, recent experience by Fluor Hanford has found that the costs of removing all types of piping 2 feet in diameter or below costs about the same, due to the physical realities of doing excavation and the fact that piping of any material of that diameter or below is easy to shear or size reduce. This experience implies that the estimate for pipes 2 feet in diameter and less (2 inches, 6 inches, 12 inches and 24 inches) can be combined into one estimate.

The decision support tool provides a method for comparing excavation/pipe removal costs with characterization sampling and analysis costs to aid in deciding whether to remove the pipe or leave it in place. While the actual costs will be situation-specific, the generalizations in this study provide good approximations for alternative analysis and can indicate where more detailed analyses are needed. The pipe excavation estimate spreadsheet developed for this study can easily be modified to evaluate situations on a case-by-case basis and provide more detailed cost estimates. Ultimately, the decision will be influenced by factors such as regulatory requirements, stakeholder interests, safety concerns, programmatic decisions, and risk reduction in addition to cost. The decision support tool does not assign values to these factors.

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Glossary, Acronyms, Definitions

AL	Action Level
CERCLA	Comprehensive Environmental Response Compensation and Liability Act
DCGL	Derived Concentration Guideline Levels
DQO	Data Quality Objectives
DOT	Department of Transportation
EPA	Environmental Protection Agency
FH	Fluor Hanford
Width of gray region	UBGR - LBGR
LBGR	Lower Bound of the Gray Region
MARSAME	Multi-Agency Radiation Survey and Assessment of Materials and Equipment Manual
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
RCRA	Resource Conservation and Recovery Act.
S&M	Surveillance and Maintenance
SOW	Statement of Work
UBGR	Upper Bound of the Gray Region
WAC	Waste Acceptance Criteria

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1. Introduction

The Hanford Site is a former weapons-production complex managed by the U.S. Department of Energy (DOE). The 580 mi^2 Site, located in southeastern Washington State, produced about 60 percent of the United States' plutonium from the mid-1940s to the late 1980s to support national defense. In 1989 the DOE announced that the production facilities were being shut down and the Site mission was changing to environmental restoration. The Central Plateau portion of the Hanford Site covers approximately 75 mi^2 near the center of the Site. The legacy waste and contaminated materials from the Hanford Site defense production mission remain on the Central Plateau in canyon buildings, underground tanks, waste sites, and other structures. The waste and contaminated materials present a risk to remediation workers and the environment.

As a result of former waste disposal practices, high volumes of contaminants were discharged to more than 800 waste sites on the Central Plateau, including cribs, ponds, trenches, and burial grounds. Some of these contaminants present a risk to the underlying groundwater and the nearby Columbia River. Other contaminants present are not mobile enough to be considered groundwater concerns, but are present in sufficient quantities to present a hazard to human health and the environment.

Many of the waste sites include sections of buried pipeline of varying depths, piping materials, and contamination levels. Several hundred miles of pipeline are within these waste sites, resulting in significant work scope for whatever remediation methods are chosen. The overall remediation goal is to protect human health and the environment.

It is desired to minimize the costs associated with remediation efforts. Knowing the relative costs between removal and sampling to assess contamination extent to guide remediation paths may allow one or the other to be substantially avoided during remediation and thereby reduce costs, while achieving the same remediation goals. This study provides a Decision Support Tool to aid evaluating breakpoints where it becomes more cost effective to remove a subsurface pipeline rather that to characterize it sufficiently to prove that leaving in place is protective of human health and the environment.

1.1 Project Scope

Project scope for this report is in two parts. The first part provides a statistical evaluation of the number of samples for a given length of pipeline to demonstrate, at several confidence intervals, that action levels for contaminants are not exceeded. A range of confidence intervals is used to allow for the potential for demonstrating ability to meet action levels at levels of varying statistical rigor, with resulting potential for cost avoidance. The confidence levels of 80, 85, 90, and 95 percent upper confidence level are used. The statistical evaluation provides an estimate for the number of samples needed to enable the stated confidence levels.

The second part of this activity provides a cost estimate in dollars per linear foot for excavating various pipeline types (materials of construction) and sizes and depths. Depths evaluated include 5, 10, 15, 20, and 25 feet below ground surface. Pipeline materials of construction include:

- Vitrified clay
- Stainless and carbon steel
- Concrete masonry
- Reinforced concrete

Pipeline sizes vary from 2 to 48 inches in diameter. Table 1 provides a list of pipeline types and diameters. Combinations shaded in gray are excluded from this study because these combinations of diameter and material do not exist in the piping industry and therefore do not exist at the Hanford site. The combinations of diameter and material (shaded in yellow), while not explicitly determined to exist at the Hanford site, represent combinations used in the piping industry and therefore have a potential to exist at the Hanford site (potentially applicable). The combinations of diameter and material (shaded in green) are known to exist at the Hanford site as confirmed by site drawings/documents (definitely applicable). The cost estimate focused on the cost associated with clean and contaminated soil excavation and pipeline removal. Other costs such as fixed costs associated with mobilization and demobilization are included but should be tailored or modified to fit specific remediation jobs.

Table 1 - Probable Underground Pipe Combinations

Pipeline Material	Pipe Diameter (inches) 2	6	12	24	36	48
Vitreous Clay						
Steel (stainless /carbon)						
Concrete Masonry						
Reinforced Concrete						

Legend:
= Not Applicable
= Potentially Applicable
= Definitely Applicable

Finally, the two estimating techniques are compared to provide a decision support tool to aid evaluating breakpoints where it becomes more cost effective to remove a subsurface pipeline rather that to characterize it sufficiently to prove that leaving in place is protective of human health and the environment.

1.2 Project Goals

The goal of this study is to provide a decision support tool addressing the question: for a given length, type of pipeline, and depth, will it be more cost effective to sample the piping to determine contaminant levels or to simply excavate and dispose of the piping (and any associated contaminated soil)?

It is desired to minimize the costs associated with remediation efforts. Knowing the relative costs between removal and sampling may allow one or the other to be substantially avoided during remediation and thereby reduce costs, while achieving the same remediation goals.

The goal of this task is to provide a decision support tool to allow objective cost evaluations of the separate pipeline remediation /closure activities of 1) removal and 2) sampling and characterization. The tool should be applicable to any section of subsurface pipeline on the Hanford Site. The objective of this task is to allow defensible comparisons of the costs associated with remediation of a site by 1) removal of subsurface pipeline sections (with subsequent disposal) versus 2) sampling and characterization of the pipeline (to support a range of possible remediation activities from no action to disposal).

1.3 Assumptions

The following list comprises assumptions used in the development of the Decision Support Tool. These assumptions form the basis for the Excel spreadsheets used in the statistical analysis to define the number of samples needed at various confidence intervals to remain below action levels for remediation and the Excel spreadsheets used to estimate the cost for excavating and removing various size buried pipe lines.

- All activities are governed by RCRA or CERCLA and applicable regulatory agreements, although some sites will be governed by an integrated RCRA/CERCLA approach.
- Wastes generated from sampling, characterization and excavation activities will be disposed at the Environmental Restoration and Disposal Facility (ERDF).
- Sampling will be for alpha, beta, gamma, and chemical constituents.
- Pipe excavation cost includes excavation, removal and placement of the pipe in an ERDF roll off burial box or ERDF can. The point of termination for excavation cost is filled ERDF cans with soil or broken clay pipe or pipe debris. The standard ERDF can or roll off box will be used for disposal of contaminated waste at ERDF. The ERDF disposal box holds 13 bank cubic yards of soil. Excavated soil expands when it is loaded in the box and the ERDF box will hold 13 – 15 cubic yards. The ERDF box will hold larger volumes but is limited to 13 bank cubic yards due to weight limits.
- Contaminated pipe debris and soil will be disposed at ERDF. Clean excavated soil will be placed in spoil piles near the excavation and may be used for backfill after pipe removal. The trench volume excavated

will be assumed to be clean soil down to a point two pipe diameters above the top outer diameter of the pipe. Below that point, all soil (plus piping) to a point two pipe diameters below the bottom outer diameter of the pipe will be considered contaminated and be removed.

- It is assumed that metal piping types will require in-trench size reduction (cut lengthwise), with heavy equipment to fit in disposal containers, while vitrified clay piping is assumed to be readily mechanically broken within the trench for disposal. Cost estimation includes these operations.
- Transuranic (TRU) waste has been excluded from the scope of this study
- Remote handled waste is not expected from pipe excavation (excluded from scope).
- Candidate piping systems include steam condensate, cooling water, process condensate, process waste, and chemical sewer lines.
- Excavated trench will include side sloping necessary to remove the pipe or provide personnel access to the trench for sampling and characterization. Slope will be 1.5 to 1 for Hanford soils. This slope is assumed to be adequate for safe personnel access and trench boxes or shoring will not be required.
- Costs for sampling need to be included in the cost estimate totals. Laboratory analytical cost per soil sample will be assumed for the purposes of this study to be $11,385 per single soil sample. Any costs for sampling of actual piping or contaminated soil can also be provided (but is excluded from the scope). It is assumed that one pit and sampling collection (labor and materials) would cost $12500 for the first sample, with $600 for every additional sample. Note that one pit would take ~1 day but 3 pits could be done in 2 days due to economy of already mobilized forces. Therefore for example a 100' pipeline would take 3 pits and 2 days or $25000 for the first sample in each of the 3 pits. On a per foot basis, the costs for the first sample would be $250/foot, with a minimum of $12500.
- Sampling may occur by bore hole, test pit or other means.
- Internal space of pipe will be sampled.
- Assume pipe systems are single pipe lines (no multiple line systems or encased systems).
- The following pipe sizes may be excluded since these are not known to exist on the Hanford site.
  - Stainless Steel pipe greater than 12 inches diameter
  - Carbon steel pipe greater than 24 inches
  - Concrete pipe less than 12 inches diameter
  - Vitrified clay pipe less than 12 inches and greater than 36 inches
- An excavation length of 100 ft was chosen for this evaluation for the following reasons:
  - It allows meaningful comparison between excavation and sampling activities.
  - It represents a median length of typical pipe runs.
  - It provides a good balance between fixed costs (i.e., mobilization and demobilization) and unit costs without inflating (or deflating) the fixed costs.

The ultimate result of the excavation estimate is to provide a cost per linear foot of pipe removed. The spreadsheet can be modified to input the exact pipe length if the scenario dictates a higher level of estimate fidelity.

- The estimate assumes that any crushing or flattening of pipe to eliminate void space will be performed at the disposal site. Cost associated with this is included in the waste disposal charge line item.
- Statistical analysis for sampling confidence will be performed based on the following references:
  1. EPA QA/G-9S, "Data Quality Assessment: Statistical Methods for Practitioners"
  2. EPA QA/G-9R, "Data Quality Assessment: A Reviewers Guide"
  3. EPA QA/G-5S, "Guidance on Choosing a Sampling Design for Environmental Data Collection"
- Upper confidence levels evaluated are 80, 85, 90, and 95%.
- Action levels for specific contaminants of concern are not used in this analysis. If needed, reference 6.9 provides examples of action levels.

1.4 Contributors

Principal contributors to this study include:

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2. Statistical Sampling Evaluation

The purpose of this section is to provide a statistical evaluation of the number of samples required for a given length of pipeline to demonstrate, at several confidence levels, that the action levels for contaminants are not exceeded. A range of confidence levels is desired to allow for the potential for demonstrating ability to meet the action levels at varying levels of statistical rigor, with resulting potential for cost avoidance. The confidence levels of 80, 85, 90, and 95% upper confidence levels should be used, although alternate statistical treatments may be performed subject to approval by Fluor Hanford. The statistical evaluation should be representative of the number of samples needed to enable the stated confidence levels.

The purpose of this decision support tool is to provide decision-making activities as they pertain to the potential remedial action (RA) activities associated with pipe removal, sampling and characterization at the Hanford site and potential removal of contaminated soils. The former weapons production complex includes sections of buried pipeline of varying depths, piping materials and contamination levels. This study supports, and results in, a logical systematic approach to sampling the residual soils, and decision making. Data from this sampling effort will be used to minimize the costs associated with remediation efforts and comparison to regulated soil clean up levels to determine if additional soil remediation is required prior to formal site closure. The sections which follow provide the necessary information and decisions made by the site owner and regulators that result in a sampling approach that will satisfy all decision needs.

2.1 Action Levels

Action levels, if needed, will be consistent with Decisional Draft DOE/RL-2007-02, Rev 0, Appendix E Action Levels and DOE/RL-2002-14, Rev 1 Work Plan. Specific action levels have not been applied to the development of the decision support tool.

2.2 Preliminary Activities

Preliminary activities affecting any area of concern are initially identified and investigated in the scoping or historical assessment stage. The activities may be reviewing historical data, performing additional surveys, determining no information is available, etc, which are explained in more detail below. These preliminary activities provide an informed identification of the initial scope and bound of the activities needed to characterize the pipe identified. The information and data obtained during these preliminary activities is essential to establishing the correct statistical parameters used to characterize the site.

2.2.1 Scoping Process

The scoping process is conducted by assigning responsibilities and completion target dates in the scoping checklist, Table 2. The objective of the scoping checklist is to provide a comprehensive tool that ensures that all relevant and available project information is obtained, analyzed, evaluated, and summarized. This checklist requires the investigator to determine information such as site history, risk drivers, operational concerns, safety concerns, radionuclides present, hazardous materials present and waste designations. The table allows tracking by providing space to put a check in column one when a task is completed. The scoping process results provide the basis for much of the statistical analysis decisions.

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Table 2 - Scoping Checklist

Completed	Item	Responsibility	Completion Date
1.	Historical site assessment		
2.	Study areas defined		
3.	Summary of existing data, surveys, lab results, monitoring results		
4.	Summary of recorded spills		
5.	Current facility conditions		
6.	Current environmental conditions		
7.	Current safety conditions		
8.	Radionuclides present		
9.	Hazardous materials present		
10.	Waste on site		
11.	Additional issues		

2.2.1.1 Historical Site Assessment (HSA) or Initial Assessment

Provide a brief description of the history of the facility, site, or study area. Discuss when and why the facility, site, or study area was originally developed and how it has been used over the years to the present. Describe the general design and dimensions of the facility or survey area, year of construction, types of improvements, and reference facility drawings. Describe the process history for facility operations from the time the facility began operations until the time it ceased operations. Categorize the survey areas as impacted or non-impacted.

Identify all regulatory criteria pertinent to the site, including action level criteria or regulatory limits, which may be dose, risk or activity based. Identify applicable administrative limits associated with disposal site Waste Acceptance Criteria (WAC). Identify applicable Department of Transportation (DOT) requirements for shipping waste material.

2.2.1.2 Study Area Defined

Describe any previous areas which have been identified as needing investigation, remediation of further action. Provide specific information such as location, blue print or map reference. Also clearly identify areas which will not be included.

2.2.1.3 Summary of Existing Data

Discuss any existing data that is relevant to the facility, site, or study area and that might influence the way this study will be developed. Provide a summary of all existing analytical data, survey data, laboratory results or relevant information. A thorough understanding of these data is essential to the statistical process since it is the basis for defining the conceptual model. An understanding of the variance and other statistical parameters for the existing data may also be valuable to the sampling design. Identify all derived concentration guideline levels (DCGL) which have been developed for the site.

2.2.1.4 Summary of Recorded Spills

The historical site assessment and existing data review may cover this area in sufficient detail, however, if possible interview individuals who worked at the area prior to the initial acceptance of RCRA. This may bring to light previous activities in areas long forgotten.

2.2.1.5 Current Conditions

Discuss any steps that are currently being taken to maintain the facility, site, or study area, to prevent further contamination from occurring, and/or to minimize risk to human health and the environment. Identify the current housekeeping practices such as mopping or vacuuming floors to prevent dust buildup. This information is important to understand the potential migration of contaminant. Identify any outdoor actions which are present to prevent contaminant migration to the soil and to water pathways, such as silt fences and collection areas. Identify all safety concerns involved with the facility, building(s), and area. These should be useful in incorporating into job hazard

analyses. Identify personnel protective equipment and measures needed to protect workers. Identify industrial hygiene sampling requirements.

2.2.1.6 Materials Present

Identify the scope of radionuclides present on the site from the HSA. Determine all hazardous materials on site and the associated quantities. Provide an inventory of waste on site by types and quantities.

2.2.1.7 Scoping Issues

Scoping issues are unresolved questions that surface while conducting the scoping process and that need to be resolved before the project can proceed. For example, historical documents may differ in their descriptions of the processes, radionuclides or chemicals used at a given site, or in a given area. If there are uncertainties regarding the processes or chemicals that were used, it will be difficult to develop a list of contaminants of concern.

2.2.2 Conceptual Model

If during the above steps information is not sufficient to support a complete decision of reuse, recycle, disposal or maintain as current, a conceptual model to support activities should be developed. This model describes the radioactivity suspected for the project. The determination of impacted or non-impacted should be supported by the model. The determination of data gaps and potential disposition strategies should be given.

2.2.3 Summary

At this step a summary of an area of concern is developed which ties all of the above items into a document that is useful for further planning. This document can cover one single area or may cover a group of related areas having similar characteristics. In developing areas of concern the Multi-Agency Radiation Survey and Assessment of Materials and Equipment Manual (MARSAME), Draft for comment, NUREG 1575, Supplement 1, EPA 402-R-06-002, DOE-EH-707, December 2006 uses the term categorization to determine if material or equipment are impacted or not impacted. This leads to an appropriate level of survey for disposition of the material from a survey unit. The survey unit provides the spatial boundaries for the disposition decision similar to the MARSSIM (NUREG 1575, Multi Agency Radiation Survey and Site Investigation Manual (MARSSIM), Rev. 1, August 2000). Guidance on classifying areas based on the potential level of residual radioactive material to provide the appropriate level of survey effort relative to the established the action level criteria. Survey and size requirements are specific to each class, Table 3, with more detailed requirements for those areas with potentially higher levels of contamination. The classifications and associated survey requirements are:

- Class 1 areas are: (1) those where residual contamination, prior to any remediation, are likely to exceed applicable unrestricted action level criteria; (2) have the highest potential for small areas of elevated contamination; and (3) insufficient evidence is available to reclassify the area as Class 2 or Class 3.
- Class 2 areas are: (1) those where the potential for residual contamination exists, but is unlikely to exceed the applicable unrestricted action level criteria; and (2) little or no potential for small areas of elevated contamination.
- Class 3 areas are: (1) those where measurable levels of residual contamination are unlikely above background; and (2) insufficient evidence to support categorization as non-impacted.

Table 3 - Area Classification Requirements

Classification	Area Size	Percent of Total Area
Class 1 structures	up to 100 m^2 surface area	100%
Class 1 land areas	up to 2,000 m^2	100%
Class 2 land areas	2,000 m^2 to 10,000 m^2	10%[1] to 100%
Class 3 areas	2,000 m^2 to 10,000 m^2	May be less than 10%

2.3 *Decision Criteria*

At this point areas of potential contamination have been determined and the question needs to be developed to determine what actions are needed. Consequences of these actions also need to be identified such that decision levels may start to be developed which are based on statistical decisions. The decision point of this study is to

[1] This percentage depends on the DQO process, reference 6.10.

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determine if it is more cost effective to remove a section of pipe without sampling or characterize the pipe without remediation and achieve the same remediation goals. These decision criteria will be developed for 4 separate decision levels (80%, 85%, 90%, 95% confidence level) based on statistical modeling.

The null hypothesis (H_o) tested for in this plan is that contamination exceeds the action level. The alternative hypothesis (H_a or H_1) is that residual contamination meets the action level criterion. The statistical tests used will attempt to reject the null hypothesis.

Type I decision error: A decision error that occurs when the *null hypothesis* is rejected when it is true. The probability of making a *Type I decision error* is called *alpha* (α). This is termed a false positive error.

Type II decision error: A decision error that occurs when the *null hypothesis* is accepted when it is false. The probability of making a *Type II decision error* is called *beta* (β). This is termed a false negative error.

If the action level (AL) for the contaminant is not zero, the surveys are designed to provide sufficient evidence about the contaminant concentration (X) to disprove H_o, with H_o: $X \geq AL$ (see section 2.1 on action levels). Any decision criteria will require a combination of accepting a probability for both error types. The risk of deciding a contaminant is not present when it truly is present provides a more severe problem because the potential consequences of this decision error include risk to human health and the environment. Therefore, a more stringent limit is typically set for the α parameter than the β parameter.

2.3.1 Develop Limits on Decision Errors

The decision process starts with determining the region where relatively large decision error rates are considered tolerable. This is referred to as the gray region. The amount of data available influences the width of the gray region. This region can be revised depending on the power of the hypothesis test. A limit must be set for a tolerable false negative decision error rate and a tolerable false positive decision error rate. The combination of these limits will be very close to the 4 separate decision levels (80%, 85%, 90%, 95% confidence level) used here. The lower bound of the gray region (LBGR) is selected depending on data availability for the site. Further information on the LBGR can be found in References 6.3, 6.5, 6.7, and 6.8.

Determine data user's objectives for the contaminant of concern and relate it to a possible background level. Translate the data user's objectives into limits on Type I or Type II decision errors. If Data Quality Objectives (DQO's) have not been developed, document the probable tolerable limits on decision errors, width of gray region, and estimated preliminary values. If DQO's were developed, confirm the limits on decision errors.

2.3.2 Information Needs

The relevant information needed to make the decision will be tabulated and analyzed for usability. This information include items such as radionuclides of concern, chemicals of concern, standard deviation, lower and upper bound of the gray region, and other data collected in the DQO process, Additional samples may be required. The areas of concern will be isolated into individual survey units that will be treated as separate cases. Each individual case will be uniquely identified. Spatial and temporal components will be identified such that data collection and use will be representative of the population. It is very important to define the population clearly and exactly. The population is the total area, volume, and/or time interval that apply to the decision (once made). If the population is not well defined, it will be unclear to what the decision applies. Time is included to take into account potential migration into or out of the area.

2.3.3 Preliminary Data Review

The action levels for radionuclides and chemicals must be established and clearly identified prior to any sampling or remediation. These criteria assist in establishing decision levels with the statistical parameters used to test the hypothesis. These criteria may be regulatory or risk based parameters. The relationship of the data received to the action level needs to be established. This asks the question of whether the action level is "equal to" or "less than" the numerical value. This study uses confidence interval statistics at 80%, 85%, 90% and 95%.

When there is existing data it will be analyzed for applicability by determining the following statistical parameters for each radionuclide or chemical of concern:

- Measure of relative standing
- Measure of central tendency

- Measure of dispersion
- Measures of association, where applicable

2.3.3.1 Measures of Relative Standing

Sometimes the analyst is interested in knowing the relative position of one or several observations in relation to all of the observations. Percentiles or quantiles are measures of relative standing that are useful for summarizing data. A percentile is the data value that is greater than or equal to a given percentage of the data values. Stated in mathematical terms, the p^{th} percentile is a data value that is greater than or equal to p% of the data values and is less than or equal to (1-p)% of the data values. Therefore, if 'x' is the p^{th} percentile, then p% of the values in the data set are less than or equal to x, and (100-p) % of the values are greater than x. A sample percentile may fall between a pair of observations. For example, the 75th percentile of a data set of 10 observations is not uniquely defined. Therefore, there are several methods for computing sample percentiles, the most common of which is described below.

Let $X_1, X_2, \ldots, X_n$ represent the n data points. To compute the p^{th} percentile, $y(p)$, first rank the data from smallest to largest and label these points $X_{(1)}, X_{(2)}, \ldots, X_{(n)}$ so that $X_{(1)}$ is the smallest, $X_{(2)}$ is the second smallest, and $X_{(n)}$ is the largest). Let t= ap/100, and multiply the sample size n by t. Divide the result in to the integer part and the fractional part, i.e., let nt = j + g where j is the integer part and g is the fraction part. Then the p^{th} percentile is calculated by:

$$\text{if } g = 0, \qquad y(p) = (X_{(j)} + X_{(j+1)})/2 \qquad (1)$$

$$\text{otherwise,} \qquad y(p) = X_{(j+1)}$$

2.3.3.2 Measures of Central Tendency

Measures of central tendency characterize the center of a data set. The three most common estimates are the mean, median, and the mode. Directions for calculating these quantities are given below.

The most commonly used measure of the center of a data set is the sample mean, denoted by $\overline{X}$. The sample mean can be thought of as the "center of gravity" of the data set. The sample mean is an arithmetic average for simple sampling designs; however, for complex sampling designs, such as stratification, the sample mean is a weighted arithmetic average. The sample mean is influenced by extreme values (large or small) and the treatment of non-detects.

The sample median is the second most popular measure of the center of the data. This value falls directly in the middle of the ordered data set. This means that ½ of the data are smaller than the sample median and ½ of the data are larger than the sample median. The median is another name for the 50th percentile. The median is not influenced by extreme values and can easily be used if non-detects are present.

Another method of measuring the center of the data is the sample mode. The sample mode is the value that occurs with the greatest frequency. Since the sample mode may not exist or be unique, it is the least commonly used measure of center. However, the mode is useful for qualitative data.

Let $X_1, X_2, \ldots, X_n$ represent the n data points.

Sample Mean: The sample mean, $\overline{X}$, is the sum of the data points divided by the sample size, n:

$$\overline{X} = \frac{1}{n}\sum_{i=1}^{n} X_i \qquad (2)$$

Sample Median: The sample median, $\tilde{x}$, is the center of the ordered data set. To compute the sample median, sort the data from smallest to largest and label these points $X_{(1)}, X_{(2)}, \ldots, X_{(n)}$. Then,

$$\tilde{x} = \begin{cases} \frac{1}{2}\left[X_{(n/2)} + X_{((n/2)+1)}\right] \text{ if } n \text{ is even} \\ X_{((n+1)/2)} \text{ if } n \text{ is odd} \end{cases} \quad (3)$$

Sample Mode: The sample mode is the value in the sample that occurs with the greatest frequency. The sample mode may not exist or be unique. Count the number of times each value occurs. The sample mode is the value that occurs most frequently.

2.3.3.3 Measures of Dispersion

Measures of central tendency are more meaningful if accompanied by a measure of the spread of values about the center. Measures of dispersion in a data set include the range, variance, sample standard deviation, coefficient of variation, and the interquartile range. Directions for computing these measures are given below.

Let $X_1, X_2, \ldots, X_n$ represent the n data points.

Sample Range: The sample range, R, is the difference between the largest and smallest values of the data set, i.e., $R = \max(X_i) - \min(X_i)$.

Sample Variance: To compute the sample variance, s^2, compute:

$$s^2 = \frac{\sum_{i=1}^{n} X_i^2 - \frac{1}{n}\left(\sum_{i=1}^{n} X_i\right)^2}{n-1} \quad (4)$$

Sample Standard Deviation: The sample standard deviation, s, is the square root of the sample variance,

$$s = \sqrt{s^2} \quad (5)$$

Coefficient of Variation: The coefficient of variation (CV) is the sample standard deviation divided by the sample mean i.e., $CV = s / \overline{X}$. The CV is often expressed as a percentage.

Interquartile Range: The interquartile range (IQR) is the difference between the 75th and the 25th percentiles, i.e., $IQR = y(75) - y(25)$.

The easiest measure of dispersion to compute is the sample range. For small samples, the range is easy to interpret and may adequately represent the dispersion of the data. For large samples, the range is not very informative because it only considers extreme values and is therefore greatly influenced by outliers.

Generally speaking, the sample variance measures the average squared distance of data points from the sample mean. A large sample variance implies the data are not clustered close to the mean. A small sample variance (relative to the mean) implies most of the data are near the mean. The sample variance is affected by extreme values and by a large number of non-detects.

The sample standard deviation is the square root of the sample variance and has the same unit of measure as the data. The coefficient of variation (CV) is a measure having no units that allows the comparison of dispersion across several sets of data. The CV (also known as the relative standard deviation) is often used in environmental applications because variability (when expressed as a standard deviation) is often proportional to the mean.

When extreme values are present, the interquartile range may be more representative of the dispersion of the data than the standard deviation. This statistical quantity is the difference of the 75th and 25th percentiles and therefore, is not influenced by extreme values.

2.3.3.4 Measures of Association

Data sets often include measurements of several characteristics (variables) for each sampling point. There may be interest in understanding the relationship or level of association between two or more of these variables. The

relationship between two variables may not be applicable in all situations for this project. One of the most common measures of association is the correlation coefficient. The correlation coefficient measures the relationship between two variables, such as a linear relationship between two sets of measurements. It is very important to note that the correlation coefficient does not imply cause and effect. The analyst may say the correlation between two variables is high and the relationship is strong, but may not say an increase or decrease in one variable causes the other variable to increase or decrease without further evidence and strong statistical controls. .

The Pearson correlation coefficient measures the strength of the linear relationship between two variables. A linear association implies that as one variable increases, the other increases or decreases linearly. Values of the correlation coefficient close to +1 (positive correlation) imply that as one variable increases, the other increases nearly linearly. On the other hand, a correlation coefficient close to −1 implies that as one variable increases, the other decreases nearly linearly. Values close to 0 imply little linear correlation between the variables. When data are truly independent, the correlation between data points is zero (note, however, that a correlation of 0 does not necessarily imply independence).

The correlation coefficient does not detect nonlinear relationships so it should be used only in conjunction with a scatter plot. A scatter plot can be used to determine if the correlation coefficient is meaningful or if some measure of nonlinear relationships should be used. The correlation coefficient can be significantly influenced by extreme values so a scatter plot should be used first to identify such values.

Pearson's correlation may be sensitive to the presence of one or two extreme values, especially when sample sizes are small. Such values may result in a high correlation, suggesting a strong linear trend, when only moderate trend is present. This may happen, for instance, if a single (X,Y) pair has very high values for both X and Y while the remaining data values are uncorrelated. Extreme values may also lead to low correlations between X and Y, thus tending to mask a strong linear trend. This may happen if all the (X,Y) pairs except one (or two) tend to cluster tightly about a straight line, and the exceptional point has a very large X value paired with a moderate or small Y value (or vice versa). As influences of extreme values can be important, it is again suggested to use a scatter plot in conjunction with a correlation coefficient.

An alternative to the Pearson correlation is Spearman's rank correlation coefficient. It is calculated by first replacing each X value by its rank (i.e., 1 for the smallest X value, 2 for the second smallest X value, etc.) and each Y value by its rank. These pairs of ranks are then treated as the (X,Y) data and Spearman's rank correlation is calculated using the same formulae as for Pearson's correlation.

Since meaningful (i.e., monotonic increasing) transformations of the data will not alter the ranks of the respective variables (e.g., the ranks for log (X) will be the same for the ranks for X), Spearman's correlation will not be altered by nonlinear increasing transformations of the Xs or the Ys. This desirable property, and the fact that Spearman's correlation is less sensitive to extreme values, makes Spearman's correlation a good alternative or complement to Pearson's correlation coefficient.

2.3.4 Identify Survey Units

To make a decision concerning the disposition of the pipe and associated surrounding soils the total must be divided into segments of the total that will be used to make an individual decision. This separate amount of material or equipment will require a separate disposition decision. These separate decision pieces are termed survey units with boundaries clearly defined to make data interpretations straightforward.

Typically the survey unit dimensions are not given in a regulation so the decision maker must make assumptions to develop action levels and survey unit boundaries based on physical characteristics such as physical dimensions, complexity, accessibility and inherent value. The size is primarily related to the scale of decision making defined by length, width and depth of soils or a related volume of material. This may allow the separation into impacted and non-impacted materials.

2.4 Select the Statistical Method

The intent here is to choose a statistical method and define the assumptions used to determine this method. Typically, there is existing data to support the method determination, however, if no data is available a determination may still be made.

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One division in the methods of this section is between parametric and nonparametric hypothesis tests. Parametric tests typically concern the population mean or quantile, use the actual data values, and assume data values follow a specific probability distribution, normal or lognormal. Nonparametric tests typically concern the population mean or median, use data ranks, and don't assume a specific probability distribution. Parametric tests will have more power than a nonparametric counterpart if the assumptions are met. However, the distributional assumptions are often strict or undesirable for the parametric tests and deviations can lead to misleading results. These will be discussed for each test.

The intent is to provide good statistical validity to defend the hypothesis testing being done at the end to determine the number of samples required to provide a reasonable statistical confidence the site is correctly represented. If the contaminant is present in the background, the multiple population method tests will be used to compare data to the release criteria or action level. If the contaminant is not present in the background the single population tests will be used.

The gray region is a range of values of the parameter of interest for a survey unit where the consequences of making a decision error are relatively minor. The upper bound of the gray region is set equal to the action level, and the lower bound of the gray region (LBGR) is a site-specific variable. The decision maker has the ability to select the width of the region. The lower bound of the gray region (LBGR) is initially set at 50% of the action level. A change in the LBGR will affect the relative shift and number of samples taken in a survey unit. This is reflected in the two types of errors associated with the data quality process:

Type I decision error: A decision error that occurs when the *null hypothesis* is rejected when it is true. The probability of making a *Type I decision error* is called *alpha* (α).

Type II decision error: A decision error that occurs when the *null hypothesis* is accepted when it is false. The probability of making a *Type II decision error* is called *beta* (β).

The LBGR is subtracted from the action level and represents the width of the gray region and is referred to as the shift, delta (Δ). This can also be bound by the specified false rejection decision error limit minus the specified false acceptance decision error limit. The shift is used with the standard deviation, σ, of the measured values in the survey unit or the reference area to determine the relative shift, Δ/σ. The relative shift is an expression of the resolution of the measurement in units of measurement uncertainty. Expressed this way it is easy to see that relative shifts of less than one standard deviation, $\Delta/\sigma < 1$, will be difficult to detect. Conversely, relative shifts greater than 3 standard deviations, $\Delta/\sigma > 3$, will be easy to detect. The number of measurements required to achieve the two errors above depends on the value of the relative shift.

The standard deviation will be determined from existing survey data, as available, and estimated otherwise. Surveys may be done to establish a better standard deviation. Different types of surfaces, soils or reference areas will require different standard deviations be determined. When preliminary data is not available MARSSIM allows an assumed standard deviation on the order of 30% of the DCGL. These concepts are used to determine the number of samples needed to determine a specific statistical accuracy.

2.4.1 Single Population Methods

The methods of this section concern comparing a single population parameter to a regulatory value (i.e. a fixed number) or the estimation of the population parameter. If the regulatory or action-value was estimated, then a one-sample method is not appropriate and a two-sample test should be selected. An example of a one-sample test would be to determine if 95% of all soil samples of Pu-239 from the area are below a fixed regulatory level. For this example, the population parameter is a proportion and the threshold value is 95% (0.95). Comparing the mean contaminant concentration of a contaminated site to the mean concentration of a background area would be a considered a two-sample test.

The hypothesis tests discussed in this section may be used to determine if there is evidence that $\theta < \theta_0$, $\theta > \theta_0$, or $\theta \neq \theta_0$ where θ represents the population mean, median, proportion, or quantile, and θ_0 represents the threshold value. There are also confidence/tolerance interval procedures to estimate θ.

2.4.1.1 One Sample Student t-Test

This one sample test is used to compare the mean of the population to a threshold value or regulatory limit. This test assumes the contaminant being compared is not present in background. The test also assumes there is no variability

in the regulatory limit. The test assumes independence of the data and the mean is approximately a normal distribution. A statistical test for normality of the data should also be done prior to performing this test. Consult a statistician to determine to what degree the data meets the normal distribution. Note that if the sample size does not meet the normal distribution this test may still be applied in a limited fashion. The t-test should be used with caution when outliers are present because the mean and standard deviation are sensitive to outliers.

If the data set has a large number of values that have been reported as less than the detection limit caution should be taken. Large numbers of values reported as less than the detection limit may cause the decision maker to throw out the data set or require additional samples be taken. Replacing the less than data with 50% of the detection limit has been considered acceptable in some cases.

The decision maker must determine the appropriate proportion for the parameters associated with this test. This information includes:

The null and alternative hypothesis, typically:

$H_o = \mu \geq$ regulatory limit

$H_A = \mu \leq$ regulatory limit

The gray region bound by a tolerable false negative decision error rate and a tolerable false positive decision error rate,

The false rejection error rate, α,

The false acceptance error rate, β.

This test is to be used when there are potential statistical outliers in the data. Outliers may represent hot spots in the distribution of contaminant. There are numerous statistical tests for outliers that may be appropriate to use at the start of the process.

Calculate the number of samples needed for the one sided *t* test using:

$$n = \frac{S_{Total}^2 \left(z_{1-\alpha} + z_{1-\beta}\right)^2}{\Delta^2} + 0.5\, z_{1-\alpha}^2 \qquad (6)$$

Where:

n	= the number of samples,
S_{Total}	= estimated standard deviation, total population,
$z_{1-\alpha}$	= where $z_{1-\alpha}$ is the z statistic for the false rejection error rate, α, Table A-1 of Reference 6.8,
$z_{1-\beta}$	= where $z_{1-\beta}$ is the z statistic for the false acceptance error rate, β, Table A-1 of Reference 6.8,
Δ	= width of the gray region (the specified false rejection decision error limit minus the specified false acceptance decision error limit).

It is customary to round sample size up to the next highest whole number.

2.4.1.2 One Sample Proportion Test

The one sample proportion test is used to compare a population proportion or percentile to a threshold value or regulatory limit. The population proportion is the ratio of the number of elements of a population that has some specific characteristic to the total number of elements. A population percentile is the percentage of elements of a population having values less than some threshold or regulatory limit.

This test assumes the contaminant being compared is not present in background. The test also assumes there is no variability in the regulatory limit. Note that for P = 0.5 this test is equal to the Sign test, however, this test is more powerful than the Sign test for symmetric distributions. The Wilcoxon signed rank test is preferred test when testing the median. The test is used to determine if the parameter being tested is a percentage (proportion) of the threshold value. The only assumption is that the samples represent a random sample. The distribution shape is valid for any underlying distributional shape.

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The decision maker must determine the appropriate proportion for the parameters associated with this test. This information includes:

The null and alternative hypothesis, typically:

H_o = P ≥ regulatory limit,

H_A = P ≤ regulatory limit,

The gray region, bound by a tolerable false negative decision error rate and a tolerable false positive decision error rate,

The false rejection error rate, α,

The false acceptance error rate, β,

Additional false rejection and acceptance error rates may be chosen.

This test is to be used when there are potential statistical outliers in the data. Outliers may represent hot spots in the distribution of contaminant. There are numerous statistical tests for outliers that may be appropriate to use at the start of the process, Reference 6.8.

Calculate the number of samples needed for the one sided test using:

$$n = \left(\frac{z_{1-\alpha}\sqrt{P_0(1-P_0)} + z_{1-\beta}\sqrt{P_1(1-P_1)}}{P_1 - P_0} \right)^2 \quad (7)$$

Where:

n = the number of samples,

$z_{1-\alpha}$ = where $z_{1-\alpha}$ is the z statistic for the false rejection error rate, α, Table A-1 of Reference 6.8,

$z_{1-\beta}$ = where $z_{1-\beta}$ is the z statistic for the false acceptance error rate, β, Table A-1 of Reference 6.8,

P_0 = the false rejection rate,

P_1 = the false acceptance rate.

Round the sample size up to the next highest whole number.

2.4.1.3 Wilcoxon Signed Rank Test

This test is good to test the mean or median of the population. The data are assumed to constitute a random sample from a symmetric population. If the population is not symmetric or normal consult a statistician for assistance. For populations where the sample size is greater than 50 the *t*-test is more robust than the Wilcoxon signed rank test. Sampling results should be reported with sufficient accuracy such that a large number of equal values are avoided. Negative numbers and estimated values for data below the detection limit (0.5 the detection limit) are used because the test relates the relative magnitude to the rest of the data.

To calculate the number of samples needed for the Wilcoxon signed test use:

$$n = \frac{\left(z_{1-\alpha} + z_{1-\beta}\right)^2}{4(Sign\ P - 0.5)^2} \quad where\ Sign\ P = \Phi\left(\frac{\Delta}{S_{Total}}\right) \quad (8)$$

Where:

n = the number of samples,

$z_{1-\alpha}$ = where $z_{1-\alpha}$ is the z statistic for the false rejection error rate, α,

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Table A-1 of Reference 6.8,

$z_{1-\beta}$ = where $z_{1-\beta}$ is the z statistic for the false acceptance error rate, β,

Table A-1 of Reference 6.8,

Φ = cumulative standard normal distribution function, $\frac{1}{\sqrt{2\pi}}\int_{-\infty}^{z} e^{\frac{x^2}{2}}\,dx$

Δ = width of the gray region (the specified false rejection decision error limit minus the specified false acceptance decision error limit)

s_{Total} = estimated total standard deviation.

Round the sample size up to the next highest whole number.

2.4.2 Multiple Population Methods

For two sample tests the hypothesis considered are different from the one sided test since a comparison is used. The comparison is between the reference area characteristics and the survey area characteristics. Multiple population methods are appropriate when the comparison population of the reference area has the constituent of concern naturally present. This is the case for radium, thorium and uranium in soil. It is important to be able to evaluate the variability of the background material in relation to the contaminant concentration. Multiple population methods allow this comparison. The decision maker must select the test to use.

For the hypothesis testing let μ_1 represent the mean for population 1 and μ_2 represent the mean for population 2 the hypotheses considered are:

Case 1: H_o: $\mu_1 - \mu_2 \leq \delta_o$ vs. H_A: $\mu_1 - \mu_2 > \delta_o$ and

Case 2: H_o: $\mu_1 - \mu_2 \geq \delta_o$ vs. H_A: $\mu_1 - \mu_2 < \delta_o$

Where δ_o is a specified value.

2.4.2.1 Two Sample Student t-Test

This test is robust for testing the means of two populations. This test assumes a random sample is drawn from each population and they are independent samples. The means for each population are assumed to be approximately normally distributed.

The decision maker must select the appropriate criteria and hypothesis case to test.

Additional information required includes:

The gray region, bound by a tolerable false negative decision error rate and a tolerable false positive decision error rate,

The false rejection error rate, α at δ_o,

The false acceptance error rate, β at δ_1,

Additional false rejection and acceptance error rates may be chosen.

To calculate the number of samples needed for the two sample t-test use:

$$n = \frac{2s^2\left(z_{1-\alpha} + z_{1-\beta}\right)^2}{(\delta_1 - \delta_0)^2} + (0.25)\, z_{1-\alpha}^2 \qquad (9)$$

Where:

n = the number of samples,

s = estimated standard deviation,

$z_{1-\alpha}$ = where $z_{1-\alpha}$ is the z statistic for the false rejection error rate, α,

Table A-1 of Reference 6.8,

$z_{1-\beta}$ = where $z_{1-\beta}$ is the z statistic for the false acceptance error rate, β,

Table A-1 of Reference 6.8,

δ_0 = the false rejection decision error rate,

δ_1 = the false acceptance decision error rate.

Round the sample size up to the next highest whole number.

2.4.2.2 Two Sample Proportion Test

This test considers hypotheses concerning two population proportions or percentiles. The population proportion is the ratio of the number of elements in a subset of the total population to the total number of elements, where the subset has some specific characteristic that the rest of the elements do not. A population percentile represents percentage of elements of a population having values less than some threshold value C.

The decision maker must decide on the hypothesis to use. If the decision is made to let P_1 represent the true proportion for population 1 and P_2 represent the true proportion for population 2 the hypotheses considered are:

Case 1: H_o: $P_1 - P_2 \leq \delta_o$ vs. H_A: $P_1 - P_2 > \delta_o$ and

Case 2: H_o: $P_1 - P_2 \geq \delta_o$ vs. H_A: $P_1 - P_2 < \delta_o$

Where δ_o is a specified value. An equivalent null hypothesis can be written for percentiles

Additional information required includes:

The gray region, bound by a tolerable false negative decision error rate and a tolerable false positive decision error rate,

The false rejection error rate, α at δ_0,

The false acceptance error rate, β at δ_1,

Additional false rejection and acceptance error rates may be chosen.

This test assumes a random sample is drawn from each population and they are independent samples. The test is robust for any underlying distributional shape and is valid to outliers

To calculate the number of samples needed for the two sample test for proportions use:

$$n = \frac{2\left(z_{1-\alpha} + z_{1-\beta}\right)^2 \overline{P}(1-\overline{P})}{(P_2 - P_1)^2} \quad where \quad \overline{P} = \frac{P_1 + P_2}{2} \qquad (10)$$

Where:

n = the number of samples,

$z_{1-\alpha}$ = where $z_{1-\alpha}$ is the z statistic for the false rejection error rate, α,
Table A-1 of Reference 6.8,

$z_{1-\beta}$ = where $z_{1-\beta}$ is the z statistic for the false acceptance error rate, β,
Table A-1 of Reference 6.8,

P_1 = the proportion from sample population 1,

P_2 = the proportion from sample population 2.

Round the sample size up to the next highest whole number.

2.4.2.3 Wilcoxon Rank Sum Test

This test is a distribution free test that compares the shape and location of the two distributions instead of a statistical parameter such as mean or median. The Wilcoxon Rank Sum Test uses the null hypothesis:

H_o: the distribution of population 1 and population 2 are identical (or the site is not more contaminated than background).

The alternative hypothesis is:

H_A: part of the distribution of population 1 is located to the right of the distribution of population 2 (or the site is more contaminated than background).

This requires care in labeling populations 1 and 2 because of the structure of the hypotheses. This test, when applied with the Quantile test, results in the most powerful for detecting true differences between two populations. Random sampling and data independence are required for this test. This test is robust for outliers.

To determine the number of data points required use:

$$n = \frac{\left(z_{1-\alpha} + z_{1-\beta}\right)^2}{3(P_r - 0.5)^2} \quad where \quad P_r = \Phi\left(\frac{\Delta}{\sqrt{2}s_{Total}}\right) \tag{11}$$

Where:

n = the number of samples in the reference and survey areas,

$z_{1-\alpha}$ = where $z_{1-\alpha}$ is the z statistic for the false rejection error rate, α, Table A-1 of Reference 6.8,

$z_{1-\beta}$ = where $z_{1-\beta}$ is the z statistic for the false acceptance error rate, β, Table A-1 of Reference 6.8,

Φ = the cumulative standard normal distribution function,

s_{Total} = the estimated total standard deviation

Δ = width of the gray region (the specified false rejection decision error limit minus the specified false acceptance decision error limit).

Round the sample size up to the next highest whole number.

2.5 Sampling Designs

The number of samples needed to accurately determine the characteristics of an area were determined using the methods in Section 2.4 above. It must be determined where to take these samples to benefit the most from the data received. Environmental sampling includes not only the number of samples but the geographic positioning of the samples and/or the time frame of sampling. All of this comes together to minimize the expenditure of resources associated with sample collection, analysis, and interpretation.

Environmental sampling designs are a complex subject which is dealt with in extensive detail in References 6.1, 6.3, 6.5, and 6.8. A simple listing of common sampling designs is given below:

Judgmental sampling

Simple random sampling

Stratified sampling

Systematic and grid sampling

Composite sampling

More innovative sampling designs include ranked set sampling and adaptive cluster sampling, Reference 6.5.

2.5.1 Judgmental Sampling

Here the selection of where to take the samples is based on knowledge of the features or condition under investigation. This method is based on professional judgment not statistical probability based sampling. For this study the restriction has been placed at two pipe diameters outside the pipe under investigation.

2.5.2 Simple Random Sampling

In this sampling method the sampling locations are selected using random numbers that designate where to take the sample. This design is good for uniformly distributed contamination but is likely to miss "hot spots" of contamination. The results are statistically unbiased estimates of the mean, proportion and variability within the survey unit. Difficulty in defining the precise random location may cause difficulties with this method.

2.5.3 Stratified Sampling

This sampling design separates the target population into non-overlapping strata or sub populations that are known or thought to be homogeneous. The strata may be chosen on the basis of preexisting information or judgment about the site. This method may achieve greater precision in estimating the mean and variance and it also allows computation of reliable estimates for population subgroups of special interest

2.5.4 Systematic and Grid Sampling

This sample design uses regularly spaced intervals over space and time. It starts with a random location and rigorously defines the remaining locations over a grid, which may be square, rectangular, triangular or radial. This technique is good to determine hot spots and spatial patterns.

2.5.5 Composite Sampling

Composite sampling uses volumes of material from several selected sampling units in combination to obtain a mixed homogeneous sample. It is very cost effective by reducing the number of analyses required. It is used in conjunction with other sampling designs to estimate the population mean when spatial information is not needed.

2.5.6 Sampling Strategy

No single sampling strategy is adequate for the project outlined here so the combination of several different sampling strategies will be employed to provide the best sampling methodology. Judgmental sampling will be used to sample near the pipe and preferentially toward any suspected area such as a joint, leak, curve, or close to the building. Stratified sampling will be employed to get to the depth of the pipe of concern. Five foot intervals have been initially proposed, but professional judgment will be considered in this decision. A systematic or grid system will be used sample within two pipe diameters of the pipe

2.6 *Impact of Gray Region and Standard Deviation*

Variation in the width of the gray region and the standard deviation can significantly affect the number of samples. These parameters may not be known until a site is identified and some level of data gathering has been accomplished. Variation in these parameters is described in the following sections.

2.6.1 Effect of Different Widths of the Gray Region

There are two important statistical parameters that have significant impact on the costs associated with the number of samples, 1) the width of the gray region and 2) the standard deviation used. The width of the gray region is typically the upper bound of the gray region minus the lower bound of the gray region. The upper bound of the gray region is typically set at the action level while the lower bound of the gray region is somewhat subjective. The wider the width of the gray region the more error may be accepted. This is used in conjunction with the false positive and negative rates.

For example, if the contaminant was in the background and the proportion of the reference area activity is being tested, a two sample proportion test would be chosen. If we choose different widths of the gray region the number of samples changes, see Table 4 for results from the two sample proportion test. All variables are able to be changed in the spreadsheet and roll up to a total cost. The combined probability represents addition of the false positive and negative rates. You cannot choose a zero rate so one is used as a placeholder to get the percentages close to the specified 80%, 85%, 90%, and 95%.

Table 4 - Example of Cost Variability with Different Statistical Parameters

(from Two Sample Proportion Test)

Width of Gray Region, (UBGR-LBGR)	Alpha	Beta	Number of Samples, n	Analytical Cost per Sample	Cost of Sampling Design for One Area	Combined Probability
0.1	0.01	0.01	553	$11,435.00	$6,323,555.00	
0.1	0.05	0.01	403	$11,435.00	$4,608,305.00	95%
0.1	0.01	0.05	403	$11,435.00	$4,608,305.00	95%
0.1	0.1	0.01	332	$11,435.00	$3,796,420.00	90%
0.1	0.01	0.1	332	$11,435.00	$3,796,420.00	90%
0.1	0.05	0.05	276	$11,435.00	$3,156,060.00	90%
0.1	0.2	0.01	256	$11,435.00	$2,927,360.00	80%
0.1	0.01	0.2	256	$11,435.00	$2,927,360.00	80%
0.15	0.01	0.01	246	$11,435.00	$2,813,010.00	
0.1	0.1	0.05	219	$11,435.00	$2,504,265.00	85%
0.1	0.05	0.1	219	$11,435.00	$2,504,265.00	85%
0.1	0.3	0.01	208	$11,435.00	$2,378,480.00	
0.1	0.01	0.3	208	$11,435.00	$2,378,480.00	
0.15	0.05	0.01	179	$11,435.00	$2,046,865.00	95%
0.15	0.01	0.05	179	$11,435.00	$2,046,865.00	95%
0.1	0.1	0.1	168	$11,435.00	$1,921,080.00	80%
0.1	0.2	0.05	158	$11,435.00	$1,806,730.00	
0.1	0.05	0.2	158	$11,435.00	$1,806,730.00	
0.15	0.1	0.01	148	$11,435.00	$1,692,380.00	90%
0.15	0.01	0.1	148	$11,435.00	$1,692,380.00	90%

This table shows the impact of changing the width of the gray region from 0.1 to 0.15 at the 95% and 90% level. The number of samples is 403 samples required at the 95% level with a width of 0.1 going down to 179 samples by widening the gray region width to 0.15. The effect of false positive and false negative rate is illustrated with the number of samples decreasing from 403 at 95%, 332 at 90%, and 256 at 80%.

If the contaminated region is not known, the number of characterization samples required is independent of pipe length. For the purpose of cost comparison with the excavation estimate, a method of comparing the assumed contaminated soil volume along the pipe length with the number of characterization samples is proposed.

2.6.2 Effect of Different Standard Deviations

If previous sampling data is available the simple sample standard deviation may be calculated. If data is not available MARSSIM uses suggested standard deviations. Choosing the appropriate standard deviation will have an influence on the number of samples and therefore the cost.

When actual data is used the effect of outliers on the number of samples may have significant cost implications. Outliers are values which lie so far away from the mean that one may suspect that the case in question is not representative of the population measured. A convenient definition of an outlier is a point which falls more than 1.5 times the interquartile range above the third quartile or below the first quartile. Using a histogram, box and whiskers plot, or scatterplot may be useful in visually identifying outliers. Justification for discarding outliers should be included in the data evaluation.

An example of the effect of changing the standard deviation is given in Table 5. Table 5 is based on the two sample student t-test. As can be seen the tighter the distribution, i.e. the smaller the standard deviation the fewer number of samples needed for the same false positive or false negative rate. In the table the width of the gray region for the example remains the same.

Table 5 – Effect of a Different Standard Deviation on the Number of Samples and the Cost

Alpha	Beta	SD	Number of Samples, n	Cost of Sampling Design for One Area	SD	Number of Samples, n	Cost of Sampling Design for One Area
0.01	0.01	1.9	1628	$ 18,616,180.00	1.1	547	$ 6,254,945.00
0.01	0.05	1.9	1187	$ 13,573,345.00	1.1	399	$ 4,562,565.00
0.05	0.01	1.9	1186	$ 13,561,910.00	1.1	398	$ 4,551,130.00
0.01	0.1	1.9	980	$ 11,206,300.00	1.1	330	$ 3,773,550.00
0.1	0.01	1.9	979	$ 11,194,865.00	1.1	329	$ 3,762,115.00
0.05	0.05	1.9	814	$ 9,308,090.00	1.1	274	$ 3,133,190.00
0.01	0.2	1.9	756	$ 8,644,860.00	1.1	255	$ 2,915,925.00
0.2	0.01	1.9	755	$ 8,633,425.00	1.1	253	$ 2,893,055.00
0.05	0.1	1.9	645	$ 7,375,575.00	1.1	217	$ 2,481,395.00
0.1	0.05	1.9	644	$ 7,364,140.00	1.1	217	$ 2,481,395.00
0.01	0.3	1.9	612	$ 6,998,220.00	1.1	207	$ 2,367,045.00
0.3	0.01	1.9	611	$ 6,986,785.00	1.1	205	$ 2,344,175.00
0.1	0.1	1.9	494	$ 5,648,890.00	1.1	166	$ 1,898,210.00

2.7 Excel Spreadsheet Instructions

Each Excel spreadsheet (see attachments in Section 7) is set up the same way so the description given here applies to all of the sheets. These calculations are dependent upon a knowledgeable person choosing the appropriate variables used in these calculations. They should use available data and decision criteria based upon the proper regulatory guidance. This individual should choose the null and alternative hypothesis to be tested. These calculations assume the null hypothesis (H_o) tested for is that residual contamination exceeds the action level criterion. The alternative hypothesis (H_a) is that residual contamination meets the action level criterion. It is suggested to make a copy of the folder containing the spreadsheets and save each Rev 0 as the template to be used later.

Each Excel file has four worksheets:

- Calculations
- Size Formula Sheet
- Cost
- Totals

The worksheets are set up to interlink and provide the analysis for the "Totals" worksheet. The "Totals" worksheet provides the results for comparison of costs at different levels of risk which is determined through the number of samples needed. All worksheets have input cells surrounded with colored borders. Input variables should be chosen carefully with the appropriate level of justification and documentation.

Start with the "Calculations" worksheet where the level of the false positive error rate (alpha value,α) and the false negative error rate (beta value,β) are entered into the appropriate colored fields. The Action Level, Estimated Standard Deviation and the LBGR should be entered from existing data or with the appropriate guidance. This

allows the calculation of the width of the gray region (Δ), the percentage of the Action Level and the number of samples using the appropriate z statistic.

The "Size Formula Sheet" is a tabular version of the "Calculations" worksheet in a manner that is easier to follow. The formula used in the calculation is shown along with references. No input is needed for this worksheet.

The "Cost" worksheet is a tabulation of costs associated with each sample. The sample collection cost (USC$) is a single cell and should include all administrative, labor, materials and miscellaneous items associated with collection of the sample. The sample analysis cost (USA$) table is set up to be a compilation of analytical costs summed at the top. These two costs are summed to give the aggregate unit sample collection and analysis cost (AUSCSA$), which is used in the "Totals" worksheet.

The "Totals" worksheet provides the total sampling cost associated with the number of samples at a specified false positive and false negative rate for three different widths of the gray region. A sampling cost budget cell is used to differentiate the decision level of the total cost between in the red border or blue. Highlighted fields differentiate different gray regions.

2.8 Sampling Statistics Results

Statistical techniques can be chosen that determine the number of samples needed for different confidence levels of false positive or false negative rates. The number of samples can be used with the MARSSIM terminology to determine the volume of material that must be sampled. This allows the decision maker to determine a sample design that best suits the needs of the user. Historical data can be used to assist in a volume classification to change the number of samples required depending on known or suspected contamination.

The number determined can be correlated with sampling and analysis costs to get an idea of the cost and relate this to simple digging and disposal costs. Tables are set up in Excel spreadsheets to investigate different decision levels at different false positive and false negative error rates. The results for the four confidence levels 80, 85, 90, and 95 percent are summarized below in Table 6. Note that the number of samples identified in Table 4 and Table 6 differ due to a change in the percent of the action level used for the width of the gray region and the estimated proportion in the survey unit and the reference area.

Table 6 - Comparison of Sample Numbers by Confidence Level

80% Confidence Level

Width of Gray region	Alpha	Beta	1 sample *t*-test	1 sample Proportion	Wilcoxon Sign test	2 sample *t*-test	2 sample Proportion	Wilcoxon Rank Sum
5 % of AL	1 %	20 %	380	1041	245	255	1526	106
	20 %	1 %	378	1106	245	253	1526	106
	10 %	10 %	248	703	161	166	999	70
	5%	15%	272	758	176	182	1093	76
	15%	5%	271	780	176	182	1093	76
10 % of AL	1 %	20 %	97	268	68	65	382	30
	20 %	1 %	95	299	68	64	382	30
	10 %	10 %	63	185	45	42	250	21
	5%	15%	69	198	48	46	274	22
	15%	5%	69	208	48	46	274	22
20 % of AL	1 %	20 %	27	70	23	18	96	12
	20 %	1 %	24	83	23	16	96	12
	10 %	10 %	17	50	15	11	63	9
	5%	15%	19	53	17	12	69	9
	15%	5%	18	57	17	12	69	9

Table 6 (Continued)

85% Confidence Level

Width of Gray region	Alpha	Beta	1 sample *t*-test	1 sample Proportion	Wilcoxon Sign test	2 sample *t*-test	2 sample Proportion	Wilcoxon Rank Sum
5 % of AL	1 %	15 %	428	1179	276	287	1719	119
	15 %	1 %	426	1240	276	286	1719	119
	5 %	10 %	324	908	209	217	1302	90
	10%	5%	323	923	209	217	1302	90
10 % of AL	1 %	15 %	109	305	76	73	430	34
	15 %	1 %	107	333	76	72	430	34
	5%	10%	82	238	57	55	326	27
	10%	5%	82	245	57	55	326	27
20 % of AL	1 %	15 %	30	80	26	20	108	14
	15 %	1 %	28	02	26	19	108	14
	5 %	10 %	22	64	20	15	82	11
	10%	5%	21	67	20	14	82	11

90% Confidence Level

Width of Gray region	Alpha	Beta	1 sample *t*-test	1 sample Proportion	Wilcoxon Sign test	2 sample *t*-test	2 sample Proportion	Wilcoxon Rank Sum
5 % of AL	1 %	10 %	492	1366	318	330	1979	137
	10 %	1 %	490	1418	318	329	1979	137
	5%	5%	408	1157	264	274	1645	114
10 % of AL	1 %	10 %	125	355	87	84	495	40
	10 %	1 %	124	379	87	83	495	40
	5%	5%	103	305	72	69	412	33
20 % of AL	1 %	10 %	34	94	29	22	124	16
	10 %	1 %	32	104	29	21	124	16
	5%	5%	27	82	24	18	103	14

95% Confidence Level

Width of Gray region	Alpha	Beta	1 sample *t*-test	1 sample Proportion	Wilcoxon Sign test	2 sample *t*-test	2 sample Proportion	Wilcoxon Rank Sum
5 % of AL	1 %	5 %	596	1667	386	399	2398	166
	5 %	1 %	594	1705	386	398	2398	166
10 % of AL	1 %	5 %	151	436	105	101	600	47
	5 %	1 %	150	453	105	100	600	47
20 % of AL	1 %	5 %	40	116	35	27	150	18
	5 %	1 %	39	124	35	26	150	18

3. Pipe Excavation and Removal Cost Estimate

The pipe excavation and removal cost estimate is summarized in dollars per linear foot for excavating pipeline types (materials of construction) and sizes and depths. Excavation depths, summarized in section 1.2 and shown in section 3.1 are 5, 10, 15, 20, and 25 feet below ground surface. Pipeline materials of construction include a) vitrified clay, b) stainless steel and carbon steel, c) concrete masonry, and d) reinforced concrete. Pipeline sizes vary from 2 to 48 inches in diameter. The cost estimate includes various combinations of depth, diameter, and materials of construction deemed applicable to the Hanford site. For the excavation estimate, it is assumed that the pipeline and surrounding soil within two pipe diameters from the outside surface of the pipe are contaminated with radionuclides or other hazardous substance in excess of action levels that require personnel protection in accordance with Occupational Safety and Health Administration (OSHA) level D standards (29 CFR 1910.120 Appendix B). Soil types surrounding the pipeline will range from fine sand to coarse gravel and sand/gravel mixtures.

The pipe excavation and removal cost estimate Excel™ Spreadsheet (see section 7) consists of numerous parameters that include the various elements associated with soil excavation and pipe removal. These parameters are summarized in Table 7. The focus of this study has been on excavation of clean soil down to the pipe, contaminated soil excavation around the pipe, and pipe sectioning and removal. The other parameters in Table 7 can be tailored to specific job sites. The advantage of the Excel spreadsheet is that these parameters can be modified (cost elements added or deleted as necessary) to fit a particular pipe excavation and removal job.

Table 7 - Cost Estimate Parameters

Mobilization	Mobilization of personnel and equipment includes relocation of resources to the job site.
Pipeline / Interference Location	Pipe excavation can start after the buried pipe and any interference such as buried utilities are identified to ensure the correct site is located.
Install Silt Barrier	Installation of a silt barrier provides runon / runoff control of silt and construction debris.
Paved Road Trenching	Cutting of asphalt or concrete paving prior to excavation of underlying soil. Estimate assumes no paved areas will require excavation.
Clean Excavation to Pipe	Clean excavation includes removal of soil overburden down to the contaminated zone.
Contaminated Soil Excavation	Contaminated soil excavation includes removal of the contaminated soil around the pipeline.
Pipe Section and Removal	Removal of the pipeline includes cutting or shearing metal pipe into sections or crushing or crumbling clay or concrete pipe and loading the resulting debris into ERDF cans for disposal.
Backfill, Compact and Grade	Once excavation is complete, this parameter provides the elements needed to backfill the excavated hole.
Demobilization	Demobilization of personnel and equipment includes relocation of resources away from the job site once the job is complete. Also includes removal of silt barrier and other project fencing.

3.1 Input Parameters

Input Parameters to the Tool:

- Excavation depths in 5 foot increments (5, 10, 15, 20, and 25 feet below grade)
- Pipeline materials of construction (vitrified clay, stainless and carbon steel, concrete masonry, and reinforced concrete)
- Pipe diameters from 2 to 48 inches (the estimate assumes 6 sizes e.g., 2, 6, 12, 24, 36 and 48 inches) in conjunction with the exclusions noted above.

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The decision support tool (Excel spreadsheet) is configured to allow a different input from each of the bullets above to result in a different cost estimate per lineal foot of pipe.

3.2 *Excavation*

Assumptions, any items specifically excluded, and methodology for excavated volume is included in the section on assumptions and the Excel spreadsheets (see section 7). Typical crew configurations and fiscal year (FY) 2007 labor costs by labor category for Fluor Hanford are given in Table 8 (based on the attachment to SOW).

Table 8 - Costs Associated with Pipe Excavation

Craft	$/hr	# in Crew	Craft $/hr
'Other' craft	67.96	1	67.96
Laborer	54.14	6	324.84
Teamster (light vehicle driver)	54.35	5	271.75
Heavy Equipment Operator	64.86	2	129.72
Health Physics Technician	68.17	6	409.02
TOTAL		**20**	**$1203.29**

Other assumptions:

1) 10 hour work day per crew for purposes of cost estimation
2) Estimate is based on 4 boxes per day at start, ramping up to 30 boxes per day at day 6
3) Soil and air sampling during excavation is assumed to be 25 % of the excavation costs.

3.3 *Waste Packaging*

The cost estimate is based on contaminated soil being placed or loaded into ERDF cans or roll-off containers for disposal at ERDF. Clean soil is placed in spoil piles and is assumed will remain at the excavation site for use in backfill of the excavation. ERDF waste handling and disposal fees are assumed to be 45 % of the excavation costs.

3.4 *Calculations*

The volume of clean and contaminated excavated soil is based on Figure 1. The excavated area is based on a 1.5 to 1 slope. This results in a trapezoidal volume above the buried pipeline as the clean soil region. The contaminated region is based on the assumption that the contaminated volume is within 2 pipe diameters around the buried pipeline. The top of this 2 pipe diameter region is assumed to be a flat plane and forms another trapezoidal volume for the contaminated region.

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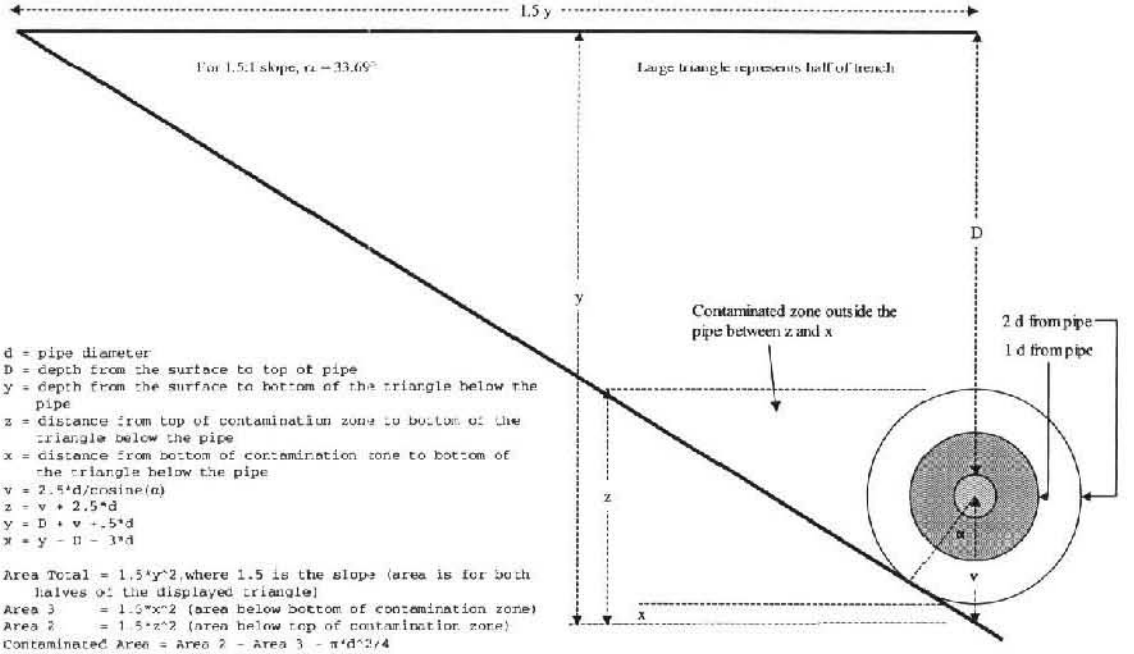
Figure 1 - Excavation Model

Model for trapezoid contamination zone 2 diameters beyond pipe



d = pipe diameter
D = depth from the surface to top of pipe
y = depth from the surface to bottom of the triangle below the pipe
z = distance from top of contamination zone to bottom of the triangle below the pipe
x = distance from bottom of contamination zone to bottom of the triangle below the pipe
v = 2.5*d/cosine(α)
z = v + 2.5*d
y = D + v +.5*d
x = y - D - 3*d

Area Total = 1.5*y^2,where 1.5 is the slope (area is for both halves of the displayed triangle)
Area 3 = 1.5*x^2 (area below bottom of contamination zone)
Area 2 = 1.5*z^2 (area below top of contamination zone)
Contaminated Area = Area 2 - Area 3 - π*d^2/4
Non-contaminated Area = Area Total - Area 2 + Area 3

Important note on model limitations:
When D is less than 2.5 d (e.g., D=5 feet & d > 24 inches) the contaminated zone is above the ground surface. In such cases the contaminated area is over-predicted and the non-contaminated area can be a negative number.

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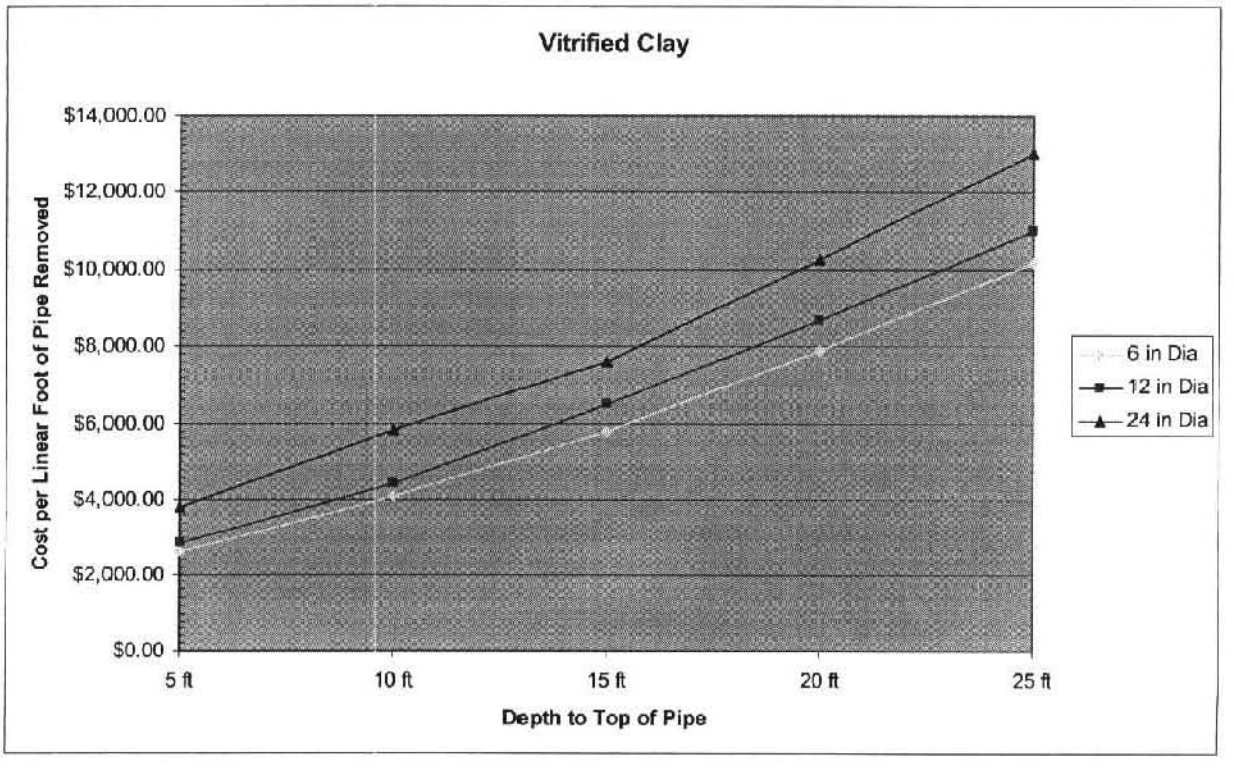
3.5 Pipe Excavation Cost Estimate

The decision support tool provides a cost estimate for each of the parameters listed as an input for the estimate. Vitrified clay is used as an example and the results are summarized in Table 9 and Figure 2. Similar cost curves are obtained for the different pipe types, stainless and carbon steel, concrete and reinforced concrete, and are included in section 7.2. Each estimate includes 30% contingency as noted in section 7.2.

Table 9 - Vitrified Clay Pipe Excavation Cost per Lineal Foot

Depth	6 in Diameter	12 in Diameter	24 in Diameter
5 ft	$2,607.64	$2,866.94	$3,794.76
10 ft	$4,104.32	$4,433.26	$5,814.85
15 ft	$5,763.51	$6,476.57	$7,614.11
20 ft	$7,900.46	$8,659.96	$10,250.49
25 ft	$10,175.93	$11,005.08	$13,026.94

Figure 2 - Excavation Cost per Lineal Foot for Vitrified Clay Pipe



4. Decision Support Tool and Cost Comparison

For the examples presented in this document, the cost to excavate vitrified clay pipe is compared to the cost for taking a number of samples at the 95 % confidence level. This comparison can be made at the different confidence levels or different pipe types and depths. Excavation costs range from $2,608 to $13,027 per foot for vitrified clay pipe at different depths and diameters (from section 3.5). From Table 4 it is shown 403 samples are required for a 95% confidence level. The cost for analyzing 403 samples is $4,608,305 (from section 2.6).

4.1 Decision Support Tool Results

Results of the decision support tool for vitrified clay are summarized in Table 9. The Excel spreadsheets in section 7.2 summarize the costs per foot for excavation for the different pipe types. These results for each pipe type at 12 inch diameter and 15 foot depth are summarized in Table 10.

Table 10 - Excavation Costs per Foot at 12 inch diameter and 15 Foot depth

Pipe Type	Costs per foot at 12 inch diameter and 15 foot depth
Vitrified clay pipe	$6,477
Steel and stainless steel	$6,517
Reinforced concrete	$6,576
Concrete masonry	$6,477

From Table 4 sampling costs range from $4,608,305 @ 95 % confidence (403 samples) to $1,921,080 @ 80% confidence (168 samples). Note the number of samples varies depending on the width of the gray region and the alpha and beta values. As noted in the assumptions the cost to obtain samples is $25,000 for the first sample in each of three sample pits over a 100 foot length. Additional samples cost $600 each. The cost for 403 samples over a 100 foot length is $266,800 and 168 samples $125,800. For rough comparison, the cost to excavate 100 feet of pipe (taken from Table 10) is about $660,000 compared with a cost range of $4,875,000 @95% confidence to $2,050,000 @80% confidence for sampling and analysis. Based on the scenarios and examples presented in this document, the cost for sampling and analysis is more than the cost for excavation.

4.2 Issues and Limitations of the Tool

The decision support tool is only as good as the inputs used in the EXCEL spreadsheets. As described below the tool has limitations and areas for improvement.

4.2.1 Waste Area Vs. Volume

MARSSIM is designed for evaluation of contaminants on surfaces and surface areas. A method is proposed to use the concepts of MARSSIM and MARSAME to relate the number of samples required at various confidence intervals for a given waste volume associated with a pipe line. Further, the assumption that the contaminated volume is restricted to 2 pipe diameters from the pipe could be significantly different than actual conditions. This situation does not account for leaking pipelines and the possible need to chase or clean up the contaminated soil associated with the leak. In some cases it might be necessary to exhume much of the waste site just to obtain the required samples. The concept for relating the number of samples to a given length of pipe is outside the scope of this study and is a topic for future evaluation.

4.2.2 Cost Parameters, Inputs, and Comparison

The costs for sampling are based on the costs to obtain the samples and analytical costs and the pipe removal costs are based primarily on excavation costs per the Statement of Work (SOW). A better comparison of sampling compared to pipe excavation and removal will rely on a more comprehensive cost evaluation. For example, sampling costs will be more realistic and comparative if the costs can be related on a per lineal foot basis. In that manner the costs of sampling can be related or compared to the costs of excavation based on a common basis, e.g., costs per foot.

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4.2.3 Excavation of Piping Less than Two Foot Diameter

Recent experience by Fluor Hanford has found that the costs of removing all types of piping 2 feet in diameter or below costs about the same, due to the physical realities of doing excavation and the fact that piping of any material of that diameter or below is easy to shear or size reduce. This experience implies that the estimate for pipes 2 feet in diameter and less (2 inches, 6 inches, 12 inches and 24 inches) can be combined into one estimate.

5. Conclusions

Choosing the statistical tool, allows for different types of statistical models to be used to evaluate the regulatory parameter of concern. The first section of this document compares a single population parameter to a regulatory value (i.e. a fixed number) or the estimation of the population parameter. If the regulatory or action-value was estimated, then a one-sample method is not appropriate and a two-sample test should be selected. For two sample tests the hypotheses considered are different from the one sided test since a comparison is used. The comparison is between the reference area characteristics and the survey area characteristics. Multiple population methods are appropriate when the comparison population of the reference area has the constituent of concern naturally present. There are six different statistical tests evaluated in this document.

The decision process starts with determining the region where relatively large decision error rates are considered tolerable. This is referred to as the gray region. The effect of varying the gray area provides a tool to determine the number of samples at different confidence interval and tolerable decision errors. The gray region is a range of values of the parameter of interest for a survey unit where the consequences of making a decision error are relatively minor. The upper bound of the gray region is set equal to the action level, and the lower bound of the gray region (LBGR) is a site-specific variable. The decision maker has the ability to select the width of the region. This section is useful at evaluating the impact of varying the decision error on the number of samples.

For the examples presented in this document, the cost to excavate vitrified clay pipe is compared to the cost for taking a number of samples at the 95 % confidence level for a 100 foot section of pipe. Excavation/removal costs range from $2,608 to $13,027 per foot for vitrified clay pipe at different depths and diameters. Results of the decision support tool for vitrified clay are summarized in Table 9 and Table 10. Sample and analysis costs to characterize a pipeline range from a few million to more than 20 million dollars. Based on the scenarios and examples presented in this document, the cost for sampling and analysis is more than the cost for excavation/removal (see section 4.1). The decision support tool can be used to predict the point at which the cost of sampling exceeds the cost for excavation.

The decision support tool provides a quick method for comparing excavation/pipe removal costs with characterization sampling and analysis costs to aid in deciding whether to remove the pipe or leave it in place. While the actual costs will be situation-specific, the generalizations in this study provide good approximations for alternative analysis and can indicate where more detailed analyses are needed. The pipe excavation estimate spreadsheet developed for this study can easily be modified to evaluate situations on a case-by-case basis and provide more detailed cost estimates. Ultimately, the decision will be influenced by factors such as regulatory requirements, stakeholder interests, safety concerns, programmatic decisions, and risk reduction in addition to cost. The decision support tool does not assign values to these factors.

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6. References

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6.8 U.S. Environmental Protection Agency, 2000. *Guidance for Data Quality Assessment, Practical Methods for Data Analysis* (EPA QA/G-9). EPA/600/R-96/084. Office of Research and Development.

6.9 Decisional Draft DOE/RL-2007-02, Rev 0, Appendix E Action Levels and DOE/RL-2002-14, Rev 1 Work Plan.

6.10 Multi-Agency Radiation Survey and Assessment of Materials and Equipment Manual (MARSAME), Draft for Comment, NUREG 1575, Supplement 1, EPA 402-R-06-002, DOE-EH-707, December 2006.

6.11 American Nuclear Standards Institute, ANSI N13.12, January 2000, Surface and Volumetric Radioactivity Guides for Materials, Equipment and Facilities to be Released for Unconditional Use.

7. Attachments

7.1 Statistical Calculations

The following pages contain a copy of the statistical spreadsheets used to determine the number of samples at various confidence intervals. The statistical tests or methods used include six tests below as described in section 2.4.

- One Sample Student t-Test
- One Sample Proportion Test
- Wilcoxon Signed Rank Test
- Two Sample Student t-Test
- Two Sample Proportion Test
- Wilcoxon Rank Sum Test

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7.1.1 One Sample Student *t*-Test

Calculations for One-Sample *t*-Test Sampling Design

User inputs are shaded areas. Null = Contaminated

For Delta = 0.31, (5% AL)		Alpha Values				
		α 1	α 2	α 3	α 4	α 5
		0.01	0.05	0.10	0.20	0.30
Beta Values	β 1 = 0.01	816	594	490	378	306
	β 2 = 0.05	596	408	323	233	177
	β 3 = 0.10	492	324	248	170	123
	β 4 = 0.20	380	234	171	107	71
	β 5 = 0.30	308	179	124	71	42

Action Level (AL)	6.20	6.20	6.20
LBGR	5.89	5.58	4.96

Delta	0.31	0.62	1.24
Delta as percent of AL	5%	10%	20%

Estimated Std Dev. 1.9

$Z_{(1-Alpha)}$	2.326348	1.644854	1.2815516	0.841621	0.524401
$0.5\ (Z_{(1-Alpha)})^2$	2.705947	1.352772	0.8211872	0.354163	0.137498
$Z_{(1-Beta)}$	2.326348	1.644854	1.2815516	0.841621	0.524401

For Delta = 0.62, (10% AL)		Alpha Values				
		α 1	α 2	α 3	α 4	α 5
		0.01	0.05	0.10	0.20	0.30
Beta Values	β 1 = 0.01	207	150	124	95	77
	β 2 = 0.05	151	103	82	59	45
	β 3 = 0.10	125	82	63	43	31
	β 4 = 0.20	97	60	44	27	18
	β 5 = 0.30	80	46	32	18	11

For Delta = 1.24, (20% AL)		Alpha Values				
		α 1	α 2	α 3	α 4	α 5
		0.01	0.05	0.10	0.20	0.30
Beta Values	β 1 = 0.01	54	39	32	24	20
	β 2 = 0.05	40	27	21	15	12
	β 3 = 0.10	34	22	17	11	8
	β 4 = 0.20	27	16	12	8	5
	β 5 = 0.30	22	13	9	5	3

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Size-Sample Equation for One-Sample *t*-Test

Null = Contaminated

$$n = \frac{s_{Total}^2 \left(z_{1-\alpha} + z_{1-\beta} \right)^2}{\Delta^2} + 0.5 z_{1-\alpha}^2$$

Values are rounded upwards (EPA 2000, p. 3-8). The equation is from (EPA 2000, p. 3-7).

	Mistakenly Concluding < Action Level				
	α = 1%	α = 5%	α = 10%	α = 20%	α = 30%
Estimated Std. Dev = 1.9	s = 1.9	s = 1.9	s = 1.9	s = 1.9	s = 1.9

Width of the Gray Region (Δ) = 0.31 (5% of AL)						
Mistakenly Concluding > = Action Level	β = 1%	816	594	490	378	306
	β = 5%	596	408	323	233	177
	β = 10%	492	324	248	170	123
	β = 20%	380	234	171	107	71
	β = 30%	308	179	124	71	42
Width of the Gray Region (Δ) = 0.62 (10% of AL)						
Mistakenly Concluding > = Action Level	β = 1%	207	150	124	95	77
	β = 5%	151	103	82	59	45
	β = 10%	125	82	63	43	31
	β = 20%	97	60	44	27	18
	β = 30%	80	46	32	18	11
Width of the Gray Region (Δ) = 1.24 (20% of AL)						
Mistakenly Concluding > = Action Level	β = 1%	54	39	32	24	20
	β = 5%	40	27	21	15	12
	β = 10%	34	22	17	11	8
	β = 20%	27	16	12	8	5
	β = 30%	22	13	9	5	3

References

EPA. 2000. *Guidance for Data Quality Assessment.*
EPA QA/G-9, U.S. Environmental Protection Agency, Washington DC.

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NULL = Contaminated

Sampling Collection and Analysis Costs

User inputs are shaded areas.

Unit Sample Collection Cost Dollars USC$	+	Unit Sample Analysis Cost Dollars USA$ (Sum)	=	AUSCSA$
$50.00	+	$11,385.00	=	$11,435.00

Definitions:

USC$ Unit sample collection cost in dollars

USA$ Unit sample analysis cost in dollars

USA$ (SUM) Unit sample analysis cost for all analytical methods in dollars

AUSCSA$ Aggregate unit sample collection and sample analysis cost in dollars

USC$ =	
$50.00	Summed from cells below
$50.00	Enter costs associated with each item for taking the sample

USA$ =	
$11,385.00	Summed from cells below
$11,385.00	Enter analytical cost for each analytical method in the cells in column C

NULL = Contaminated

Total Cost for One-Sample *t*-Test Sampling Design

Sampling-Cost Budget	$2,000,000.00

User inputs are shaded areas.

Width of Gray Region, (UBGR-LBGR)	Alpha	Beta	SD	Number of Samples, n	AUSCA $	Total Cost of Sampling Design		
0.31	1%	1%	1.9	816	$11,435.00	**$9,330,960.00**		
0.31	1%	5%	1.9	596	$11,435.00	**$6,815,260.00**	95%	confident residual contaminant meets the action level criterion
0.31	5%	1%	1.9	594	$11,435.00	**$6,792,390.00**	95%	confident residual contaminant exceeds the action level criterion
0.31	1%	10%	1.9	492	$11,435.00	**$5,626,020.00**	90%	confident residual contaminant meets the action level criterion
0.31	10%	1%	1.9	490	$11,435.00	**$5,603,150.00**	90%	confident residual contaminant exceeds the action level criterion
0.31	5%	5%	1.9	408	$11,435.00	**$4,665,480.00**	90%	5% confident volume meets the action level criterion and 5% confident exceeds
0.31	1%	20%	1.9	380	$11,435.00	**$4,345,300.00**	80%	confident residual contaminant meets the action level criterion
0.31	20%	1%	1.9	378	$11,435.00	**$4,322,430.00**	80%	confident residual contaminant exceeds the action level criterion
0.31	10%	5%	1.9	323	$11,435.00	**$3,693,505.00**	85%	10% confident volume exceeds the action level criterion and 5% confident volume meets criterion
0.31	5%	10%	1.9	324	$11,435.00	**$3,704,940.00**	85%	5% confident volume exceeds the action level criterion and 10% confident volume meets criterion
0.31	1%	30%	1.9	308	$11,435.00	**$3,521,980.00**		
0.31	30%	1%	1.9	306	$11,435.00	**$3,499,110.00**		
0.31	10%	10%	1.9	248	$11,435.00	**$2,835,880.00**	80%	10% confident volume exceeds the action level criterion and 10% confident volume meets criterion
0.31	5%	20%	1.9	234	$11,435.00	**$2,675,790.00**		
0.31	20%	5%	1.9	233	$11,435.00	**$2,664,355.00**		
0.62	1%	1%	1.9	207	$11,435.00	**$2,367,045.00**		
0.31	5%	30%	1.9	179	$11,435.00	**$2,046,865.00**		
0.31	30%	5%	1.9	177	$11,435.00	**$2,023,995.00**		
0.31	20%	10%	1.9	170	$11,435.00	**$1,943,950.00**		
0.31	10%	20%	1.9	171	$11,435.00	**$1,955,385.00**		
0.62	1%	5%	1.9	151	$11,435.00	**$1,726,685.00**	95%	confident residual contaminant meets the action level criterion
0.62	5%	1%	1.9	150	$11,435.00	**$1,715,250.00**	95%	confident residual contaminant exceeds the action level criterion
0.31	10%	30%	1.9	124	$11,435.00	**$1,417,940.00**		
0.31	30%	10%	1.9	123	$11,435.00	**$1,406,505.00**		
0.62	1%	10%	1.9	125	$11,435.00	**$1,429,375.00**	90%	confident residual contaminant meets the action level criterion
0.62	10%	1%	1.9	124	$11,435.00	**$1,417,940.00**	90%	confident residual contaminant exceeds the action level criterion
0.31	20%	20%	1.9	107	$11,435.00	**$1,223,545.00**		

0.62	5%	5%	1.9	103	$11,435.00	**$1,177,805.00**	90%	5% confident volume meets the action level criterion and 5% confident volume exceeds criterion
0.62	1%	20%	1.9	97	$11,435.00	**$1,109,195.00**	80%	confident residual contaminant meets the action level criterion
0.62	20%	1%	1.9	95	$11,435.00	**$1,086,325.00**	80%	confident residual contaminant exceeds the action level criterion
0.62	10%	5%	1.9	82	$11,435.00	**$937,670.00**	85%	10% confident volume exceeds criterion and 5% confident volume meets criterion
0.62	5%	10%	1.9	82	$11,435.00	**$937,670.00**	85%	5% confident volume exceeds the action level criterion and 10% confident volume meets criterion
0.62	1%	30%	1.9	80	$11,435.00	**$914,800.00**		
0.62	30%	1%	1.9	77	$11,435.00	**$880,495.00**		
0.31	30%	20%	1.9	71	$11,435.00	**$811,885.00**		
0.31	20%	30%	1.9	71	$11,435.00	**$811,885.00**		
0.62	10%	10%	1.9	63	$11,435.00	**$720,405.00**	80%	10% confident volume exceeds the action level criterion and 10% confident volume meets criterion
0.62	5%	20%	1.9	60	$11,435.00	**$686,100.00**		
0.62	20%	5%	1.9	59	$11,435.00	**$674,665.00**		
1.24	1%	1%	1.9	54	$11,435.00	**$617,490.00**		
0.62	5%	30%	1.9	46	$11,435.00	**$526,010.00**		
0.62	30%	5%	1.9	45	$11,435.00	**$514,575.00**		
0.62	20%	10%	1.9	43	$11,435.00	**$491,705.00**		
0.62	10%	20%	1.9	44	$11,435.00	**$503,140.00**		
0.31	30%	30%	1.9	42	$11,435.00	**$480,270.00**		
1.24	1%	5%	1.9	40	$11,435.00	**$457,400.00**	95%	confident residual contaminant meets the action level criterion
1.24	5%	1%	1.9	39	$11,435.00	**$445,965.00**	95%	confident residual contaminant exceeds the action level criterion
1.24	1%	10%	1.9	34	$11,435.00	**$388,790.00**	90%	confident residual contaminant meets the action level criterion
0.62	30%	10%	1.9	31	$11,435.00	**$354,485.00**		
0.62	10%	30%	1.9	32	$11,435.00	**$365,920.00**		
1.24	10%	1%	1.9	32	$11,435.00	**$365,920.00**	90%	confident residual contaminant exceeds the action level criterion
0.62	20%	20%	1.9	27	$11,435.00	**$308,745.00**		
1.24	5%	5%	1.9	27	$11,435.00	**$308,745.00**	90%	5% confident volume meets the action level criterion and 5% confident volume exceeds criterion
1.24	1%	20%	1.9	27	$11,435.00	**$308,745.00**	80%	confident residual contaminant meets the action level criterion
1.24	20%	1%	1.9	24	$11,435.00	**$274,440.00**	80%	confident residual contaminant exceeds the action level criterion
1.24	5%	10%	1.9	22	$11,435.00	**$251,570.00**		
1.24	10%	5%	1.9	21	$11,435.00	**$240,135.00**	85%	5% confident volume exceeds the action level criterion and 10% confident volume meets criterion
1.24	1%	30%	1.9	22	$11,435.00	**$251,570.00**	85%	10% confident volume exceeds criterion and 5% confident volume meets criterion
1.24	30%	1%	1.9	20	$11,435.00	**$228,700.00**		
0.62	30%	20%	1.9	18	$11,435.00	**$205,830.00**		
0.62	20%	30%	1.9	18	$11,435.00	**$205,830.00**		
1.24	10%	10%	1.9	17	$11,435.00	**$194,395.00**	80%	10% confident volume exceeds the action level criterion and 10% confident volume meets criterion
1.24	5%	20%	1.9	16	$11,435.00	**$182,960.00**		

1.24	20%	5%	1.9	15	$11,435.00	**$171,525.00**
1.24	5%	30%	1.9	13	$11,435.00	**$148,655.00**
1.24	30%	5%	1.9	12	$11,435.00	**$137,220.00**
1.24	20%	10%	1.9	11	$11,435.00	**$125,785.00**
1.24	10%	20%	1.9	12	$11,435.00	**$137,220.00**
0.62	30%	30%	1.9	11	$11,435.00	**$125,785.00**
1.24	10%	30%	1.9	9	$11,435.00	**$102,915.00**
1.24	30%	10%	1.9	8	$11,435.00	**$91,480.00**
1.24	20%	20%	1.9	8	$11,435.00	**$91,480.00**
1.24	20%	30%	1.9	5	$11,435.00	**$57,175.00**
1.24	30%	20%	1.9	5	$11,435.00	**$57,175.00**
1.24	30%	30%	1.9	3	$11,435.00	**$34,305.00**

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7.1.2 One Sample Proportion Test

Calculations for One-Sample Proportion Test Sampling Design

User inputs are shaded areas. Null = Contaminated

For Delta = 0.04, (10% AL)		Alpha Values					$Z_{(1-Beta)}$
		α 1	α 2	α 3	α 4	α 5	
		0.01	0.05	0.10	0.20	0.30	
Beta Values	β 1 = 0.01	3182	2310	1902	1462	1180	2.326348
	β 2 = 0.05	2327	1591	1256	903	685	1.644854
	β 3 = 0.10	1925	1262	966	660	476	1.281552
	β 4 = 0.20	1490	915	666	417	273	0.841621
	β 5 = 0.30	1210	699	484	276	162	0.524401

Action Level (AL)	0.40	0.40	0.40
LBGR	0.36	0.32	0.28

Delta		0.04	0.08	0.12	
Delta as percent of AL		10%	20%	30%	
$Sqrt(P_0(1 - P_0))$	0.489898	0.489898	0.4898979		
$Sqrt(P_1(1 - P_1))$	0.48	0.466476	0.4489989		
$Z_{(1-Alpha)}$	2.326348	1.644854	1.2815516	0.841621	0.524401

For Delta = 0.08, (20% AL)		Alpha Values					$Z_{(1-Beta)}$
		α 1	α 2	α 3	α 4	α 5	
		0.01	0.05	0.10	0.20	0.30	
Beta Values	β 1 = 0.01	774	559	459	351	282	2.326348
	β 2 = 0.05	569	387	305	218	164	1.644854
	β 3 = 0.10	472	308	235	160	115	1.281552
	β 4 = 0.20	367	225	163	102	66	0.841621
	β 5 = 0.30	300	173	119	68	40	0.524401

For Delta = 0.08, (30% AL)		Alpha Values					$Z_{(1-Beta)}$
		α 1	α 2	α 3	α 4	α 5	
		0.01	0.05	0.10	0.20	0.30	
Beta Values	β 1 = 0.01	332	238	195	148	118	2.326348
	β 2 = 0.05	245	166	130	92	69	1.644854
	β 3 = 0.10	205	133	101	68	49	1.281552
	β 4 = 0.20	160	98	71	44	28	0.841621
	β 5 = 0.30	132	76	52	30	17	0.524401

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Size-Sample Equation for One-Sample Proportion Test

$$n = \left(\frac{z_{1-\alpha}\sqrt{P_0(1-P_0)} + z_{1-\beta}\sqrt{P_1(1-P_1)}}{P_1 - P_0} \right)^2$$

Null = Contaminated

Values are rounded upwards (EPA 2000, p. 3-8). The equation is from (EPA 2000, p. 3-19).

		Mistakenly Concluding < Action Level				
		α = 1%	α = 5%	α = 10%	α = 20%	α = 30%
Width of the Gray Region (Δ) = 0.04 (10% of AL)						
Mistakenly Concluding > = Action Level	β = 1%	3182	2310	1902	1462	1180
	β = 5%	2327	1591	1256	903	685
	β = 10%	1925	1262	966	660	476
	β = 20%	1490	915	666	417	273
	β = 30%	1210	699	484	276	162
Width of the Gray Region (Δ) = 0.08 (20% of AL)						
Mistakenly Concluding > = Action Level	β = 1%	774	559	459	351	282
	β = 5%	569	387	305	218	164
	β = 10%	472	308	235	160	115
	β = 20%	367	225	163	102	66
	β = 30%	300	173	119	68	40
Width of the Gray Region (Δ) = 0.12 (30% of AL)						
Mistakenly Concluding > = Action Level	β = 1%	332	238	195	148	118
	β = 5%	245	166	130	92	69
	β = 10%	205	133	101	68	49
	β = 20%	160	98	71	44	28
	β = 30%	132	76	52	30	17

References

EPA. 2000. *Guidance for Data Quality Assessment.*
EPA QA/G-9, U.S. Environmental Protection Agency, Washington DC.

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NULL = Contaminated

Sampling Collection and Analysis Costs

User inputs are shaded areas.

Unit Sample Collection Cost Dollars		Unit Sample Analysis Cost Dollars		
USC$	**+**	**USA$ (Sum)**	**=**	**AUSCSA$**
$50.00	+	$11,385.00	=	**$11,435.00**

Definitions:

USC$ Unit sample collection cost in dollars
USA$ Unit sample analysis cost in dollars
USA$ (SUM) Unit sample analysis cost for all analytical methods in dollars
AUSCSA$ Aggregate unit sample collection and sample analysis cost in dollars

USC$ =	$50.00	Summed from cells below
	$50.00	Enter costs associated with each item for taking the sample

USA$ =	$11,385.00	Summed from cells below
	$11,385.00	Enter analytical cost for each analytical method in the cells in column C

NULL = Contaminated

Total Cost for One-Sample Proportion Test Sampling Design

Sampling-Cost Budget	$2,000,000.00

User inputs are shaded areas.

Width of Gray Region, (UBGR-LBGR)	Alpha	Beta	Number of Samples, n	AUSCA $	Total Cost of Sampling Design		
0.04	1%	1%	3182	$11,435.00	**$36,386,170.00**		
0.04	1%	5%	2327	$11,435.00	**$26,609,245.00**	95%	confident residual contaminant meets the action level criterion
0.04	5%	1%	2310	$11,435.00	**$26,414,850.00**	95%	confident residual contaminant exceeds the action level criterion
0.04	1%	10%	1925	$11,435.00	**$22,012,375.00**	90%	confident residual contaminant meets the action level criterion
0.04	10%	1%	1902	$11,435.00	**$21,749,370.00**	90%	confident residual contaminant exceeds the action level criterion
0.04	5%	5%	1591	$11,435.00	**$18,193,085.00**	90%	5% confident volume meets action level criterion and 5% confident volume exceeds criteric
0.04	1%	20%	1490	$11,435.00	**$17,038,150.00**	80%	confident residual contaminant meets the action level criterion
0.04	20%	1%	1462	$11,435.00	**$16,717,970.00**	80%	confident residual contaminant exceeds the action level criterion
0.04	5%	10%	1262	$11,435.00	**$14,430,970.00**	85%	5% confident vol. exceeds action level criterion and 10% confident volume meets criterion
0.04	10%	5%	1256	$11,435.00	**$14,362,360.00**	85%	10% confident vol. exceeds action level criterion and 5% confident volume meets criterion
0.04	1%	30%	1210	$11,435.00	**$13,836,350.00**		
0.04	30%	1%	1180	$11,435.00	**$13,493,300.00**		
0.04	10%	10%	966	$11,435.00	**$11,046,210.00**	80%	10% confident vol. exceeds action level criterion and 10% confident volume meets criterior
0.04	5%	20%	915	$11,435.00	**$10,463,025.00**		
0.04	20%	5%	903	$11,435.00	**$10,325,805.00**		
0.08	1%	1%	774	$11,435.00	**$8,850,690.00**		
0.04	5%	30%	699	$11,435.00	**$7,993,065.00**		
0.04	30%	5%	685	$11,435.00	**$7,832,975.00**		
0.04	10%	20%	666	$11,435.00	**$7,615,710.00**		
0.04	20%	10%	660	$11,435.00	**$7,547,100.00**		
0.08	1%	5%	569	$11,435.00	**$6,506,515.00**	95%	confident residual contaminant meets the action level criterion
0.08	5%	1%	559	$11,435.00	**$6,392,165.00**	95%	confident residual contaminant exceeds the action level criterion
0.04	10%	30%	484	$11,435.00	**$5,534,540.00**		
0.04	30%	10%	476	$11,435.00	**$5,443,060.00**		
0.08	1%	10%	472	$11,435.00	**$5,397,320.00**	90%	confident residual contaminant meets the action level criterion
0.08	10%	1%	459	$11,435.00	**$5,248,665.00**	90%	confident residual contaminant exceeds the action level criterion
0.04	20%	20%	417	$11,435.00	**$4,768,395.00**		

0.04	20%	20%	417	$11,435.00	$4,768,395.00		
0.08	5%	5%	387	$11,435.00	$4,425,345.00	90%	5% confident vol. meets action level criterion and 5% confident volume exceeds criterion
0.08	1%	20%	367	$11,435.00	$4,196,645.00	80%	confident residual contaminant meets the action level criterion
0.08	20%	1%	351	$11,435.00	$4,013,685.00	80%	confident residual contaminant exceeds the action level criterion
0.12	1%	1%	332	$11,435.00	$3,796,420.00		
0.08	5%	10%	308	$11,435.00	$3,521,980.00	85%	5% confident vol. exceeds action level criterion and 10% confident volume meets criterio
0.08	1%	30%	300	$11,435.00	$3,430,500.00		
0.08	10%	5%	305	$11,435.00	$3,487,675.00	85%	10% confident vol. exceeds action level criterion and 5% confident volume meets criterio
0.04	20%	30%	276	$11,435.00	$3,156,060.00		
0.04	30%	20%	273	$11,435.00	$3,121,755.00		
0.08	30%	1%	282	$11,435.00	$3,224,670.00		
0.12	1%	5%	245	$11,435.00	$2,801,575.00	95%	confident residual contaminant meets the action level criterion
0.08	10%	10%	235	$11,435.00	$2,687,225.00	80%	10% confident vol. exceeds action level criterion and 10% confident vol. meets criterion
0.12	5%	1%	238	$11,435.00	$2,721,530.00	95%	confident residual contaminant exceeds the action level criterion
0.08	5%	20%	225	$11,435.00	$2,572,875.00		
0.08	20%	5%	218	$11,435.00	$2,492,830.00		
0.12	1%	10%	205	$11,435.00	$2,344,175.00	90%	confident residual contaminant meets the action level criterion
0.12	10%	1%	195	$11,435.00	$2,229,825.00	90%	confident residual contaminant exceeds the action level criterion
0.08	5%	30%	173	$11,435.00	$1,978,255.00		
0.04	30%	30%	162	$11,435.00	$1,852,470.00		
0.08	10%	20%	163	$11,435.00	$1,863,905.00		
0.12	5%	5%	166	$11,435.00	$1,898,210.00	90%	5% confident vol. meets action level criterion and 5% confident volume exceeds criterion
0.12	1%	20%	160	$11,435.00	$1,829,600.00	80%	confident residual contaminant meets the action level criterion
0.08	30%	5%	164	$11,435.00	$1,875,340.00		
0.08	20%	10%	160	$11,435.00	$1,829,600.00		
0.12	20%	1%	148	$11,435.00	$1,692,380.00	80%	confident residual contaminant exceeds the action level criterion
0.12	1%	30%	132	$11,435.00	$1,509,420.00		
0.12	5%	10%	133	$11,435.00	$1,520,855.00	85%	5% confident vol. exceeds action level criterion and 10% confident vol. meets criterion
0.12	10%	5%	130	$11,435.00	$1,486,550.00	85%	10% confident vol. exceeds action level criterion and 5% confident vol. meets criterion
0.08	10%	30%	119	$11,435.00	$1,360,765.00		
0.08	30%	10%	115	$11,435.00	$1,315,025.00		
0.12	30%	1%	118	$11,435.00	$1,349,330.00		
0.08	20%	20%	102	$11,435.00	$1,166,370.00		
0.12	10%	10%	101	$11,435.00	$1,154,935.00	80%	10% confident vol. exceeds action level criterion and 10% confident vol. meets criterion
0.12	5%	20%	98	$11,435.00	$1,120,630.00		

0.12	10%	20%	71	$11,435.00	**$811,885.00**
0.08	20%	30%	68	$11,435.00	**$777,580.00**
0.12	30%	5%	69	$11,435.00	**$789,015.00**
0.12	20%	10%	68	$11,435.00	**$777,580.00**
0.08	30%	20%	66	$11,435.00	**$754,710.00**
0.12	10%	30%	52	$11,435.00	**$594,620.00**
0.12	30%	10%	49	$11,435.00	**$560,315.00**
0.12	20%	20%	44	$11,435.00	**$503,140.00**
0.08	30%	30%	40	$11,435.00	**$457,400.00**
0.12	20%	30%	30	$11,435.00	**$343,050.00**
0.12	30%	20%	28	$11,435.00	**$320,180.00**
0.12	30%	30%	17	$11,435.00	**$194,395.00**

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7.1.3 Wilcoxon Sign Test

Calculations for MARSSIM Sign Test Sampling Design

User inputs are shaded areas. Null = Contaminated

For Delta – 0.31, (5 % AL)		Alpha Values					$Z_{(1-Beta)}$
		α 1	α 2	α 3	α 4	α 5	
		0.01	0.05	0.10	0.20	0.30	
Beta Values	β 1 = 0.01	1547	1127	930	718	581	2.326348
	β 2 = 0.05	1127	774	612	443	338	1.644854
	β 3 = 0.10	930	612	471	323	234	1.281552
	β 4 = 0.20	718	443	323	203	135	0.841621
	β 5 = 0.30	581	338	234	135	80	0.524401

Action Level (AL)	6.20	6.20	6.20
LBGR	5.89	5.58	4.96

Delta	0.31	0.62	1.24
Delta as percent of AL	5%	10%	20%
Estimated Std Dev.	1.9		
Inflation %	20%	MARSSIM default is 20%	

$Z_{(1-Alpha)}$	2.326348	1.644854	1.2815516	0.841621	0.52440
Sign P	0.564803	0.627907	0.743003		

For Delta = 0.62, (10 % AL)		Alpha Values					$Z_{(1-Beta)}$
		α 1	α 2	α 3	α 4	α 5	
		0.01	0.05	0.10	0.20	0.30	
Beta Values	β 1 = 0.01	398	290	239	185	150	2.326348
	β 2 = 0.05	290	200	158	114	87	1.644854
	β 3 = 0.10	239	158	122	83	60	1.281552
	β 4 = 0.20	185	114	83	53	35	0.841621
	β 5 = 0.30	150	87	60	35	21	0.524401

For Delta = 1.24, (20% AL)		Alpha Values					$Z_{(1-Beta)}$
		α 1	α 2	α 3	α 4	α 5	
		0.01	0.05	0.10	0.20	0.30	
Beta Values	β 1 = 0.01	111	81	68	52	42	2.326348
	β 2 = 0.05	81	56	45	33	24	1.644854
	β 3 = 0.10	68	45	34	24	17	1.281552
	β 4 = 0.20	52	33	24	15	10	0.841621
	β 5 = 0.30	42	24	17	10	6	0.524401

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Size-Sample Equation for MARSSIM Sign Test

Null = Contaminated

$$n = \frac{\left(z_{1-\alpha} + z_{1-\beta}\right)^2}{4\left(Sign\ P - 0.5\right)^2} \text{ where } Sign\ P = \Phi\left(\frac{\Delta}{s_{Total}}\right)$$

where Φ is the cummulative stand. norm. dist. function.

Values are rounded upwards (EPA 2000, p. 3-8). The equation is from (EPA 2000, p. 5-33).

	Mistakenly Concluding < Action Level				
	α = 1%	α = 5%	α = 10%	α = 20%	α = 30%
Estimated Std. Dev = 1.9	s = 1.9	s = 1.9	s = 1.9	s = 1.9	s = 1.9

Width of the Gray Region (Δ) = 0.31 (5% of AL)						
Mistakenly Concluding > = Action Level	β = 1%	1547	1127	930	718	581
	β = 5%	1127	774	612	443	338
	β = 10%	930	612	471	323	234
	β = 20%	718	443	323	203	135
	β = 30%	581	338	234	135	80
Width of the Gray Region (Δ) = 0.62 (10% of AL)						
Mistakenly Concluding > = Action Level	β = 1%	398	290	239	185	150
	β = 5%	290	200	158	114	87
	β = 10%	239	158	122	83	60
	β = 20%	185	114	83	53	35
	β = 30%	150	87	60	35	21
Width of the Gray Region (Δ) = 1.24 (20% of AL)						
Mistakenly Concluding > = Action Level	β = 1%	111	81	68	52	42
	β = 5%	81	56	45	33	24
	β = 10%	68	45	34	24	17
	β = 20%	52	33	24	15	10
	β = 30%	42	24	17	10	6

References

EPA. 2000. *Guidance for Data Quality Assessment.*
PA QA/G-9, U.S. Environmental Protection Agency, Washington DC.

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NULL = Contaminated

Sampling Collection and Analysis Costs

User inputs are shaded areas.

Unit Sample Collection Cost Dollars USC$	+	Unit Sample Analysis Cost Dollars USA$ (Sum)	=	AUSCSA$
$50.00	+	$11,385.00	=	**$11,435.00**

Definitions:

USC$ Unit sample collection cost in dollars
USA$ Unit sample analysis cost in dollars
USA$ (SUM) Unit sample analysis cost for all analytical methods in dollars
AUSCSA$ Aggregate unit sample collection and sample analysis cost in dollars

USC$ =	$50.00	Summed from cells below
	$50.00	Enter costs associated with each item for taking the sample

USA$ =	$11,385.00	Summed from cells below
	$11,385.00	Enter analytical cost for each analytical method in the cells in column C

NULL = Contaminated

Total Cost for MARSSIM Sign Test Sampling Design

Sampling-Cost Budget $2,000,000.00

User inputs are shaded areas.

Width of Gray Region, (UBGR-LBGR)	Alpha	Beta	SD	Number of Samples, n	AUSCA $	Total Cost of Sampling Design		
0.31	1%	1%	1.9	1547	$11,435.00	$17,689,945.00		
0.31	1%	5%	1.9	1127	$11,435.00	$12,887,245.00	95%	confident residual contaminant meets the action level criterion
0.31	5%	1%	1.9	1127	$11,435.00	$12,887,245.00	95%	confident residual contaminant exceeds the action level criterion
0.31	1%	10%	1.9	930	$11,435.00	$10,634,550.00	90%	confident residual contaminant exceeds the action level criterion
0.31	10%	1%	1.9	930	$11,435.00	$10,634,550.00	90%	confident residual contaminant meets the action level criterion
0.31	5%	5%	1.9	774	$11,435.00	$8,850,690.00	90%	5% confident volume meets the action level criterion and 5% confident volume exceeds cr
0.31	1%	20%	1.9	718	$11,435.00	$8,210,330.00	80%	confident residual contaminant exceeds the action level criterion
0.31	20%	1%	1.9	718	$11,435.00	$8,210,330.00	80%	confident residual contaminant meets the action level criterion
0.31	5%	10%	1.9	612	$11,435.00	$6,998,220.00	85%	5% confident volume exceeds the action level criterion and 10% confident volume meets
0.31	10%	5%	1.9	612	$11,435.00	$6,998,220.00	85%	10% confident volume exceeds the action level criterion and 5% confident volume meets
0.31	1%	30%	1.9	581	$11,435.00	$6,643,735.00		
0.31	30%	1%	1.9	581	$11,435.00	$6,643,735.00		
0.31	10%	10%	1.9	471	$11,435.00	$5,385,885.00	80%	10% confident volume exceeds the action level criterion and 10% confident volume meets
0.31	5%	20%	1.9	443	$11,435.00	$5,065,705.00		
0.31	20%	5%	1.9	443	$11,435.00	$5,065,705.00		
0.62	1%	1%	1.9	398	$11,435.00	$4,551,130.00		
0.31	5%	30%	1.9	338	$11,435.00	$3,865,030.00		
0.31	30%	5%	1.9	338	$11,435.00	$3,865,030.00		
0.31	10%	20%	1.9	323	$11,435.00	$3,693,505.00		
0.31	20%	10%	1.9	323	$11,435.00	$3,693,505.00		
0.62	1%	5%	1.9	290	$11,435.00	$3,316,150.00	95%	confident residual contaminant meets the action level criterion
0.62	5%	1%	1.9	290	$11,435.00	$3,316,150.00	95%	confident residual contaminant exceeds the action level criterion
0.62	1%	10%	1.9	239	$11,435.00	$2,732,965.00	90%	confident residual contaminant meets the action level criterion
0.31	10%	30%	1.9	234	$11,435.00	$2,675,790.00		
0.62	10%	1%	1.9	239	$11,435.00	$2,732,965.00	90%	confident residual contaminant exceeds the action level criterion
0.31	30%	10%	1.9	234	$11,435.00	$2,675,790.00		
0.31	20%	20%	1.9	203	$11,435.00	$2,321,305.00		
0.62	5%	5%	1.9	200	$11,435.00	$2,287,000.00	90%	5% confident volume meets the action level criterion and 5% confident volume exceeds cr

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0.62	5%	5%	1.9	200	$11,435.00	**$2,287,000.00**	90%	5% confident vol. meets action level criterion and 5% confident vol. exceeds criterion
0.62	1%	20%	1.9	185	$11,435.00	**$2,115,475.00**	80%	confident residual contaminant meets the action level criterion
0.62	20%	1%	1.9	185	$11,435.00	**$2,115,475.00**	80%	confident residual contaminant exceeds the action level criterion
0.62	5%	10%	1.9	158	$11,435.00	**$1,806,730.00**	85%	5% confident vol. exceeds action level criterion and 10% confident vol. meets criterion
0.62	10%	5%	1.9	158	$11,435.00	**$1,806,730.00**	85%	10% confident vol. exceeds action level criterion and 5% confident vol. meets criterion
0.62	1%	30%	1.9	150	$11,435.00	**$1,715,250.00**		
0.62	30%	1%	1.9	150	$11,435.00	**$1,715,250.00**		
0.31	20%	30%	1.9	135	$11,435.00	**$1,543,725.00**		
0.31	30%	20%	1.9	135	$11,435.00	**$1,543,725.00**		
0.62	10%	10%	1.9	122	$11,435.00	**$1,395,070.00**	80%	10% confident vol. exceeds action level criterion and 10% confident vol. meets criterion
0.62	5%	20%	1.9	114	$11,435.00	**$1,303,590.00**		
0.62	20%	5%	1.9	114	$11,435.00	**$1,303,590.00**		
1.24	1%	1%	1.9	111	$11,435.00	**$1,269,285.00**		
0.62	5%	30%	1.9	87	$11,435.00	**$994,845.00**		
0.62	30%	5%	1.9	87	$11,435.00	**$994,845.00**		
0.62	10%	20%	1.9	83	$11,435.00	**$949,105.00**		
0.62	20%	10%	1.9	83	$11,435.00	**$949,105.00**		
0.31	30%	30%	1.9	80	$11,435.00	**$914,800.00**		
1.24	1%	5%	1.9	81	$11,435.00	**$926,235.00**	95%	confident residual contaminant meets the action level criterion
1.24	5%	1%	1.9	81	$11,435.00	**$926,235.00**	95%	confident residual contaminant exceeds the action level criterion
1.24	1%	10%	1.9	68	$11,435.00	**$777,580.00**	90%	confident residual contaminant meets the action level criterion
0.62	10%	30%	1.9	60	$11,435.00	**$686,100.00**		
1.24	10%	1%	1.9	68	$11,435.00	**$777,580.00**	90%	confident residual contaminant exceeds the action level criterion
0.62	30%	10%	1.9	60	$11,435.00	**$686,100.00**		
1.24	1%	20%	1.9	52	$11,435.00	**$594,620.00**	80%	confident residual contaminant meets the action level criterion
1.24	5%	5%	1.9	56	$11,435.00	**$640,360.00**	90%	5% confident vol. meets action level criterion and 5% confident vol. exceeds criterion
0.62	20%	20%	1.9	53	$11,435.00	**$606,055.00**		
1.24	20%	1%	1.9	52	$11,435.00	**$594,620.00**	80%	confident residual contaminant exceeds the action level criterion
1.24	1%	30%	1.9	42	$11,435.00	**$480,270.00**		
1.24	5%	10%	1.9	45	$11,435.00	**$514,575.00**	85%	5% confident vol. exceeds action level criterion and 10% confident vol. meets criterion
1.24	10%	5%	1.9	45	$11,435.00	**$514,575.00**	85%	10% confident vol. exceeds action level criterion and 5% confident vol. meets criterion
1.24	30%	1%	1.9	42	$11,435.00	**$480,270.00**		
0.62	20%	30%	1.9	35	$11,435.00	**$400,225.00**		
0.62	30%	20%	1.9	35	$11,435.00	**$400,225.00**		
1.24	10%	10%	1.9	34	$11,435.00	**$388,790.00**	80%	10% confident vol. exceeds action level criterion and 10% confident vol. meets criterion
1.24	5%	20%	1.9	33	$11,435.00	**$377,355.00**		

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1.24	5%	30%	1.9	24	$11,435.00	$274,440.00
1.24	10%	20%	1.9	24	$11,435.00	$274,440.00
1.24	30%	5%	1.9	24	$11,435.00	$274,440.00
1.24	20%	10%	1.9	24	$11,435.00	$274,440.00
0.62	30%	30%	1.9	21	$11,435.00	$240,135.00
1.24	10%	30%	1.9	17	$11,435.00	$194,395.00
1.24	30%	10%	1.9	17	$11,435.00	$194,395.00
1.24	20%	20%	1.9	15	$11,435.00	$171,525.00
1.24	20%	30%	1.9	10	$11,435.00	$114,350.00
1.24	30%	20%	1.9	10	$11,435.00	$114,350.00
1.24	30%	30%	1.9	6	$11,435.00	$68,610.00

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7.1.4 Two Sample Student *t*-Test

Calculations for Two-Sample *t*-Test Sampling Design

User inputs are shaded areas.

Null = Contaminated

For Delta = 0.31, (5% AL)		Alpha Values				
		α 1	α 2	α 3	α 4	α 5
		0.01	0.05	0.10	0.20	0.30
Beta Values	β 1 = 0.01	1628	1186	979	755	611
	β 2 = 0.05	1187	814	644	465	354
	β 3 = 0.10	980	645	494	339	246
	β 4 = 0.20	756	466	340	214	141
	β 5 = 0.30	612	355	246	141	83

Action Level (AL)	6.20	6.20	6.20
LBGR	5.89	5.58	4.96

Delta	0.31	0.62	1.24
Delta as percent of AL	5%	10%	20%

Estimated Std Dev. 1.9

$Z_{(1-Alpha)}$	2.326348	1.644854	1.2815516	0.841621	0.524401
$0.5\ (Z_{(1-Alpha)})^2$	2.705947	1.352772	0.8211872	0.354163	0.137498
$Z_{(1-Beta)}$	2.326348	1.644854	1.2815516	0.841621	0.524401

For Delta = 0.62, (10% AL)		Alpha Values				
		α 1	α 2	α 3	α 4	α 5
		0.01	0.05	0.10	0.20	0.30
Beta Values	β 1 = 0.01	408	297	245	189	153
	β 2 = 0.05	298	204	162	117	89
	β 3 = 0.10	246	162	124	85	62
	β 4 = 0.20	190	117	86	54	36
	β 5 = 0.30	154	90	62	36	21

For Delta = 1.24, (20% AL)		Alpha Values				
		α 1	α 2	α 3	α 4	α 5
		0.01	0.05	0.10	0.20	0.30
Beta Values	β 1 = 0.01	104	75	62	48	39
	β 2 = 0.05	76	52	41	30	23
	β 3 = 0.10	63	41	32	22	16
	β 4 = 0.20	49	30	22	14	9
	β 5 = 0.30	40	23	16	9	6

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Size-Sample Equation for Two-Sample *t*-Test

Null = Contaminated

$$m = n = \frac{2s_{total}^2\left(z_{1-\alpha} + z_{1-\beta}\right)^2}{\Delta^2} + 0.25z_{1-\alpha}^2$$

Values are rounded upwards (EPA 2000, p. 3-8). The equation is from (EPA 2000, p. 3-24.

	Mistakenly Concluding < Action Level				
	α = 1%	α = 5%	α = 10%	α = 20%	α = 30%
Estimated Std. Dev = 1.9	s = 1.9	s = 1.9	s = 1.9	s = 1.9	s = 1.9

Width of the Gray Region (Δ) = 0.31 (5% of AL)						
Mistakenly Concluding > = Action Level	β = 1%	1628	1186	979	755	611
	β = 5%	1187	814	644	465	354
	β = 10%	980	645	494	339	246
	β = 20%	756	466	340	214	141
	β = 30%	612	355	246	141	83
Width of the Gray Region (Δ) = 0.62 (10% of AL)						
Mistakenly Concluding > = Action Level	β = 1%	408	297	245	189	153
	β = 5%	298	204	162	117	89
	β = 10%	246	162	124	85	62
	β = 20%	190	117	86	54	36
	β = 30%	154	90	62	36	21
Width of the Gray Region (Δ) = 1.24 (20% of AL)						
Mistakenly Concluding > = Action Level	β = 1%	104	75	62	48	39
	β = 5%	76	52	41	30	23
	β = 10%	63	41	32	22	16
	β = 20%	49	30	22	14	9
	β = 30%	40	23	16	9	6

References

EPA. 2000. *Guidance for Data Quality Assessment.*
EPA QA/G-9, U.S. Environmental Protection Agency, Washington DC.

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NULL = Contaminated

Sampling Collection and Analysis Costs

User inputs are shaded areas.

Unit Sample Collection Cost Dollars USC$	+	Unit Sample Analysis Cost Dollars USA$ (Sum)	=	AUSCSA$
$50.00	+	$11,385.00	=	**$11,435.00**

Definitions:

USC$ Unit sample collection cost in dollars

USA$ Unit sample analysis cost in dollars

USA$ (SUM) Unit sample analysis cost for all analytical methods in dollars

AUSCSA$ Aggregate unit sample collection and sample analysis cost in dollars

USC$ =	
$50.00	Summed from cells below
$50.00	Enter costs associated with each item for taking the sample

USA$ =	
$11,385.00	Summed from cells below
$11,385.00	Enter analytical cost for each analytical method in the cells in column C

NULL = Contaminated

Total Cost for Two-Sample *t*-Test Sampling Design

Sampling-Cost Budget: $2,000,000.00

User inputs are shaded areas.

Width of Gray Region, (UBGR-LBGR)	Alpha	Beta	SD	Number of Samples, n	AUSCA $	Total Cost of Sampling Design		
0.31	1%	1%	1.9	1628	$11,435.00	$18,616,180.00		
0.31	1%	5%	1.9	1187	$11,435.00	$13,573,345.00	95%	confident residual contaminant meets the action level criterion
0.31	5%	1%	1.9	1186	$11,435.00	$13,561,910.00	95%	confident residual contaminant exceeds the action level criterion
0.31	1%	10%	1.9	980	$11,435.00	$11,206,300.00	90%	confident residual contaminant meets the action level criterion
0.31	10%	1%	1.9	979	$11,435.00	$11,194,865.00	90%	confident residual contaminant exceeds the action level criterion
0.31	5%	5%	1.9	814	$11,435.00	$9,308,090.00	90%	5% confident vol. meets action level criterion and 5% confident volume exceeds criterion
0.31	1%	20%	1.9	756	$11,435.00	$8,644,860.00	80%	confident residual contaminant meets the action level criterion
0.31	20%	1%	1.9	755	$11,435.00	$8,633,425.00	80%	confident residual contaminant exceeds the action level criterion
0.31	5%	10%	1.9	645	$11,435.00	$7,375,575.00	85%	10% confident vol. exceeds action level criterion and 5% confident volume meets criterion
0.31	10%	5%	1.9	644	$11,435.00	$7,364,140.00	85%	5% confident vol. exceeds action level criterion and 10% confident volume meets criterion
0.31	1%	30%	1.9	612	$11,435.00	$6,998,220.00		
0.31	30%	1%	1.9	611	$11,435.00	$6,986,785.00		
0.31	10%	10%	1.9	494	$11,435.00	$5,648,890.00	80%	10% confident vol. exceeds action level criterion and 10% confident vol. meets criterion
0.31	5%	20%	1.9	466	$11,435.00	$5,328,710.00		
0.31	20%	5%	1.9	465	$11,435.00	$5,317,275.00		
0.62	1%	1%	1.9	408	$11,435.00	$4,665,480.00		
0.31	5%	30%	1.9	355	$11,435.00	$4,059,425.00		
0.31	30%	5%	1.9	354	$11,435.00	$4,047,990.00		
0.31	10%	20%	1.9	340	$11,435.00	$3,887,900.00		
0.31	20%	10%	1.9	339	$11,435.00	$3,876,465.00		
0.62	1%	5%	1.9	298	$11,435.00	$3,407,630.00	95%	confident residual contaminant meets the action level criterion
0.62	5%	1%	1.9	297	$11,435.00	$3,396,195.00	95%	confident residual contaminant exceeds the action level criterion
0.62	1%	10%	1.9	246	$11,435.00	$2,813,010.00	90%	confident residual contaminant meets the action level criterion
0.31	10%	30%	1.9	246	$11,435.00	$2,813,010.00		
0.62	10%	1%	1.9	245	$11,435.00	$2,801,575.00	90%	confident residual contaminant exceeds the action level criterion
0.31	30%	10%	1.9	246	$11,435.00	$2,813,010.00		

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0.31	20%	20%	1.9	214	$11,435.00	$2,447,090.00		
0.62	5%	5%	1.9	204	$11,435.00	$2,332,740.00	90%	5% confident vol. meets action level criterion and 5% confident volume exceeds criterion
0.62	1%	20%	1.9	190	$11,435.00	$2,172,650.00	80%	confident residual contaminant meets the action level criterion
0.62	20%	1%	1.9	189	$11,435.00	$2,161,215.00	80%	confident residual contaminant exceeds the action level criterion
0.62	5%	10%	1.9	162	$11,435.00	$1,852,470.00	85%	5% confident vol. exceeds action level criterion and 10% confident volume meets criterion
0.62	10%	5%	1.9	162	$11,435.00	$1,852,470.00	85%	10% confident vol. exceeds action level criterion and 5% confident volume meets criterion
0.62	1%	30%	1.9	154	$11,435.00	$1,760,990.00		
0.62	30%	1%	1.9	153	$11,435.00	$1,749,555.00		
0.31	20%	30%	1.9	141	$11,435.00	$1,612,335.00		
0.31	30%	20%	1.9	141	$11,435.00	$1,612,335.00		
0.62	10%	10%	1.9	124	$11,435.00	$1,417,940.00	80%	10% confident vol. exceeds action level criterion and 10% confident vol. meets criterion
0.62	5%	20%	1.9	117	$11,435.00	$1,337,895.00		
0.62	20%	5%	1.9	117	$11,435.00	$1,337,895.00		
1.24	1%	1%	1.9	104	$11,435.00	$1,189,240.00		
0.62	5%	30%	1.9	90	$11,435.00	$1,029,150.00		
0.62	30%	5%	1.9	89	$11,435.00	$1,017,715.00		
0.62	10%	20%	1.9	86	$11,435.00	$983,410.00		
0.62	20%	10%	1.9	85	$11,435.00	$971,975.00		
0.31	30%	30%	1.9	83	$11,435.00	$949,105.00		
1.24	1%	5%	1.9	76	$11,435.00	$869,060.00	95%	confident residual contaminant meets the action level criterion
1.24	5%	1%	1.9	75	$11,435.00	$857,625.00	95%	confident residual contaminant exceeds the action level criterion
1.24	1%	10%	1.9	63	$11,435.00	$720,405.00	90%	confident residual contaminant meets the action level criterion
0.62	10%	30%	1.9	62	$11,435.00	$708,970.00		
1.24	10%	1%	1.9	62	$11,435.00	$708,970.00	90%	confident residual contaminant exceeds the action level criterion
0.62	30%	10%	1.9	62	$11,435.00	$708,970.00		
1.24	1%	20%	1.9	49	$11,435.00	$560,315.00	80%	confident residual contaminant meets the action level criterion
1.24	5%	5%	1.9	52	$11,435.00	$594,620.00	90%	5% confident vol. meets action level criterion and 5% confident volume exceeds criterion
0.62	20%	20%	1.9	54	$11,435.00	$617,490.00		
1.24	20%	1%	1.9	48	$11,435.00	$548,880.00	80%	confident residual contaminant exceeds the action level criterion
1.24	1%	30%	1.9	40	$11,435.00	$457,400.00		
1.24	5%	10%	1.9	41	$11,435.00	$468,835.00	85%	5% confident vol. exceeds action level criterion and 10% confident volume meets criterion
1.24	10%	5%	1.9	41	$11,435.00	$468,835.00	85%	10% confident vol. exceeds action level criterion and 5% confident volume meets criterion
1.24	30%	1%	1.9	39	$11,435.00	$445,965.00		
0.62	20%	30%	1.9	36	$11,435.00	$411,660.00		
0.62	30%	20%	1.9	36	$11,435.00	$411,660.00		
1.24	10%	10%	1.9	32	$11,435.00	$365,920.00	80%	10% confident vol. exceeds action level criterion and 10% confident vol. meets criterion

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1.24	20%	5%	1.9	30	$11,435.00	**$343,050.00**
1.24	5%	30%	1.9	23	$11,435.00	**$263,005.00**
1.24	10%	20%	1.9	22	$11,435.00	**$251,570.00**
1.24	30%	5%	1.9	23	$11,435.00	**$263,005.00**
1.24	20%	10%	1.9	22	$11,435.00	**$251,570.00**
0.62	30%	30%	1.9	21	$11,435.00	**$240,135.00**
1.24	10%	30%	1.9	16	$11,435.00	**$182,960.00**
1.24	30%	10%	1.9	16	$11,435.00	**$182,960.00**
1.24	20%	20%	1.9	14	$11,435.00	**$160,090.00**
1.24	20%	30%	1.9	9	$11,435.00	**$102,915.00**
1.24	30%	20%	1.9	9	$11,435.00	**$102,915.00**
1.24	30%	30%	1.9	6	$11,435.00	**$68,610.00**

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7.1.5 Two Sample Proportion Test

Calculations for Two Sample Proportion Test Sampling Design

User inputs are shaded areas. Null = Contaminated

For Delta = 0.04, (10% AL)		Alpha Values					$Z_{(1-Beta)}$
		α 1	α 2	α 3	α 4	α 5	
		0.01	0.05	0.10	0.20	0.30	
Beta Values	β 1 = 0.01	553	403	332	256	208	2.326348
	β 2 = 0.05	403	276	219	158	120	1.644854
	β 3 = 0.10	332	219	168	115	84	1.281552
	β 4 = 0.20	256	158	115	73	48	0.841621
	β 5 = 0.30	208	120	84	48	29	0.524401

Estimated Proportion in Survey Unit, P_1	0.2	0.2	0.2
Estimated Proportion in Reference Area, P_2	0.1	0.1	0.1
Action Level (Specified difference of proportions	0.5	0.5	0.5
Width of Gray Region, Delta	0.1	0.15	0.2
Delta as percent of AL	20%	30%	40%

Pooled Proportion	0.15				
PBar(1 - PBar)	0.1275				
$Z_{(1-Alpha)}$	2.326348	1.644854	1.2815516	0.841621	0.524401

For Delta = 0.08, (20% AL)		Alpha Values					$Z_{(1-Beta)}$
		α 1	α 2	α 3	α 4	α 5	
		0.01	0.05	0.10	0.20	0.30	
Beta Values	β 1 = 0.01	246	179	148	114	93	2.326348
	β 2 = 0.05	179	123	98	71	54	1.644854
	β 3 = 0.10	148	98	75	52	37	1.281552
	β 4 = 0.20	114	71	52	33	22	0.841621
	β 5 = 0.30	93	54	37	22	13	0.524401

For Delta = 0.08, (30% AL)		Alpha Values					$Z_{(1-Beta)}$
		α 1	α 2	α 3	α 4	α 5	
		0.01	0.05	0.10	0.20	0.30	
Beta Values	β 1 = 0.01	139	101	83	64	52	2.326348
	β 2 = 0.05	101	69	55	40	30	1.644854
	β 3 = 0.10	83	55	42	29	21	1.281552
	β 4 = 0.20	64	40	29	19	12	0.841621
	β 5 = 0.30	52	30	21	12	8	0.524401

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Size-Sample Equation for Two-Sample Proportion Test

Null = Contaminated

$$n = \frac{2\left(z_{1-\alpha} + z_{1-\beta}\right)^2 \overline{P}\left(1-\overline{P}\right)}{\left(\delta_0 - \delta_1\right)^2} \text{ where } \overline{P} = \frac{P_1 + P_2}{2}$$

Values are rounded upwards (EPA 2000, p. 3-8). The equation is modified from (EPA 2000, p. 3-29). See Gilbert et al. 2000 pp 3.14, 3.15

		Mistakenly Concluding < Action Level				
		α = 1%	α = 5%	α = 10%	α = 20%	α = 30%
Width of the Gray Region (Δ) = 0.1 (20% of AL)						
Mistakenly Concluding > = Action Level	β = 1%	553	403	332	256	208
	β = 5%	403	276	219	158	120
	β = 10%	332	219	168	115	84
	β = 20%	256	158	115	73	48
	β = 30%	208	120	84	48	29
Width of the Gray Region (Δ) = 0.15 (30% of AL)						
Mistakenly Concluding > = Action Level	β = 1%	246	179	148	114	93
	β = 5%	179	123	98	71	54
	β = 10%	148	98	75	52	37
	β = 20%	114	71	52	33	22
	β = 30%	93	54	37	22	13
Width of the Gray Region (Δ) = 0.2 (40% of AL)						
Mistakenly Concluding > = Action Level	β = 1%	139	101	83	64	52
	β = 5%	101	69	55	40	30
	β = 10%	83	55	42	29	21
	β = 20%	64	40	29	19	12
	β = 30%	52	30	21	12	8

References

EPA. 2000. *Guidance for Data Quality Assessment*. EPA QA/G-9,
U.S. Environmental Protection Agency, Washington DC.

Gilbert, RO, JR Davidson, JE Wilson, BA Pulsipher. 2001. Visual Sample Plan (VSP) Models and Code Verification. PNNL-13450, Pacific Northwest National Laboratory, Richland, Washington.

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Sampling Collection and Analysis Costs

NULL = Contaminated

User inputs are shaded areas.

Unit Sample Collection Cost Dollars		Unit Sample Analysis Cost Dollars		
USC$	+	**USA$ (Sum)**	=	**AUSCSA$**
$50.00	+	$11,385.00	=	**$11,435.00**

Definitions:

USC$ Unit sample collection cost in dollars

USA$ Unit sample analysis cost in dollars

USA$ (SUM) Unit sample analysis cost for all analytical methods in dollars

AUSCSA$ Aggregate unit sample collection and sample analysis cost in dollars

USC$ =	$50.00	Summed from cells below
	$50.00	Enter costs associated with each item for taking the sample

USA$ =	$11,385.00	Summed from cells below
	$11,385.00	Enter analytical cost for each analytical method in the cells in column C

Total Cost for Two-Sample Proportion Test Sampling Design

NULL = Contaminated

Sampling-Cost Budget	$2,000,000.00

User inputs are shaded areas.

Width of Gray Region, (UBGR-LBGR)	Alpha	Beta	Number of Samples, n	AUSCA $	Total Cost of Sampling Design		
0.1	1%	1%	553	$11,435.00	**$6,323,555.00**		
0.1		1%	403	$11,435.00	**$4,608,305.00**	95%	confident residual contaminant exceeds the action level criterion
0.1	1%	5%	403	$11,435.00	**$4,608,305.00**	95%	confident residual contaminant meets the action level criterion
0.1	10%	1%	332	$11,435.00	**$3,796,420.00**	90%	confident residual contaminant exceeds the action level criterion
0.1	1%	10%	332	$11,435.00	**$3,796,420.00**	90%	confident residual contaminant meets the action level criterion
0.1	5%	5%	276	$11,435.00	**$3,156,060.00**	90%	5% confident volume meets the action level criterion and 5% confident volume exceeds criterion
0.1	20%	1%	256	$11,435.00	**$2,927,360.00**	80%	confident residual contaminant exceeds the action level criterion
0.1	1%	20%	256	$11,435.00	**$2,927,360.00**	80%	confident residual contaminant meets the action level criterion
0.15	1%	1%	246	$11,435.00	**$2,813,010.00**		
0.1	10%	5%	219	$11,435.00	**$2,504,265.00**	85%	10% confident volume exceeds the action level criterion and 5% confident volume meets criterion
0.1	5%	10%	219	$11,435.00	**$2,504,265.00**	85%	5% confident volume exceeds the action level criterion and 10% confident volume meets criterion
0.1	30%	1%	208	$11,435.00	**$2,378,480.00**		
0.1	1%	30%	208	$11,435.00	**$2,378,480.00**		
0.15	5%	1%	179	$11,435.00	**$2,046,865.00**	95%	confident residual contaminant exceeds the action level criterion
0.15	1%	5%	179	$11,435.00	**$2,046,865.00**	95%	confident residual contaminant meets the action level criterion
0.1	10%	10%	168	$11,435.00	**$1,921,080.00**	80%	10% confident volume exceeds the action level criterion and 10% confident volume meets criterion
0.1	20%	5%	158	$11,435.00	**$1,806,730.00**		
0.1	5%	20%	158	$11,435.00	**$1,806,730.00**		
0.15	10%	1%	148	$11,435.00	**$1,692,380.00**	90%	confident residual contaminant exceeds the action level criterion
0.15	1%	10%	148	$11,435.00	**$1,692,380.00**	90%	confident residual contaminant meets the action level criterion
0.15	1%	1%	139	$11,435.00	**$1,589,465.00**		
0.15	5%	5%	123	$11,435.00	**$1,406,505.00**		

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0.1	30%	5%	120	$11,435.00	**$1,372,200.00**	90%	5% confident volume meets the action level criterion and 5% confident volume exceeds criterion
0.1	5%	30%	120	$11,435.00	**$1,372,200.00**		
0.1	20%	10%	115	$11,435.00	**$1,315,025.00**		
0.1	10%	20%	115	$11,435.00	**$1,315,025.00**		
0.15	20%	1%	114	$11,435.00	**$1,303,590.00**	80%	confident residual contaminant exceeds the action level criterion
0.15	1%	20%	114	$11,435.00	**$1,303,590.00**	80%	confident residual contaminant meets the action level criterion
0.2	5%	1%	101	$11,435.00	**$1,154,935.00**	95%	confident residual contaminant exceeds the action level criterion
0.2	1%	5%	101	$11,435.00	**$1,154,935.00**	95%	confident residual contaminant meets the action level criterion
0.15	10%	5%	98	$11,435.00	**$1,120,630.00**	85%	10% confident volume exceeds the action level criterion and 5% confident volume meet criterion
0.15	5%	10%	98	$11,435.00	**$1,120,630.00**	85%	5% confident volume exceeds the action level criterion and 10% confident volume meet criterion
0.15	30%	1%	93	$11,435.00	**$1,063,455.00**		
0.15	1%	30%	93	$11,435.00	**$1,063,455.00**		
0.1	30%	10%	84	$11,435.00	**$960,540.00**		
0.1	10%	30%	84	$11,435.00	**$960,540.00**		
0.2	10%	1%	83	$11,435.00	**$949,105.00**	90%	confident residual contaminant exceeds the action level criterion
0.2	1%	10%	83	$11,435.00	**$949,105.00**	90%	confident residual contaminant meets the action level criterion
0.15	10%	10%	75	$11,435.00	**$857,625.00**	80%	10% confident volume exceeds the action level criterion and 10% confident volume meets criterion
0.1	20%	20%	73	$11,435.00	**$834,755.00**		
0.15	20%	5%	71	$11,435.00	**$811,885.00**		
0.15	5%	20%	71	$11,435.00	**$811,885.00**		
0.2	5%	5%	69	$11,435.00	**$789,015.00**	90%	5% confident volume meets the action level criterion and 5% confident volume exceeds criterion
0.2	20%	1%	64	$11,435.00	**$731,840.00**	80%	confident residual contaminant exceeds the action level criterion
0.2	1%	20%	64	$11,435.00	**$731,840.00**	80%	confident residual contaminant meets the action level criterion
0.2	10%	5%	55	$11,435.00	**$628,925.00**	85%	10% confident volume exceeds the action level criterion and 5% confident volume meet criterion
0.2	5%	10%	55	$11,435.00	**$628,925.00**	85%	5% confident volume exceeds the action level criterion and 10% confident volume meet criterion
0.15	30%	5%	54	$11,435.00	**$617,490.00**		
0.15	5%	30%	54	$11,435.00	**$617,490.00**		
0.2	30%	1%	52	$11,435.00	**$594,620.00**		
0.2	1%	30%	52	$11,435.00	**$594,620.00**		
0.15	20%	10%	52	$11,435.00	**$594,620.00**		

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0.15	10%	20%	52	$11,435.00	**$594,620.00**		
0.1	30%	20%	48	$11,435.00	**$548,880.00**		
0.1	20%	30%	48	$11,435.00	**$548,880.00**		
0.2	10%	10%	42	$11,435.00	**$480,270.00**	80%	10% confident volume exceeds the action level criterion and 10% confident volume meets criterion
0.2	20%	5%	40	$11,435.00	**$457,400.00**		
0.2	5%	20%	40	$11,435.00	**$457,400.00**		
0.15	30%	10%	37	$11,435.00	**$423,095.00**		
0.15	10%	30%	37	$11,435.00	**$423,095.00**		
0.15	20%	20%	33	$11,435.00	**$377,355.00**		
0.2	30%	5%	30	$11,435.00	**$343,050.00**		
0.2	5%	30%	30	$11,435.00	**$343,050.00**		
0.2	20%	10%	29	$11,435.00	**$331,615.00**		
0.2	10%	20%	29	$11,435.00	**$331,615.00**		
0.1	30%	30%	29	$11,435.00	**$331,615.00**		
0.15	30%	20%	22	$11,435.00	**$251,570.00**		
0.15	20%	30%	22	$11,435.00	**$251,570.00**		
0.2	30%	10%	21	$11,435.00	**$240,135.00**		
0.2	10%	30%	21	$11,435.00	**$240,135.00**		
0.2	20%	20%	19	$11,435.00	**$217,265.00**		
0.15	30%	30%	13	$11,435.00	**$148,655.00**		
0.2	30%	20%	12	$11,435.00	**$137,220.00**		
0.2	20%	30%	12	$11,435.00	**$137,220.00**		
0.2	30%	30%	8	$11,435.00	**$91,480.00**		

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7.1.6 Wilcoxon Rank Sign (WRS) Test

Calculations for MARSSIM WRS Test Sampling Design

User inputs are shaded areas. Null = Contaminated

For Delta – 0.31, (5 % AL)		Alpha Values					$Z_{(1-Beta)}$
		α 1	α 2	α 3	α 4	α 5	
		0.01	0.05	0.10	0.20	0.30	
Beta Values	β 1 = 0.01	228	166	137	106	86	2.326348
	β 2 = 0.05	166	114	90	65	51	1.644854
	β 3 = 0.10	137	90	70	48	35	1.281552
	β 4 = 0.20	106	65	48	30	21	0.841621
	β 5 = 0.30	86	51	35	21	12	0.524401

Action Level (AL)	6.20	6.20	6.20
LBGR	5.89	5.58	4.96

Delta	0.31	0.62	1.24
Delta as percent of AL	5%	10%	20%

Estimated Std Dev. 0.62

Inflation % 20% **MARSSIM default is 20%**

$Z_{(1-Alpha)}$	2.326348	1.644854	1.2815516	0.841621	0.524401
P_r	0.638163	0.76025	0.92135		

For Delta = 0.62, (10 % AL)		Alpha Values					$Z_{(1-Beta)}$
		α 1	α 2	α 3	α 4	α 5	
		0.01	0.05	0.10	0.20	0.30	
Beta Values	β 1 = 0.01	65	47	40	30	24	2.326348
	β 2 = 0.05	47	33	27	20	15	1.644854
	β 3 = 0.10	40	27	21	15	11	1.281552
	β 4 = 0.20	30	20	15	9	6	0.841621
	β 5 = 0.30	24	15	11	6	4	0.524401

For Delta = 1.24, (20% AL)		Alpha Values					$Z_{(1-Beta)}$
		α 1	α 2	α 3	α 4	α 5	
		0.01	0.05	0.10	0.20	0.30	
Beta Values	β 1 = 0.01	26	18	16	12	10	2.326348
	β 2 = 0.05	18	14	11	8	6	1.644854
	β 3 = 0.10	16	11	9	6	5	1.281552
	β 4 = 0.20	12	8	6	4	3	0.841621
	β 5 = 0.30	10	6	5	3	3	0.524401

Size-Sample Equation for MARSSIM WRS Test

Null = Contaminated

$$N = n + m = \frac{\left(z_{1-\alpha} + z_{1-\beta}\right)^2}{3\left(P_r - 0.5\right)^2} \text{ where } P_r = \Phi\left(\frac{\Delta}{\sqrt{2}s_{Total}}\right) \text{ and}$$

$\Phi(z)$ = the cummulative std. normal dist. function, $\frac{1}{\sqrt{2\pi}}\int_{-\infty}^{z} e^{-\frac{x^2}{2}}dx$

$n = m = N/2$

n = number of samples in a sample area, i.e., survey unit

m = number of samples in the reference area

Values are rounded upwards (EPA 2000, p. 3-8). The equation is from (EPA 2000, p. 5-28).

	Mistakenly Concluding < Action Level				
	α = 1%	α = 5%	α = 10%	α = 20%	α = 30%
Estimated Std. Dev = 0.62	s = 0.62	s = 0.62	s = 0.62	s = 0.62	s = 0.62

Width of the Gray Region (Δ) = 0.31 (5% of AL)						
Mistakenly Concluding >= Action Level	β = 1%	228	166	137	106	86
	β = 5%	166	114	90	65	51
	β = 10%	137	90	70	48	35
	β = 20%	106	65	48	30	21
	β = 30%	86	51	35	21	12
Width of the Gray Region (Δ) = 0.62 (10% of AL)						
Mistakenly Concluding >= Action Level	β = 1%	65	47	40	30	24
	β = 5%	47	33	27	20	15
	β = 10%	40	27	21	15	11
	β = 20%	30	20	15	9	6
	β = 30%	24	15	11	6	4
Width of the Gray Region (Δ) = 1.24 (20% of AL)						
Mistakenly Concluding >= Action Level	β = 1%	26	18	16	12	10
	β = 5%	18	14	11	8	6
	β = 10%	16	11	9	6	5
	β = 20%	12	8	6	4	3
	β = 30%	10	6	5	3	3

References

EPA. 2000a. *Guidance for Data Quality Assessment.* EPA QA/G-9, U.S. Environmental Protection Agency, Washington DC.

EPA. 2000b. *Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM).* EPA 402-R-97-016, Rev.1. Environmental Protection Agency, Washington DC.

Note on Rounding

After *N* is calculated using the above equation, the following equation is used to divide *N* by 2, round up (ceiling function), increase the size by 20%, and round up to the nearest integer. Using the ceiling function first on the initial sample size and then on the inflated sample size follows the method used by Visual Sample Plan 1.0 and 2.0.

Final Sample Size = ceiling(1.2 * ceiling(*N*/2))

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NULL = Contaminated

Sampling Collection and Analysis Costs

User inputs are shaded areas.

Unit Sample Collection Cost Dollars USC$	+	Unit Sample Analysis Cost Dollars USA$ (Sum)	=	AUSCSA$
$50.00	+	$11,385.00	=	$11,435.00

Definitions:

USC$ Unit sample collection cost in dollars

USA$ Unit sample analysis cost in dollars

USA$ (SUM) Unit sample analysis cost for all analytical methods in dollars

AUSCSA$ Aggregate unit sample collection and sample analysis cost in dollars

USC$ =	
$50.00	Summed from cells below
$50.00	Enter costs associated with each item for taking the sample

USA$ =	
$11,385.00	Summed from cells below
$11,385.00	Enter analytical cost for each analytical method in the cells in column C

NULL = Contaminated

Total Cost for MARSSIM WRS Test Sampling Design

Sampling-Cost Budget $2,000,000.00 **User inputs are shaded areas.**

Width of Gray Region, (UBGR-LBGR)	Alpha	Beta	SD	Number of Samples, n	AUSCA $	Total Cost of Sampling Design		
0.31	1%	1%	0.62	228	$11,435.00	**$2,607,180.00**		
0.31	1%	5%	0.62	166	$11,435.00	$1,898,210.00	95%	confident residual contaminant meets the action level criterion
0.31	5%	1%	0.62	166	$11,435.00	$1,898,210.00	95%	confident residual contaminant exceeds the action level criterion
0.31	1%	10%	0.62	137	$11,435.00	$1,566,595.00	90%	confident residual contaminant meets the action level criterion
0.31	10%	1%	0.62	137	$11,435.00	$1,566,595.00	90%	confident residual contaminant exceeds the action level criterion
0.31	5%	5%	0.62	114	$11,435.00	$1,303,590.00	90%	5% confident vol. meets action level criterion and 5% confident volume exceeds criterion
0.31	1%	20%	0.62	106	$11,435.00	$1,212,110.00	80%	confident residual contaminant meets the action level criterion
0.31	20%	1%	0.62	106	$11,435.00	$1,212,110.00	80%	confident residual contaminant exceeds the action level criterion
0.31	5%	10%	0.62	90	$11,435.00	$1,029,150.00	85%	5% confident vol. exceeds action level criterion and 10% confident volume meets criterion
0.31	10%	5%	0.62	90	$11,435.00	$1,029,150.00	85%	10% confident vol. exceeds action level criterion and 5% confident volume meets criterion
0.31	1%	30%	0.62	86	$11,435.00	$983,410.00		
0.31	30%	1%	0.62	86	$11,435.00	$983,410.00		
0.31	10%	10%	0.62	70	$11,435.00	$800,450.00	80%	10% confident vol. exceeds action level criterion and 10% confident vol. meets criterion
0.31	5%	20%	0.62	65	$11,435.00	$743,275.00		
0.31	20%	5%	0.62	65	$11,435.00	$743,275.00		
0.62	1%	1%	0.62	65	$11,435.00	$743,275.00		
0.31	5%	30%	0.62	51	$11,435.00	$583,185.00		
0.31	30%	5%	0.62	51	$11,435.00	$583,185.00		
0.31	10%	20%	0.62	48	$11,435.00	$548,880.00		
0.31	20%	10%	0.62	48	$11,435.00	$548,880.00		
0.62	1%	5%	0.62	47	$11,435.00	$537,445.00	95%	confident residual contaminant meets the action level criterion
0.62	5%	1%	0.62	47	$11,435.00	$537,445.00	95%	confident residual contaminant exceeds the action level criterion
0.62	1%	10%	0.62	40	$11,435.00	$457,400.00	90%	confident residual contaminant meets the action level criterion
0.31	10%	30%	0.62	35	$11,435.00	$400,225.00		
0.62	10%	1%	0.62	40	$11,435.00	$457,400.00	90%	confident residual contaminant exceeds the action level criterion
0.31	30%	10%	0.62	35	$11,435.00	$400,225.00		
0.31	20%	20%	0.62	30	$11,435.00	$343,050.00		
0.62	5%	5%	0.62	33	$11,435.00	$377,355.00	90%	5% confident vol. meets action level criterion and 5% confident volume exceeds criterion

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0.62	1%	20%	0.62	30	$11,435.00	$343,050.00	80%	confident residual contaminant meets the action level criterion
0.62	20%	1%	0.62	30	$11,435.00	$343,050.00	80%	confident residual contaminant exceeds the action level criterion
0.62	5%	10%	0.62	27	$11,435.00	$308,745.00	85%	5% confident vol. exceeds action level criterion and 10% confident vol. meets criterion
0.62	10%	5%	0.62	27	$11,435.00	$308,745.00	85%	10% confident vol. exceeds action level criterion and 5% confident vol. meets criterion
0.62	1%	30%	0.62	24	$11,435.00	$274,440.00		
0.62	30%	1%	0.62	24	$11,435.00	$274,440.00		
0.31	20%	30%	0.62	21	$11,435.00	$240,135.00		
0.31	30%	20%	0.62	21	$11,435.00	$240,135.00		
0.62	10%	10%	0.62	21	$11,435.00	$240,135.00	80%	10% confident vol. exceeds action level criterion and 10% confident vol. meets criterion
0.62	5%	20%	0.62	20	$11,435.00	$228,700.00		
0.62	20%	5%	0.62	20	$11,435.00	$228,700.00		
1.24	1%	1%	0.62	26	$11,435.00	$297,310.00		
0.62	5%	30%	0.62	15	$11,435.00	$171,525.00		
0.62	30%	5%	0.62	15	$11,435.00	$171,525.00		
0.62	10%	20%	0.62	15	$11,435.00	$171,525.00		
0.62	20%	10%	0.62	15	$11,435.00	$171,525.00		
0.31	30%	30%	0.62	12	$11,435.00	$137,220.00		
1.24	1%	5%	0.62	18	$11,435.00	$205,830.00	95%	confident residual contaminant meets the action level criterion
1.24	5%	1%	0.62	18	$11,435.00	$205,830.00	95%	confident residual contaminant exceeds the action level criterion
1.24	1%	10%	0.62	16	$11,435.00	$182,960.00	90%	confident residual contaminant meets the action level criterion
0.62	10%	30%	0.62	11	$11,435.00	$125,785.00		
1.24	10%	1%	0.62	16	$11,435.00	$182,960.00	90%	confident residual contaminant exceeds the action level criterion
0.62	30%	10%	0.62	11	$11,435.00	$125,785.00		
1.24	1%	20%	0.62	12	$11,435.00	$137,220.00	80%	confident residual contaminant meets the action level criterion
1.24	5%	5%	0.62	14	$11,435.00	$160,090.00	90%	5% confident vol. meets action level criterion and 5% confident volume exceeds criterion
0.62	20%	20%	0.62	9	$11,435.00	$102,915.00		
1.24	20%	1%	0.62	12	$11,435.00	$137,220.00	80%	confident residual contaminant exceeds the action level criterion
1.24	1%	30%	0.62	10	$11,435.00	$114,350.00		
1.24	5%	10%	0.62	11	$11,435.00	$125,785.00	85%	comb. of 10% conf. cont. meets action level criterion and 5% conf. cont. exceeds criterior
1.24	10%	5%	0.62	11	$11,435.00	$125,785.00	85%	comb. of 5% conf. cont. meets action level criterion and 10% conf. cont. exceeds criterion
1.24	30%	1%	0.62	10	$11,435.00	$114,350.00		
0.62	20%	30%	0.62	6	$11,435.00	$68,610.00		
0.62	30%	20%	0.62	6	$11,435.00	$68,610.00		
1.24	10%	10%	0.62	9	$11,435.00	$102,915.00	80%	10% confident vol. exceeds action level criterion and 10% confident vol. meets criterion
1.24	5%	20%	0.62	8	$11,435.00	$91,480.00		
1.24	20%	5%	0.62	8	$11,435.00	$91,480.00		

1.24	5%	30% 0.62	6	$11,435.00	$68,610.00
1.24	10%	20% 0.62	6	$11,435.00	$68,610.00
1.24	30%	5% 0.62	6	$11,435.00	$68,610.00
1.24	20%	10% 0.62	6	$11,435.00	$68,610.00
0.62	30%	30% 0.62	4	$11,435.00	$45,740.00
1.24	10%	30% 0.62	5	$11,435.00	$57,175.00
1.24	30%	10% 0.62	5	$11,435.00	$57,175.00
1.24	20%	20% 0.62	4	$11,435.00	$45,740.00
1.24	20%	30% 0.62	3	$11,435.00	$34,305.00
1.24	30%	20% 0.62	3	$11,435.00	$34,305.00
1.24	30%	30% 0.62	3	$11,435.00	$34,305.00

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7.2 Excavation Cost Estimate Excel Spreadsheets

The following pages contain a copy of the Excel Workbooks used to determine the cost for excavating and removing various types of pipe at various different diameters and depths. Types of pipe analyzed include the following.

- Vitrified Clay Pipe (5, 10, 15, 20, and 25 foot depths with 6, 12, and 24 inch diameter examples).
- Steel and Stainless Steel (5 and 15 foot depths with 2 and 12 inch diameter examples).
- Reinforced Concrete Pipe (5 and 15 foot depths and 12 inch diameter examples).
- Concrete Masonry (5 and 15 foot depths and 12 inch diameter examples).

Excavation/Removal Cost per Linear Foot

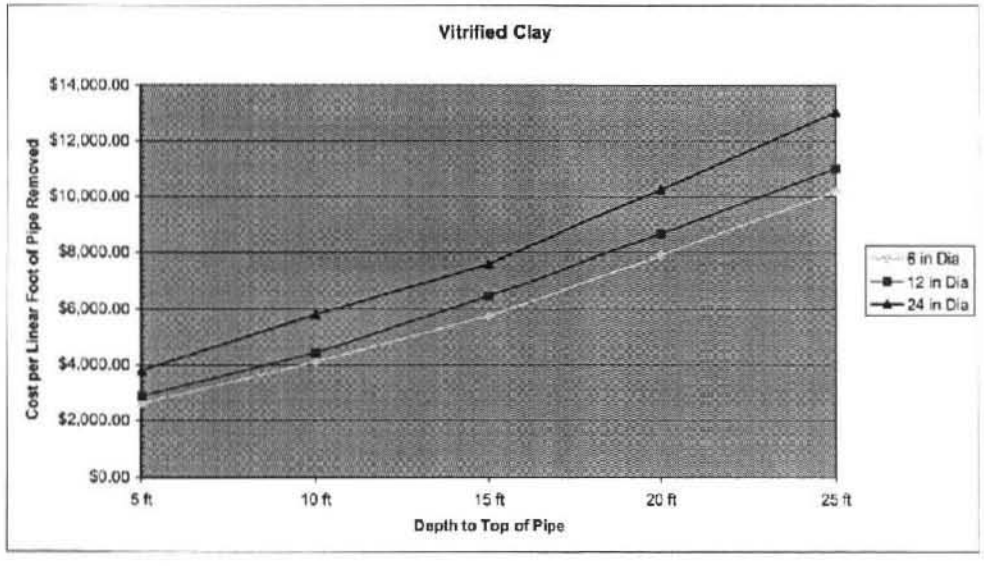
Estimate Scenario		Depth to Top of Pipe				
Pipe Material	Pipe Diameter (In)	5 ft	10 ft	15 ft	20 ft	25 ft
Vitrified Clay	2					
Vitrified Clay	6	$2,607.64	$4,104.32	$5,763.51	$7,900.46	$10,175.93
Vitrified Clay	12	$2,866.94	$4,433.26	$6,476.57	$8,659.96	$11,005.08
Vitrified Clay	24	$3,794.76	$5,814.85	$7,614.11	$10,250.49	$13,026.94
Vitrified Clay	36					
Vitrified Clay	48					

Estimate Assumptions

= Scenario not applicable to Hanford site.

Assume pipe crumbles apart during excavation.
Pipe debris removal included in contaminated soil excavation activity labor.

General Assumptions
Clean soil removed from trench and stockpiled close to excavation site for reuse as backfill material.
Contaminated soil loaded into lined ERDF boxes for disposal.
All scenarios do not involve any excavation of paved areas.
Silt fencing calculated based on (2.5 x L) + (8 x y); where L is the length of pipe to be removed, and y is depth from the surface to bottom of the triangle below the pipe (from geometry calcs).



Plot Data

	6 in Dia	12 in Dia	24 in Dia
5 ft	$2,607.64	$2,866.94	$3,794.76
10 ft	$4,104.32	$4,433.26	$5,814.85
15 ft	$5,763.51	$6,476.57	$7,614.11
20 ft	$7,900.46	$8,659.96	$10,250.49
25 ft	$10,175.93	$11,005.08	$13,026.94

Vitrified Clay Pipe

Labor		
1	Supervisor	$76.00
2	General Laborer	$54.14
3	Teamster	$54.35
4	Heavy Eqpmt Operator	$64.86
5	HP Technician	$68.17
6	Burner/Pipefitter	$67.96
7	Other Craft	$67.96
8	Spare	
9	Spare	
10	Spare	

Values Used Throughout	
Estimating Contingency	30%
Labor Hours per Work Shift	10
Construction Consumables (% of direct labor)	3.5%
Excavation Air Sampling (% of total cost)	25%
ERDF LLW disposal (% of total cost)	45%
Soil Expansion Factor	25%
Pipe Rubble Factor	40%
Steel Pipe Lengths for Removal, maximum (ft)	8

Unit Prices (2007 $)

Type	Unit	Description	$$
A	each	50 feet silt brace	$500
B	per day	CAT 320 Excavator Rental	$1,500
C	each	Trench box	$550
D	per month	Forklift	$1,000
E	per month	Generators	$500
F	per month	Job Trailer	$600
G	per month	Drill Rig	$1,000
H	per day	Dump Truck	$250
I	per day	Grader	$250
J	per day	Roller	$250
K	per day	Front-end Loader	$250
L	Case	Tape - 6"	$400.00
M	Case	Tape - 2"	$180.00
N	ft	Sleeving	$4.00
O	100-ft roll	Plastic Sheeting	$650.00
P	pair	Gloves	$5.53
Q	25-lb box	Rags	$130.00
R	$	Tools	$500.00
S	5-ft section	Casing	$1,000.00
T	split spoon	Split Spoons	$2,600.00
U	each	Split Spoon Liners	$20.00
V	pair	Laundry	$25.00
W	ft	Cable	$10.00
X	each	Retooling	$100.00
Y	drum	Drums	$56.36
Z	per sheet	Plywood (4'x8' 3/4 cdx exterior)	$20.00
AA	each	Drum Pallets	$35.00
AB	each	2 x 4s	$9.00
AC	$	Rope	$100.00
AD	blank	Signs	$20.00
AE	yd	Gravel	$40.00
AF	per hour	CAT 320 Excavator	$80.00
AG	per hour	Shuttle Dump Truck	$30.00
AH	per hour	Water Truck	$30.00
AI	per hour	Paving Saw	$15.00
AJ	per hour	Backhoe	$48.00
AK	100-ft roll	Silt Fencing w/ Stakes	$35.00
AL			
AM			

Type	Crew Activity	Crew Size	Crew	Rate
1	Mobilize	1	Supervisor	76.00
		6	General Laborer	54.14
		5	Teamster	54.35
		2	Heavy Eqpmt Ope	64.86
		6	HP Technician	68.17
			Burner/Pipefitter	67.96
			Other Craft	67.96
2	Pipeline / Interference Location	1	Supervisor	75.00
		3	General Laborer	54.14
			Teamster	54.35
			Heavy Eqpmt Ope	64.86
		1	HP Technician	68.17
			Burner/Pipefitter	67.96
			Other Craft	67.96
3	Install Silt Barrier	1	Supervisor	75.00
		4	General Laborer	54.14
			Teamster	54.35
		1	Heavy Eqpmt Ope	64.86
			HP Technician	68.17
			Burner/Pipefitter	67.96
			Other Craft	67.96
4	Paved Road Trenching		Supervisor	76.00
			General Laborer	54.14
			Teamster	54.35
			Heavy Eqpmt Ope	64.86
			HP Technician	68.17
			Burner/Pipefitter	67.96
			Other Craft	67.96
5	Clean Excavation to Pipe	1	Supervisor	76.00
		6	General Laborer	54.14
		5	Teamster	54.35
		2	Heavy Eqpmt Ope	64.86
		6	HP Technician	68.17
			Burner/Pipefitter	67.96
		1	Other Craft	67.96
6	Contaminated Soil Excavation	1	Supervisor	75.00
		6	General Laborer	54.14
		5	Teamster	54.35
		2	Heavy Eqpmt Ope	64.86
		6	HP Technician	68.17
			Burner/Pipefitter	67.96
		1	Other Craft	67.96
7	Pipe Section & Remove	1	Supervisor	75.00
		4	General Laborer	54.14
			Teamster	54.35
		1	Heavy Eqpmt Ope	64.86
		4	HP Technician	68.17
		1	Burner/Pipefitter	67.96
			Other Craft	67.96
8	Backfill, Compact, Grade	1	Supervisor	76.00
		4	General Laborer	54.14
		6	Teamster	54.35
		2	Heavy Eqpmt Ope	64.86
			HP Technician	68.17
			Burner/Pipefitter	67.96
			Other Craft	67.96
9	Demobilize	1	Supervisor	76.00
		4	General Laborer	54.14
			Teamster	54.35
		1	Heavy Eqpmt Ope	64.86
		4	HP Technician	68.17
			Burner/Pipefitter	67.96
			Other Craft	67.96

Type	Crew Name	Crew Rate
1	Mobilize	$1,210.33
2	Pipeline / Interference	$305.59
3	Install Silt Barrier	$356.42
4	Paved Road Trenching	$0.00
5	Clean Excavation to Pi	$1,278.29
6	Contaminated Soil Exc	$1,278.29
7	Pipe Section & Remov	$697.06
8	Backfill, Compact, Gra	$747.38
9	Demobilize	$629.10

Activity Duration Constants		
Activity	Duration	Unit
Field (Miss Utility) Survey	20	ft^2 per hour
Silt Barrier Installation	200	ln ft per hour
Paving Saw Trench Cutting	50	ln ft per hour
Steel Pipe Sectioning & Removal	44	ln ft per hour
RC Pipe Sectioning & Removal	18	ln ft per hour
Backfill	60	CY per hour

Excavation Duration Calculation Basis	
CY (bank) per ERDF Box	13
Boxes per day @ Day 1	4
Boxes per day @ Day 6	30

Probable Underground Pipe Combinations at the Hanford Site

Pipeline Material	Pipe Diameter (inches) 2	6	12	24	36	48
Vitreous Clay						
Steel (stainless/carbon)						
Concrete Masonry						
Reinforced Concrete						

Legend
- = Not Applicable
- = Potentially Applicable
- = Definitely Applicable

Pipeline Removal Vs. Characterization Study - Decision Support Tool

Pipe Excavation Estimate

Hanford Project ID No.
Project Title: VC-6

Pipe Material: Vitreous Clay

	Activity	Crew Rate ($/Hr)	Duration (Hours)	Labor Cost	Materials	QTY	UNIT	U.P.	Cost	Equipment	QTY	UNIT	U.P.	Cost	Total Activity Cost
1	Mobilize	$1,210.33	5	$6,051.65						Pickup Truck	1	$/hr	$10.00	$50.00	$6,101.65
2	Pipeline / Interference Location	$305.59	101	$30,856.27	Construction Consumables				$1,083.47	Pickup Truck	1	$/hr	$10.00	$1,013.00	$33,002.74
3	Install Silt Barrier	$356.42	1.6	$570.27	Construction Consumables				$19.90	Pickup Truck	1	$/hr	$10.00	$16.00	$823.03
					Silt Barrier & Stakes	304	$/100 ln ft	$35.00	$140.00	Backhoe	1	$/hr	$48.00	$76.80	
4	Paved Road Trenching				Construction Consumables					Paving Saw		$/hr	$18.00		
										Water Truck		$/hr	$30.00		
5	Clean Excavation to Pipe	$1,278.20	30	$38,346.70	Construction Consumables				$1,342.20	CAT Excavator	2	$/hr	$80.00	$4,800.00	$48,000.00
										Dump Truck	4	$/hr	$30.00	$3,600.00	
										Water Truck	1	$/hr	$30.00	$900.00	
6	Contaminated Soil Excavation	$1,278.29	10	$12,782.90	Construction Consumables				$447.40	CAT Excavator	2	$/hr	$80.00	$1,600.00	$18,330.30
										ERDF Box Truck	4	$/hr	$30.00	$1,200.00	
										Water Truck	1	$/hr	$30.00	$300.00	
7	Pipe Section & Remove	$697.06			Construction Consumables					CAT Excavator w/ Attachment		$/hr	$80.00		
8	Backfill, Compact, Grade	$747.38	6	$4,484.28	Construction Consumables				$156.95	5 CY Loader	1	$/hr	$32.00	$192.00	$6,303.23
					Fill Material					300-hp Dozer	1	$/hr	$65.00	$390.00	
										Dump Truck	5	$/hr	$30.00	$900.00	
										Water Truck	1	$/hr	$30.00	$180.00	
9	Demobilize	$629.10	10	$6,291.00						Pickup Truck	1	$/hr	$10.00	$100.00	$6,391.00
	Excavation Air Sampling														$29,498.21
	ERDF LLW Disposal														$53,096.78
	Estimating Contingency	30%													$60,179.30
	TOTAL PROJECT COST			$99,485.07					$3,189.98					$15,317.89	$260,764.21
															$260,764.21
										Calculated Cost per Linear Foot of Pipe removed:					$2,897.64

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Input		
Depth to top of pipe	5	ft
Pipe Diameter	6	in
Trench Slope	1.5	: 1
Pipe Length	100	ft

Excavation Volume Results

	ft³	CY
Contaminated Volume	1,107	41
Clean Volume	5,712	212
Total Volume	6,819	253

Input Pipe Diameter	0.5	ft
Slope down angle	33.7	degrees
2.5/cos(alpha)	3.00	
v	1.50	ft
z	2.75	ft
y	6.75	ft
x	0.25	ft
Total Area	68.39	sq ft
Pipe Area	0.20	sq ft
Area 3	0.10	sq ft
Area 2	11.36	sq ft
Outer contaminated Area	11.27	sq ft
Net Contaminated Area	11.07	sq ft
Non-Contaminated Area	57.12	sq ft

Excavation Duration Calculation Results

	Days	No. Boxes
Contaminated Volume	1.0	3
Clean Volume	3.0	

(for scenario Input Pipe Length)

Day 1 cans per day	4
Day 6 cans per day	30
yds per can	13 (bank volume)

	CY	Days	Roundup days
Clean Volume	212	2.214	3.000
Total Volume	253	2.433	3.000
Contaminated Volume	41	0.219	1.000

Day	Boxes Per Day	Yards Per Day	Cumulative Boxes	Cumulative Yards	Delta Yards
1	4	52	4	52	52
2	9.2	119.6	13.2	172	120
3	14.4	187.2	27.6	359	187
4	19.6	254.8	47.2	614	255
5	24.8	322.4	72	936	322
6	30	390	102	1,326	390

Net Contaminated Area

Pipe Diameter		
inch		sq ft
2	0.500	11.1
6	0.5	11.1
12	1	44.3
24	2	177.1
36	3	398.6
48	4	708.5

Calculated ERDF Disposal Cost: $1,294.93 /CY

Pipeline Removal Vs. Characterization Study - Decision Support Tool

Pipe Excavation Estimate

Hanford Project ID No.
Project Title: VC-6

Pipe Material: Vitreous Clay

	Activity	Crew Rate ($/Hr)	Duration (Hours)	Labor Cost	Materials	QTY	UNIT	U.P.	Cost	Equipment	QTY	UNIT	U.P.	Cost	Total Activity Cost
1	Mobilize	$1,210.33	5	$6,051.65						Pickup Truck	1	$/hr	$10.00	$50.00	$6,101.65
2	Pipeline / Interference Location	$306.59	176	$53,875.52	Construction Consumables				$1,885.04	Pickup Truck	1	$/hr	$10.00	$1,763.00	$57,524.16
3	Install Silt Barrier	$366.42	1.8	$841.56	Construction Consumables				$22.45	Pickup Truck	1	$/hr	$10.00	$18.00	$908.41
					Silt Barrier & Stakes	344	$/100 ln ft	$36.00	$140.00	Backhoe	1	$/hr	$48.00	$86.40	
4	Paved Road Trenching				Construction Consumables					Paving Saw		$/hr	$18.00		
										Water Truck		$/hr	$30.00		
5	Clean Excavation to Pipe	$1,278.29	50	$63,914.50	Construction Consumables				$2,237.01	CAT Excavator	2	$/hr	$80.00	$8,000.00	$81,651.51
										Dump Truck	4	$/hr	$30.00	$6,000.00	
										Water Truck	1	$/hr	$30.00	$1,500.00	
6	Contaminated Soil Excavation	$1,278.29	10	$12,782.90	Construction Consumables				$447.40	CAT Excavator	2	$/hr	$80.00	$1,600.00	$16,330.30
										ERDF Box Truck	4	$/hr	$30.00	$1,200.00	
										Water Truck	1	$/hr	$30.00	$300.00	
7	Pipe Section & Remove	$697.06			Construction Consumables					CAT Excavator w/ Attachment		$/hr	$80.00		
8	Backfill, Compact, Grade	$747.38	16	$11,958.08	Construction Consumables				$418.53	5 CY Loader	1	$/hr	$32.00	$512.00	$16,808.81
					Fill Material					300-hp Dozer	1	$/hr	$65.00	$1,040.00	
										Dump Truck	5	$/hr	$30.00	$2,400.00	
										Water Truck	1	$/hr	$30.00	$480.00	
9	Demobilize	$629.10	10	$6,291.00						Pickup Truck	1	$/hr	$10.00	$100.00	$6,391.00
	Excavation Air Sampling														$46,428.91
	ERDF LLW Disposal														$89,572.04
	Estimating Contingency	30%													$94,714.98
	TOTAL PROJECT COST			$155,515.20					$5,151.04					$25,049.40	$410,431.57
															$410,431.57
										Calculated Cost per Linear Foot of Pipe removed:					$4,104.32

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Input		
Depth to top of pipe	10	ft
Pipe Diameter	6	in
Trench Slope	1.5	: 1
Pipe Length	100	ft

Excavation Volume Results

	ft³	CY
Contaminated Volume	1,107	41
Clean Volume	19,591	726
Total Volume	20,698	767

Input Pipe Diameter	0.5	ft
Slope down angle	33.7	degrees
2.5/cos(alpha)	3.00	
v	1.50	ft
z	2.75	ft
y	11.75	ft
x	0.25	ft
Total Area	207.18	sq ft
Pipe Area	0.20	sq ft
Area 3	0.10	sq ft
Area 2	11.36	sq ft
Outer contaminated Area	11.27	sq ft
Net Contaminated Area	11.07	sq ft
Non-Contaminated Area	195.91	sq ft

Excavation Duration Calculation Results

	Days	No. Boxes
Contaminated Volume	1.0	3
Clean Volume	5.0	

(for scenario Input Pipe Length)

Day 1 cans per day	4
Day 6 cans per day	30
yds per can	13 (bank volume)

	CY	Days	Roundup days
Clean Volume	726	4.347	5.000
Total Volume	767	4.475	5.000
Contaminated Volume	41	0.127	1.000

Day	Boxes Per Day	Yards Per Day	Cumulative Boxes	Cumulative Yards	Delta Yards
1	4	52	4	52	52
2	9.2	119.6	13.2	172	120
3	14.4	187.2	27.6	359	187
4	19.6	254.8	47.2	614	255
5	24.8	322.4	72	936	322
6	30	390	102	1,326	390

Net Contaminated Area

Pipe Diameter		
inch		sq ft
2	0.500	11.1
6	0.5	11.1
12	1	44.3
24	2	177.1
36	3	398.6
48	4	708.5

Calculated ERDF Disposal Cost: $2,038.16 /CY

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Pipeline Removal Vs. Characterization Study - Decision Support Tool

Pipe Excavation Estimate

Hanford Project ID No.
Project Title: VC-6

Pipe Material: Vibreous Clay

	Activity	Crew Rate ($/Hr)	Duration (Hours)	Labor Cost	Materials	QTY	UNIT	U.P.	Cost	Equipment	QTY	UNIT	U.P.	Cost	Total Activity Cost
1	Mobilize	$1,210.33	5	$6,051.65						Pickup Truck	1	$/hr	$10.00	$50.00	$6,101.65
2	Pipeline / Interference Location	$305.59	251	$76,794.77	Construction Consumables				$2,687.82	Pickup Truck	1	$/hr	$10.00	$2,513.00	$81,995.58
3	Install Silt Barrier	$356.42	2.0	$712.84	Construction Consumables				$24.95	Pickup Truck	1	$/hr	$10.00	$20.00	$993.79
					Silt Barrier & Stakes	384	$/100 ln ft	$35.00	$140.00	Backhoe	1	$/hr	$48.00	$96.00	
4	Paved Road Trenching				Construction Consumables					Paving Saw		$/hr	$18.00		
										Water Truck		$/hr	$30.00		
5	Clean Excavation to Pipe	$1,278.20	70	$89,480.30	Construction Consumables				$3,131.81	CAT Excavator	2	$/hr	$80.00	$11,200.00	$114,312.11
										Dump Truck	4	$/hr	$30.00	$8,400.00	
										Water Truck	1	$/hr	$30.00	$2,100.00	
6	Contaminated Soil Excavation	$1,278.20	10	$12,782.90	Construction Consumables				$447.40	CAT Excavator	2	$/hr	$80.00	$1,600.00	$10,330.30
										ERDF Box Truck	4	$/hr	$30.00	$1,200.00	
										Water Truck	1	$/hr	$30.00	$300.00	
7	Pipe Section & Remove	$897.00			Construction Consumables					CAT Excavator w/ Attachment		$/hr	$80.00		
8	Backfill, Compact, Grade	$747.38	33	$24,663.54	Construction Consumables				$663.22	5 CY Loader	1	$/hr	$32.00	$1,056.00	$34,667.76
					Fill Material					300-hp Dozer	1	$/hr	$65.00	$2,145.00	
										Dump Truck	5	$/hr	$30.00	$4,950.00	
										Water Truck	1	$/hr	$30.00	$990.00	
9	Demobilize	$829.10	10	$8,291.00						Pickup Truck	1	$/hr	$10.00	$100.00	$8,391.00
	Excavation Air Sampling														$65,198.05
	ERDF LLW Disposal														$117,356.49
	Estimating Contingency	30%													$133,004.02
	TOTAL PROJECT COST			$216,777.00					$7,295.20					$36,720.00	$576,350.76
															$576,350.76
										Calculated Cost per Linear Foot of Pipe removed:					$8,763.51

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Input		
Depth to top of pipe	15	ft
Pipe Diameter	6	in
Trench Slope	1.5	: 1
Pipe Length	100	ft

Excavation Volume Results

	ft³	CY
Contaminated Volume	1,107	41
Clean Volume	40,969	1,517
Total Volume	42,076	1,558

Input Pipe Diameter	0.5	ft
Slope down angle	33.7	degrees
2.5/cos(alpha)	3.00	
v	1.50	ft
z	2.75	ft
y	16.75	ft
x	0.25	ft
Total Area	420.98	sq ft
Pipe Area	0.20	sq ft
Area 3	0.10	sq ft
Area 2	11.38	sq ft
Outer contaminated Area	11.27	sq ft
Net Contaminated Area	11.07	sq ft
Non-Contaminated Area	409.69	sq ft

Excavation Duration Calculation Results

	Days	No. Boxes
Contaminated Volume	1.0	3
Clean Volume	7.0	

(for scenario Input Pipe Length)

Day 1 cans per day	4	
Day 6 cans per day	30	
yds per can	13	(bank volume)

	CY	Days	Roundup days
Clean Volume	1,517	6.491	7.000
Total Volume	1,558	6.596	7.000
Contaminated Volume	41	0.105	1.000

Day	Boxes Per Day	Yards Per Day	Cumulative Boxes	Cumulative Yards	Delta Yards
1	4	52	4	52	52
2	9.2	119.6	13.2	172	120
3	14.4	187.2	27.6	359	187
4	19.6	254.8	47.2	614	255
5	24.8	322.4	72	936	322
6	30	390	102	1,326	390

Net Contaminated Area

Pipe Diameter		
inch		sq ft
2	0.500	11.1
6	0.5	11.1
12	1	44.3
24	2	177.1
36	3	398.6
48	4	708.5

Calculated ERDF Disposal Cost: $2,862.10 /CY

Pipeline Removal Vs. Characterization Study - Decision Support Tool

Pipe Excavation Estimate

Hanford Project ID No.
Project Title: VC-6

Pipe Material: Vitreous Clay

	Activity	Crew Rate ($/Hr)	Duration (Hours)	Labor Cost	Materials	QTY	UNIT	U.P.	Cost	Equipment	QTY	UNIT	U.P.	Cost	Total Activity Cost
1	Mobilize	$1,210.33	5	$6,051.65						Pickup Truck	1	$/hr	$10.00	$50.00	$6,101.65
2	Pipeline / Interference Location	$305.69	326	$99,714.02	Construction Consumables				$3,489.99	Pickup Truck	1	$/hr	$10.00	$3,203.00	$106,407.01
3	Install Silt Barrier	$356.42	2.2	$784.12	Construction Consumables				$27.44	Pickup Truck	1	$/hr	$10.00	$22.00	$1,114.17
					Silt Barrier & Stakes	424	$/100 ln ft	$35.00	$176.00	Backhoe	1	$/hr	$48.00	$105.60	
4	Paved Road Trenching				Construction Consumables					Paving Saw		$/hr	$18.00		
										Water Truck		$/hr	$30.00		
5	Clean Excavation to Pipe	$1,278.29	100	$127,829.00	Construction Consumables				$4,474.02	CAT Excavator	2	$/hr	$80.00	$16,000.00	$163,303.02
										Dump Truck	4	$/hr	$30.00	$12,000.00	
										Water Truck	1	$/hr	$30.00	$3,000.00	
6	Contaminated Soil Excavation	$1,278.29	10	$12,782.90	Construction Consumables				$147.40	CAT Excavator	2	$/hr	$80.00	$1,600.00	$16,330.30
										ERDF Box Truck	4	$/hr	$30.00	$1,200.00	
										Water Truck	1	$/hr	$30.00	$300.00	
7	Pipe Section & Remove	$897.06			Construction Consumables					CAT Excavator w/ Attachment		$/hr	$80.00		
8	Backfill, Compact, Grade	$747.30	55	$41,106.90	Construction Consumables				$1,438.71	6 CY Loader	1	$/hr	$32.00	$1,760.00	$57,779.61
					Fill Material					300-hp Dozer	1	$/hr	$65.00	$3,575.00	
										Dump Truck	6	$/hr	$30.00	$9,250.00	
										Water Truck	1	$/hr	$30.00	$1,650.00	
9	Demobilize	$629.10	10	$6,291.00						Pickup Truck	1	$/hr	$10.00	$100.00	$6,391.00
	Excavation Air Sampling														$89,371.60
	ERDF LLW Disposal														$160,869.04
	Estimating Contingency	30%													$182,318.24
	TOTAL PROJECT COST			$294,558.59					$10,052.56					$52,675.60	$790,045.72
															$790,045.72
										Calculated Cost per Linear Foot of Pipe removed:					$7,900.46

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Input		
Depth to top of pipe	20	ft
Pipe Diameter	6	in
Trench Slope	1.5	: 1
Pipe Length	100	ft

Excavation Volume Results

	ft^3	CY
Contaminated Volume	1,107	41
Clean Volume	69,848	2,587
Total Volume	70,955	2,628

Input Pipe Diameter	0.5	ft
Slope down angle	33.7	degrees
2.5/cos(alpha)	3.00	
v	1.50	ft
z	2.75	ft
y	21.75	ft
x	0.25	ft
Total Area	709.74	sq ft
Pipe Area	0.20	sq ft
Area 3	0.10	sq ft
Area 2	11.36	sq ft
Outer contaminated Area	11.27	sq ft
Net Contaminated Area	11.07	sq ft
Non-Contaminated Area	698.48	sq ft

Excavation Duration Calculation Results

	Days	No. Boxes
Contaminated Volume	1.0	3
Clean Volume	10.0	

(for scenario Input Pipe Length)

Day 1 cans per day	4	
Day 6 cans per day	30	
yds per can	13	(bank volume)

	CY	Days	Roundup days
Clean Volume	2,567	9.233	10.000
Total Volume,	2,626	9.336	10.000
Contaminated Volume	41	0.105	1.000

Day	Boxes Per Day	Yards Per Day	Cumulative Boxes	Cumulative Yards	Delta Yards
1	4	52	4	52	52
2	9.2	119.6	13.2	172	120
3	14.4	187.2	27.6	359	187
4	19.6	254.8	47.2	614	255
5	24.8	322.4	72	938	322
6	30	390	102	1,326	390

Net Contaminated Area

Pipe Diameter		
inch		sq ft
2	0.500	11.1
6	0.5	11.1
12	1	44.3
24	2	177.1
36	3	398.6
48	4	708.5

Calculated ERDF Disposal Cost: $3,923.28 /CY

Pipe Excavation Estimate

Hanford Project ID No.

Project Title: VC-6

Pipe Material: Vitreous Clay

	Activity	Crew Rate ($/Hr)	Duration (Hours)	Labor Cost	Materials	QTY	UNIT	U.P.	Cost	Equipment	QTY	UNIT	U.P.	Cost	Total Activity Cost
1	Mobilize	$1,210.33	5	$6,051.65						Pickup Truck	1	$/hr	$10.00	$50.00	$6,101.65
2	Pipeline / Interference Location	$305.59	401	$122,633.27	Construction Consumables				$4,292.18	Pickup Truck	1	$/hr	$10.00	$4,013.00	$130,938.43
3	Install Silt Barrier	$368.42	2.4	$885.41	Construction Consumables				$29.04	Pickup Truck	1	$/hr	$10.00	$24.00	$1,109.65
					Silt Barrier & Stakes	464	$/100 ln ft	$35.00	$175.00	Backhoe	1	$/hr	$48.00	$115.20	
4	Paved Road Trenching				Construction Consumables					Paving Saw		$/hr	$18.00		
										Water Truck		$/hr	$30.00		
5	Clean Excavation to Pipe	$1,278.29	130	$166,177.70	Construction Consumables				$5,616.22	CAT Excavator	2	$/hr	$80.00	$20,800.00	$212,293.92
										Dump Truck	4	$/hr	$30.00	$15,600.00	
										Water Truck	1	$/hr	$30.00	$3,900.00	
6	Contaminated Soil Excavation	$1,278.29	10	$12,782.90	Construction Consumables				$447.40	CAT Excavator	2	$/hr	$80.00	$1,600.00	$16,330.30
										ERDF Box Truck	4	$/hr	$30.00	$1,200.00	
										Water Truck	1	$/hr	$30.00	$300.00	
7	Pipe Section & Remove	$697.06			Construction Consumables					CAT Excavator w/ Attachment		$/hr	$80.00		
8	Backfill, Compact, Grade	$747.38	83	$62,032.54	Construction Consumables				$2,171.14	5 CY Loader	1	$/hr	$32.00	$2,656.00	$87,104.68
					Fill Material					300-hp Dozer	1	$/hr	$65.00	$5,395.00	
										Dump Truck	5	$/hr	$30.00	$12,450.00	
										Water Truck	1	$/hr	$30.00	$2,490.00	
9	Demobilize	$629.10	10	$6,291.00						Pickup Truck	1	$/hr	$10.00	$100.00	$6,391.00
	Excavation Air Sampling														$115,112.38
	ERDF LLW Disposal														$207,292.29
	Estimating Contingency	30%													$234,829.29
	TOTAL PROJECT COST			$378,824.47					$12,931.86					$70,693.20	$1,017,593.46
															$1,017,593.46
										Calculated Cost per Linear Foot of Pipe removed:					$19,175.93

Pipeline Removal Vs. Characterization Study - Decision Support Tool

Input		
Depth to top of pipe	25	ft
Pipe Diameter	6	In
Trench Slope	1.5	: 1
Pipe Length	100	ft

Excavation Volume Results

	ft^3	CY
Contaminated Volume	1,107	41
Clean Volume	106,226	3,934
Total Volume	107,333	3,975

Input Pipe Diameter	0.5	ft
Slope down angle	33.7	degrees
2.5/cos(alpha)	3.00	
v	1.50	ft
z	2.75	ft
y	26.75	ft
x	0.25	ft
Total Area	1073.53	sq ft
Pipe Area	0.20	sq ft
Area 3	0.10	sq ft
Area 2	11.36	sq ft
Outer contaminated Area	11.27	sq ft
Net Contaminated Area	11.07	sq ft
Non-Contaminated Area	1062.26	sq ft

Excavation Duration Calculation Results

	Days	No. Boxes
Contaminated Volume	1.0	3
Clean Volume	13.0	

(for scenario Input Pipe Length)

Day 1 cans per day	4		
Day 6 cans per day	30		
yds per can	13	(bank volume)	

	CY	Days	Roundup days
Clean Volume	3,934	12.688	13.000
Total Volume	3,975	12.793	13.000
Contaminated Volume	41	0.105	1.000

Day	Boxes Per Day	Yards Per Day	Cumulative Boxes	Cumulative Yards	Delta Yards
1	4	52	4	52	52
2	9.2	119.6	13.2	172	120
3	14.4	187.2	27.6	359	187
4	19.6	254.8	47.2	614	255
5	24.8	322.4	72	936	322
6	30	390	102	1,326	390

Net Contaminated Area

Pipe Diameter		
Inch		sq ft
2	0.500	11.1
6	0.5	11.1
12	1	44.3
24	2	177.1
36	3	398.6
48	4	708.5

Calculated ERDF Disposal Cost: $5,053.26 /CY

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Pipeline Removal Vs. Characterization Study - Decision Support Tool

Pipe Excavation Estimate

Hanford Project ID No.
Project Title VC-12

Pipe Material: Vitreous Clay

	Activity	Crew Rate ($/Hr)	Duration (Hours)	Labor Cost	Materials	QTY	UNIT	U.P.	Cost	Equipment	QTY	UNIT	U.P.	Cost	Total Activity Cost
1	Mobilize	$1,210.33	5	$6,051.65						Pickup Truck	1	$/hr	$10.00	$50.00	$6,101.65
2	Pipeline / Interference Location	$305.60	128	$38,993.28	Construction Consumables				$1,304.70	Pickup Truck	1	$/hr	$10.00	$1,278.00	$41,634.06
3	Install Silt Barrier	$356.42	1.6	$570.27	Construction Consumables				$19.90	Pickup Truck	1	$/hr	$10.00	$16.00	$823.03
					Silt Barrier & Stakes	318	$/100 in ft	$35.00	$140.00	Backhoe	1	$/hr	$40.00	$76.80	
4	Paved Road Trenching				Construction Consumables					Paving Saw		$/hr	$18.00		
										Water Truck		$/hr	$30.00		
5	Clean Excavation to Pipe	$1,278.29	30	$38,348.70	Construction Consumables				$1,342.20	CAT Excavator	2	$/hr	$80.00	$4,800.00	$48,990.90
										Dump Truck	4	$/hr	$30.00	$3,600.00	
										Water Truck	1	$/hr	$30.00	$900.00	
6	Contaminated Soil Excavation	$1,278.29	10	$12,782.90	Construction Consumables				$447.40	CAT Excavator	2	$/hr	$80.00	$1,600.00	$16,330.30
										ERDF Box Truck	4	$/hr	$30.00	$1,200.00	
										Water Truck	1	$/hr	$30.00	$300.00	
7	Pipe Section & Remove	$697.09			Construction Consumables					CAT Excavator w/ Attachment		$/hr	$80.00		
8	Backfill, Compact, Grade	$747.38	9	$6,726.42	Construction Consumables				$236.42	5 CY Loader	1	$/hr	$32.00	$288.00	$9,454.84
					Fill Material					300-hp Dozer	1	$/hr	$65.00	$585.00	
										Dump Truck	5	$/hr	$30.00	$1,350.00	
										Water Truck	1	$/hr	$30.00	$270.00	
9	Demobilize	$629.10	10	$6,291.00						Pickup Truck	1	$/hr	$10.00	$100.00	$6,391.00
	Excavation Air Sampling														$32,431.45
	ERDF LLW Disposal														$58,376.60
	Estimating Contingency	30%													$66,160.15
	TOTAL PROJECT COST			$109,764.23					$3,549.76					$16,411.80	$286,693.98
															$286,693.98
										Calculated Cost per Linear Foot of Pipe removed:					$2,866.94

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Pipeline Removal Vs. Characterization Study - Decision Support Tool

Input		
Depth to top of pipe	5	ft
Pipe Diameter	12	in
Trench Slope	1.5	: 1
Pipe Length	100	ft

Excavation Volume Results

	ft^3	CY
Contaminated Volume	4,428	164
Clean Volume	6,342	235
Total Volume	10,771	399

Input Pipe Diameter	1	ft
Slope down angle	33.7	degrees
2.5/cos(alpha)	3.00	
v	3.00	ft
z	5.50	ft
y	8.50	ft
x	0.50	ft
Total Area	108.49	sq ft
Pipe Area	0.79	sq ft
Area 3	0.38	sq ft
Area 2	45.45	sq ft
Outer contaminated Area	45.07	sq ft
Net Contaminated Area	44.28	sq ft
Non-Contaminated Area	63.42	sq ft

Excavation Duration Calculation Results

	Days	No. Boxes
Contaminated Volume	1.0	13
Clean Volume	3.0	

(for scenario Input Pipe Length)

Day 1 cans per day	4	
Day 6 cans per day	30	
yds per can	13	(bank volume)

	CY	Days	Roundup days
Clean Volume	235	2.338	3.000
Total Volume	399	3.157	4.000
Contaminated Volume	164	0.819	1.000

Day	Boxes Per Day	Yards Per Day	Cumulative Boxes	Cumulative Yards	Delta Yards
1	4	52	4	52	52
2	9.2	119.6	13.2	172	120
3	14.4	187.2	27.6	359	187
4	19.6	254.8	47.2	614	255
5	24.8	322.4	72	936	322
6	30	390	102	1,326	390

Net Contaminated Area

Pipe Diameter		
inch		sq ft
2	0.500	11.1
6	0.5	11.1
12	1	44.3
24	2	177.1
36	3	398.6
48	4	708.5

Calculated ERDF Disposal Cost: $355.92 /CY

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Pipeline Removal Vs. Characterization Study - Decision Support Tool

Pipe Excavation Estimate

Hanford Project ID No.
Project Title: VC-12

Pipe Material: Vitreous Clay

	Activity	Crew Rate ($/Hr)	Duration (Hours)	Labor Cost	Materials	QTY	UNIT	U.P.	Cost	Equipment	QTY	UNIT	U.P.	Cost	Total Activity Cost
1	Mobilize	$1,210.33	5	$6,051.65						Pickup Truck	1	$/hr	$10.00	$50.00	$6,101.65
2	Pipeline / Interference Location	$305.59	203	$61,912.53	Construction Consumables				$2,166.94	Pickup Truck	1	$/hr	$10.00	$2,026.00	$66,105.47
3	Install Silt Barrier	$356.42	1.8	$641.56	Construction Consumables				$22.45	Pickup Truck	1	$/hr	$10.00	$18.00	$908.41
					Silt Barrier & Stakes	356	$/100 ln ft	$35.00	$140.00	Backhoe	1	$/hr	$48.00	$86.40	
4	Paved Road Trenching				Construction Consumables					Paving Saw		$/hr	$18.00		
										Water Truck		$/hr	$30.00		
5	Clean Excavation to Pipe	$1,278.29	50	$63,914.50	Construction Consumables				$2,237.01	CAT Excavator	2	$/hr	$80.00	$8,000.00	$81,681.51
										Dump Truck	4	$/hr	$30.00	$6,000.00	
										Water Truck	1	$/hr	$30.00	$1,500.00	
6	Contaminated Soil Excavation	$1,278.29	10	$12,782.90	Construction Consumables				$447.40	CAT Excavator	2	$/hr	$80.00	$1,600.00	$16,330.30
										ERDF Box Truck	4	$/hr	$30.00	$1,200.00	
										Water Truck	1	$/hr	$30.00	$300.00	
7	Pipe Section & Remove	$697.06			Construction Consumables					CAT Excavator w/ Attachment		$/hr	$80.00		
8	Backfill, Compact, Grade	$747.38	22	$16,442.36	Construction Consumables				$575.48	5 CY Loader	1	$/hr	$32.00	$704.00	$23,111.84
					Fill Material					300-hp Dozer	1	$/hr	$65.00	$1,430.00	
										Dump Truck	5	$/hr	$30.00	$3,300.00	
										Water Truck	1	$/hr	$30.00	$660.00	
9	Demobilize	$629.10	10	$6,291.00						Pickup Truck	1	$/hr	$10.00	$100.00	$6,391.00
	Excavation Air Sampling														$50,150.05
	ERDF LLW Disposal														$90,270.00
	Estimating Contingency	30%													$102,306.09
	TOTAL PROJECT COST			$168,036.50					$5,589.28					$26,974.40	$443,326.41
															$443,326.41
										Calculated Cost per Linear Foot of Pipe removed:					$4,433.26

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Input		
Depth to top of pipe	10	ft
Pipe Diameter	12	In
Trench Slope	1.5	: 1
Pipe Length	100	ft

Excavation Volume Results

	ft^3	CY
Contaminated Volume	4,428	164
Clean Volume	22,849	846
Total Volume	27,278	1,010

Input Pipe Diameter	1	ft
Slope down angle	33.7	degrees
2.5/cos(alpha)	3.00	
v	3.00	ft
z	5.50	ft
y	13.50	ft
x	0.50	ft
Total Area	273.56	sq ft
Pipe Area	0.79	sq ft
Area 3	0.38	sq ft
Area 2	45.45	sq ft
Outer contaminated Area	45.07	sq ft
Net Contaminated Area	44.28	sq ft
Non-Contaminated Area	228.49	sq ft

Excavation Duration Calculation Results

	Days	No. Boxes
Contaminated Volume	1.0	13
Clean Volume	5.0	

(for scenario Input Pipe Length)

Day 1 cans per day	4		
Day 6 cans per day	30		
yds per can	13	(bank volume)	

	CY	Days	Roundup days
Clean Volume	846	4.722	5.000
Total Volume,	1,010	5.190	6.000
Contaminated Volume	164	0.469	1.000

Day	Boxes Per Day	Yards Per Day	Cumulative Boxes	Cumulative Yards	Delta Yards
1	4	52	4	52	52
2	9.2	119.6	13.2	172	120
3	14.4	187.2	27.6	359	187
4	19.6	254.8	47.2	614	255
5	24.8	322.4	72	936	322
6	30	390	102	1,326	390

Net Contaminated Area

Pipe Diameter inch		sq ft
2	0.500	11.1
6	0.5	11.1
12	1	44.3
24	2	177.1
36	3	398.6
48	4	708.5

Calculated ERDF Disposal Cost: $550.38 /CY

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Pipeline Removal Vs. Characterization Study - Decision Support Tool

Pipe Excavation Estimate

Hanford Project ID No.
Project Title: VC-12

Pipe Material: Vitreous Clay

	Activity	Crew Rate ($/Hr)	Duration (Hours)	Labor Cost	Materials	QTY	UNIT	U.P.	Cost	Equipment	QTY	UNIT	U.P.	Cost	Total Activity Cost
1	Mobilize	$1,210.33	6	$6,051.65						Pickup Truck	1	$/hr	$10.00	$50.00	$6,101.65
2	Pipeline / Interference Location	$305.50	278	$84,851.78	Construction Consumables				$2,989.11	Pickup Truck	1	$/hr	$10.00	$2,776.00	$90,576.90
3	Install Silt Barrier	$356.42	2.0	$712.84	Construction Consumables				$24.95	Pickup Truck	1	$/hr	$10.00	$20.00	$993.79
					Silt Barrier & Stakes	368	$/100 ln ft	$38.00	$140.00	Backhoe	1	$/hr	$48.00	$96.00	
4	Paved Road Trenching				Construction Consumables					Paving Saw		$/hr	$18.00		
										Water Truck		$/hr	$30.00		
5	Clean Excavation to Pipe	$1,278.29	80	$102,263.20	Construction Consumables				$3,579.21	CAT Excavator	2	$/hr	$80.00	$12,800.00	$130,642.41
										Dump Truck	4	$/hr	$30.00	$9,600.00	
										Water Truck	1	$/hr	$30.00	$2,400.00	
6	Contaminated Soil Excavation	$1,278.29	10	$12,782.90	Construction Consumables				$447.40	CAT Excavator	2	$/hr	$80.00	$1,600.00	$16,330.30
										ERDF Box Truck	4	$/hr	$30.00	$1,200.00	
										Water Truck	1	$/hr	$30.00	$300.00	
7	Pipe Section & Remove	$697.06			Construction Consumables					CAT Excavator w/ Attachment		$/hr	$80.00		
8	Backfill, Compact, Grade	$747.38	40	$29,895.20	Construction Consumables				$1,046.39	5 CY Loader	1	$/hr	$32.00	$1,280.00	$42,021.53
					Fill Material					300-hp Dozer	1	$/hr	$65.00	$2,600.00	
										Dump Truck	5	$/hr	$30.00	$6,000.00	
										Water Truck	1	$/hr	$30.00	$1,200.00	
9	Demobilize	$629.10	10	$6,291.00						Pickup Truck	1	$/hr	$10.00	$100.00	$6,391.00
	Excavation Air Sampling														$73,264.40
	ERDF LLW Disposal														$131,975.91
	Estimating Contingency	30%													$149,459.37
	TOTAL PROJECT COST			$242,828.57					$8,207.01					$42,022.00	$647,657.25
															$647,657.25
										Calculated Cost per Linear Foot of Pipe removed:					$6,476.57

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Pipeline Removal Vs. Characterization Study - Decision Support Tool

Input		
Depth to top of pipe	15	ft
Pipe Diameter	12	in
Trench Slope	1.5	: 1
Pipe Length	100	ft

Excavation Volume Results

	ft³	CY
Contaminated Volume	4,428	164
Clean Volume	46,856	1,735
Total Volume	51,285	1,899

Input Pipe Diameter	1	ft
Slope down angle	33.7	degrees
2.5/cos(alpha)	3.00	
v	3.00	ft
z	5.50	ft
y	18.50	ft
x	0.50	ft
Total Area	513.63	sq ft
Pipe Area	0.79	sq ft
Area 3	0.38	sq ft
Area 2	45.45	sq ft
Outer contaminated Area	45.07	sq ft
Net Contaminated Area	44.28	sq ft
Non-Contaminated Area	468.56	sq ft

Excavation Duration Calculation Results

	Days	No. Boxes
Contaminated Volume	1.0	13
Clean Volume	8.0	

(for scenario Input Pipe Length)

Day 1 cans per day	4		
Day 6 cans per day	30		
yds per can	13	(bank volume)	

	CY	Days	Roundup days
Clean Volume	1,735	7.050	8.000
Total Volume,	1,899	7.470	8.000
Contaminated Volume	164	0.421	1.000

Day	Boxes Per Day	Yards Per Day	Cumulative Boxes	Cumulative Yards	Delta Yards
1	4	52	4	52	52
2	9.2	119.6	13.2	172	120
3	14.4	187.2	27.6	359	187
4	19.6	254.8	47.2	614	255
5	24.8	322.4	72	936	322
6	30	390	102	1,326	390

Net Contaminated Area

Pipe Diameter		
inch		sq ft
2	0.500	11.1
6	0.5	11.1
12	1	44.3
24	2	177.1
36	3	398.6
48	4	708.5

Calculated ERDF Disposal Cost: $804.05 /CY

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Pipe Excavation Estimate

Hanford Project ID No.

Project Title VC-12

Pipe Material: Vitreous Clay

	Activity	Crew Rate ($/Hr)	Duration (Hours)	Labor Cost	Materials	QTY	UNIT	U.P.	Cost	Equipment	QTY	UNIT	U.P.	Cost	Total Activity Cost
1	Mobilize	$1,210.33	5	$6,051.65						Pickup Truck	1	$/hr	$10.00	$50.00	$6,101.65
2	Pipeline / Interference Location	$305.59	353	$107,751.03	Construction Consumables				$3,771.29	Pickup Truck	1	$/hr	$10.00	$3,520.00	$115,048.32
3	Install Silt Barrier	$356.42	2.2	$784.12	Construction Consumables				$27.44	Pickup Truck	1	$/hr	$10.00	$22.00	$1,114.17
					Silt Barrier & Stakes	438	$/100 ln ft	$35.00	$175.00	Backhoe	1	$/hr	$48.00	$105.60	
4	Paved Road Trenching				Construction Consumables					Paving Saw		$/hr	$18.00		
										Water Truck		$/hr	$30.00		
5	Clean Excavation to Pipe	$1,278.29	110	$140,611.90	Construction Consumables				$4,921.42	CAT Excavator	2	$/hr	$80.00	$17,600.00	$179,633.32
										Dump Truck	4	$/hr	$30.00	$13,200.00	
										Water Truck	1	$/hr	$50.00	$3,300.00	
6	Contaminated Soil Excavation	$1,278.29	10	$12,782.90	Construction Consumables				$447.40	CAT Excavator	2	$/hr	$80.00	$1,600.00	$16,330.30
										ERDF Box Truck	4	$/hr	$30.00	$1,200.00	
										Water Truck	1	$/hr	$30.00	$300.00	
7	Pipe Section & Remove	$697.00			Construction Consumables					CAT Excavator w/ Attachment		$/hr	$80.00		
8	Backfill, Compact, Grade	$747.38	64	$47,832.32	Construction Consumables				$1,674.13	5 CY Loader	1	$/hr	$32.00	$2,048.00	$67,234.45
					Fill Material					300-hp Dozer	1	$/hr	$65.00	$4,160.00	
										Dump Truck	5	$/hr	$30.00	$9,600.00	
										Water Truck	1	$/hr	$30.00	$1,920.00	
9	Demobilize	$829.10	10	$8,291.00						Pickup Truck	1	$/hr	$10.00	$100.00	$8,391.00
	Excavation Air Sampling														$97,983.30
	ERDF LLW Disposal														$178,333.94
	Estimating Contingency	30%													$199,845.14
	TOTAL PROJECT COST			$322,104.93					$11,016.68					$58,731.60	$865,995.59
															$865,195.59
										Calculated Cost per Linear Foot of Pipe removed.					$8,659.96

Pipeline Removal Vs. Characterization Study - Decision Support Tool

Input		
Depth to top of pipe	20	ft
Pipe Diameter	12	in
Trench Slope	1.5	: 1
Pipe Length	100	ft

Excavation Volume Results

	ft³	CY
Contaminated Volume	4,428	164
Clean Volume	78,363	2,902
Total Volume	82,792	3,066

Input Pipe Diameter	1	ft
Slope down angle	33.7	degrees
2.5/cos(alpha)	3.00	
v	3.00	ft
z	5.50	ft
y	23.50	ft
x	0.50	ft
Total Area	828.70	sq ft
Pipe Area	0.79	sq ft
Area 3	0.38	sq ft
Area 2	45.45	sq ft
Outer contaminated Area	45.07	sq ft
Net Contaminated Area	44.28	sq ft
Non-Contaminated Area	783.63	sq ft

Excavation Duration Calculation Results

	Days	No. Boxes
Contaminated Volume	1.0	13
Clean Volume	11.0	

(for scenario Input Pipe Length)

Day 1 cans per day	4			
Day 6 cans per day	30			
yds per can	13	(bank volume)		
	CY		Days	Roundup days
Clean Volume	2,902		10.042	11.000
Total Volume,	3,066		10.462	11.000
Contaminated Volume	164		0.421	1.000

Day	Boxes Per Day	Yards Per Day	Cumulative Boxes	Cumulative Yards	Delta Yards
1	4	52	4	52	52
2	9.2	119.6	13.2	172	120
3	14.4	187.2	27.6	359	187
4	19.6	254.8	47.2	614	255
5	24.8	322.4	72	936	322
6	30	390	102	1,326	390

Net Contaminated Area

Pipe Diameter inch		sq ft
2	0.500	11.1
6	0.5	11.1
12	1	44.3
24	2	177.1
36	3	398.6
48	4	708.5

Calculated ERDF Disposal Cost: $1,075.11 /CY

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Pipe Excavation Estimate

Hanford Project ID No.

Project Title: VC-12

Pipe Material: Vitreous Clay

	Activity	Crew Rate ($/Hr)	Duration (Hours)	Labor Cost	Materials	QTY	UNIT	U.P.	Cost	Equipment	QTY	UNIT	U.P.	Cost	Total Activity Cost
1	Mobilize	$1,210.33	5	$6,051.65						Pickup Truck	1	$/hr	$10.00	$50.00	$6,101.65
2	Pipeline / Interference Location	$305.59	428	$130,670.28	Construction Consumables				$4,573.46	Pickup Truck	1	$/hr	$10.00	$4,270.00	$139,519.74
3	Install Silt Barrier	$356.42	2.4	$855.41	Construction Consumables				$29.94	Pickup Truck	1	$/hr	$10.00	$24.00	$1,109.55
					Silt Barrier & Stakes	478	$/100 ln ft	$35.00	$175.00	Backhoe	1	$/hr	$48.00	$115.20	
4	Paved Road Trenching				Construction Consumables					Paving Saw		$/hr	$18.00		
										Water Truck		$/hr	$30.00		
5	Clean Excavation to Pipe	$1,278.29	140	$178,960.60	Construction Consumables				$6,263.62	CAT Excavator	2	$/hr	$80.00	$22,400.00	$228,624.22
										Dump Truck	4	$/hr	$30.00	$16,800.00	
										Water Truck	1	$/hr	$30.00	$4,200.00	
6	Contaminated Soil Excavation	$1,278.29	10	$12,782.90	Construction Consumables				$447.40	CAT Excavator	2	$/hr	$80.00	$1,600.00	$16,330.50
										ERDF Box Truck	4	$/hr	$30.00	$1,200.00	
										Water Truck	1	$/hr	$30.00	$300.00	
7	Pipe Section & Remove	$697.06			Construction Consumables					CAT Excavator w/ Attachment		$/hr	$80.00		
8	Backfill, Compact, Grade	$747.38	95	$71,001.10	Construction Consumables				$2,485.04	5 CY Loader	1	$/hr	$32.00	$3,040.00	$99,801.14
					Fill Material					300-hp Dozer	1	$/hr	$65.00	$6,175.00	
										Dump Truck	5	$/hr	$30.00	$14,250.00	
										Water Truck	1	$/hr	$30.00	$2,850.00	
9	Demobilize	$629.10	10	$6,291.00						Pickup Truck	1	$/hr	$10.00	$100.00	$6,391.00
	Excavation Air Sampling														$124,491.90
	ERDF LLW Disposal														$224,085.42
	Estimating Contingency	30%													$259,993.48
	TOTAL PROJECT COST			$406,612.94					$13,974.46					$77,389.20	$1,100,506.40
															$1,100,506.40
										Calculated Cost per Linear Foot of Pipe removed:					$11,005.06

Input		
Depth to top of pipe	25	ft
Pipe Diameter	12	in
Trench Slope	1.5	: 1
Pipe Length	100	ft

Excavation Volume Results

	ft^3	CY
Contaminated Volume	4,428	164
Clean Volume	117,370	4,347
Total Volume	121,799	4,511

Input Pipe Diameter	1	ft
Slope down angle	33.7	degrees
2.5/cos(alpha)	3.00	
v	3.00	ft
z	5.50	ft
y	28.50	ft
x	0.50	ft
Total Area	1216.77	sq ft
Pipe Area	0.79	sq ft
Area 3	0.38	sq ft
Area 2	45.45	sq ft
Outer contaminated Area	45.07	sq ft
Net Contaminated Area	44.28	sq ft
Non-Contaminated Area	1173.70	sq ft

Excavation Duration Calculation Results

	Days	No. Boxes
Contaminated Volume	1.0	13
Clean Volume	14.0	

(for scenario Input Pipe Length)

Day 1 cans per day	4	
Day 6 cans per day	30	
yds per can	13	(bank volume)

	CY	Days	Roundup days
Clean Volume	4,347	13.746	14.000
Total Volume	4,511	14.167	15.000
Contaminated Volume	164	0.421	1.000

Day	Boxes Per Day	Yards Per Day	Cumulative Boxes	Cumulative Yards	Delta Yards
1	4	52	4	52	52
2	9.2	119.6	13.2	172	120
3	14.4	187.2	27.6	359	187
4	19.6	254.8	47.2	614	255
5	24.8	322.4	72	936	322
6	30	390	102	1,326	390

Net Contaminated Area

Pipe Diameter		
inch		sq ft
2	0.500	11.1
6	0.5	11.1
12	1	44.3
24	2	177.1
36	3	398.6
48	4	708.5

Calculated ERDF Disposal Cost: $1,366.25 /CY

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Pipe Excavation Estimate

Hanford Project ID No.

Project Title: VC-24

Pipe Material: Vitreous Clay

	Activity	Crew Rate ($/Hr)	Duration (Hours)	Labor Cost	Materials	QTY	UNIT	U.P.	Cost	Equipment	QTY	UNIT	U.P.	Cost	Total Activity Cost
1	Mobilize	$1,210.33	5	$6,051.65						Pickup Truck	1	$/hr	$10.00	$50.00	$6,101.65
2	Pipeline / Interference Location	$305.59	180	$55,067.32	Construction Consumables				$1,927.36	Pickup Truck	1	$/hr	$10.00	$1,802.00	$58,796.67
3	Install Silt Barrier	$356.42	1.8	$641.56	Construction Consumables				$22.45	Pickup Truck	1	$/hr	$10.00	$18.00	$908.41
					Silt Barrier & Stakes	346	$/100 ln ft	$35.00	$140.00	Backhoe	1	$/hr	$46.00	$86.40	
4	Paved Road Trenching				Construction Consumables					Paving Saw		$/hr	$18.00		
										Water Truck		$/hr	$30.00		
5	Clean Excavation to Pipe	$1,278.29	20	$25,565.80	Construction Consumables				$894.80	CAT Excavator	2	$/hr	$80.00	$3,200.00	$32,660.60
										Dump Truck	4	$/hr	$30.00	$2,400.00	
										Water Truck	1	$/hr	$30.00	$600.00	
6	Contaminated Soil Excavation	$1,278.29	30	$38,348.70	Construction Consumables				$1,342.20	CAT Excavator	2	$/hr	$80.00	$4,800.00	$48,990.90
										ERDF Box Truck	4	$/hr	$30.00	$3,600.00	
										Water Truck	1	$/hr	$30.00	$900.00	
7	Pipe Section & Remove	$697.06			Construction Consumables					CAT Excavator w/ Attachment		$/hr	$80.00		
8	Backfill, Compact, Grade	$747.38	17	$12,705.46	Construction Consumables				$444.69	5 CY Loader	1	$/hr	$32.00	$544.00	$17,859.15
					Fill Material					300-hp Dozer	1	$/hr	$65.00	$1,105.00	
										Dump Truck	5	$/hr	$30.00	$2,550.00	
										Water Truck	1	$/hr	$30.00	$510.00	
9	Demobilize	$629.10	10	$6,291.00						Pickup Truck	1	$/hr	$10.00	$100.00	$6,391.00
	Excavation Air Sampling														$42,927.10
	ERDF LLW Disposal														$77,268.78
	Estimating Contingency	30%													$87,571.28
	TOTAL PROJECT COST			$144,671.48					$4,771.51					$22,265.40	$379,475.55
															$379,475.55
										Calculated Cost per Linear Foot of Pipe removed:					$3,794.76

Input		
Depth to top of pipe	5	ft
Pipe Diameter	24	in
Trench Slope	1.5	: 1
Pipe Length	100	ft

Excavation Volume Results

	ft^3	CY
Contaminated Volume	17,714	656
Clean Volume	3,606	134
Total Volume	21,319	790

Input Pipe Diameter	2	ft
Slope down angle	33.7	degrees
2.5/cos(alpha)	3.00	
v	6.01	ft
z	11.01	ft
y	12.01	ft
x	1.01	ft
Total Area	216.33	sq ft
Pipe Area	3.14	sq ft
Area 3	1.53	sq ft
Area 2	181.81	sq ft
Outer contaminated Area	180.28	sq ft
Net Contaminated Area	177.14	sq ft
Non-Contaminated Area	36.06	sq ft

Excavation Duration Calculation Results

	Days	No. Boxes
Contaminated Volume	3.0	50
Clean Volume	2.0	

(for scenario Input Pipe Length)

Day 1 cans per day	4	
Day 6 cans per day	30	
yds per can	13	(bank volume)

	CY	Days	Roundup days
Clean Volume	134	1.682	2.000
Total Volume	790	4.546	5.000
Contaminated Volume	656	2.864	3.000

Day	Boxes Per Day	Yards Per Day	Cumulative Boxes	Cumulative Yards	Delta Yards
1	4	52	4	52	52
2	9.2	119.6	13.2	172	120
3	14.4	187.2	27.6	359	187
4	19.6	254.8	47.2	614	255
5	24.8	322.4	72	936	322
6	30	390	102	1,326	390

Net Contaminated Area

Pipe Diameter		
inch		sq ft
2	0.500	11.1
6	0.5	11.1
12	1	44.3
24	2	177.1
36	3	398.6
48	4	708.5

Calculated ERDF Disposal Cost: $117.78 /CY

Pipe Excavation Estimate

Hanford Project ID No.

Project Title VC-24

Pipe Material: Vitreous Clay

	Activity	Crew Rate ($/Hr)	Duration (Hours)	Labor Cost	Materials	QTY	UNIT	U.P.	Cost	Equipment	QTY	UNIT	U.P.	Cost	Total Activity Cost
1	Mobilize	$1,210.33	5	$6,051.65						Pickup Truck	1	$/hr	$10.00	$50.00	$6,101.65
2	Pipeline / Interference Location	$305.59	255	$77,956.57	Construction Consumables				$2,729.53	Pickup Truck	1	$/hr	$10.00	$2,552.00	$83,288.10
3	Install Silt Barrier	$356.42	2.0	$712.84	Construction Consumables				$24.95	Pickup Truck	1	$/hr	$10.00	$20.00	$993.79
					Silt Barrier & Stakes	386	$/100 ln ft	$35.00	$140.00	Backhoe	1	$/hr	$48.00	$96.00	
4	Paved Road Trenching				Construction Consumables					Paving Saw		$/hr	$18.00		
										Water Truck		$/hr	$30.00		
5	Clean Excavation to Pipe	$1,278.29	60	$76,697.40	Construction Consumables				$2,684.41	CAT Excavator	2	$/hr	$80.00	$9,600.00	$97,981.81
										Dump Truck	4	$/hr	$30.00	$7,200.00	
										Water Truck	1	$/hr	$30.00	$1,800.00	
6	Contaminated Soil Excavation	$1,278.29	20	$25,565.80	Construction Consumables				$894.80	CAT Excavator	2	$/hr	$80.00	$3,200.00	$32,660.60
										ERDF Box Truck	4	$/hr	$30.00	$2,400.00	
										Water Truck	1	$/hr	$30.00	$600.00	
7	Pipe Section & Remove	$697.06			Construction Consumables					CAT Excavator w/ Attachment		$/hr	$80.00		
8	Backfill, Compact, Grade	$747.38	34	$25,410.92	Construction Consumables				$889.38	6 CY Loader	1	$/hr	$32.00	$1,088.00	$36,718.30
					Fill Material					300-hp Dozer	1	$/hr	$65.00	$2,210.00	
										Dump Truck	5	$/hr	$30.00	$5,100.00	
										Water Truck	1	$/hr	$30.00	$1,020.00	
9	Demobilize	$629.10	10	$6,291.00						Pickup Truck	1	$/hr	$10.00	$100.00	$6,391.00
	Excavation Air Sampling														$65,776.81
	ERDF LLW Disposal														$118,401.86
	Estimating Contingency	30%													$134,188.78
	TOTAL PROJECT COST			$218,716.18					$7,363.07					$37,036.00	$581,484.71
															$581,484.71
										Calculated Cost per Linear Foot of Pipe removed:					$5,814.85

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Pipeline Removal Vs. Characterization Study - Decision Support Tool

Input		
Depth to top of pipe	10	ft
Pipe Diameter	24	in
Trench Slope	1.5	: 1
Pipe Length	100	ft

Excavation Volume Results

	ft³	CY
Contaminated Volume	17,714	656
Clean Volume	25,369	940
Total Volume	43,083	1,596

Input Pipe Diameter	2	ft
Slope down angle	33.7	degrees
2.5/cos(alpha)	3.00	
v	6.01	ft
z	11.01	ft
y	17.01	ft
x	1.01	ft
Total Area	433.97	sq ft
Pipe Area	3.14	sq ft
Area 3	1.53	sq ft
Area 2	181.81	sq ft
Outer contaminated Area	180.28	sq ft
Net Contaminated Area	177.14	sq ft
Non-Contaminated Area	253.69	sq ft

Excavation Duration Calculation Results

	Days	No. Boxes
Contaminated Volume	2.0	50
Clean Volume	6.0	

(for scenario Input Pipe Length)

Day 1 cans per day	4	
Day 6 cans per day	30	
yds per can	13	(bank volume)

	CY	Days	Roundup days
Clean Volume	940	5.009	6.000
Total Volume,	1,596	6.691	7.000
Contaminated Volume	656	1.682	2.000

Day	Boxes Per Day	Yards Per Day	Cumulative Boxes	Cumulative Yards	Delta Yards
1	4	52	4	52	52
2	9.2	119.6	13.2	172	120
3	14.4	187.2	27.6	359	187
4	19.6	254.8	47.2	614	255
5	24.8	322.4	72	936	322
6	30	390	102	1,326	390

Net Contaminated Area		
Pipe Diameter		
inch		sq ft
2	0.500	11.1
6	0.5	11.1
12	1	44.3
24	2	177.1
36	3	398.6
48	4	708.5

Calculated ERDF Disposal Cost: $180.47 /CY

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Pipeline Removal Vs. Characterization Study - Decision Support Tool

Pipe Excavation Estimate

Hanford Project ID No.

Project Title: VC-24

Pipe Material: Vitreous Clay

	Activity	Crew Rate ($/Hr)	Duration (Hours)	Labor Cost	Materials	QTY	UNIT	U.P.	Cost	Equipment	QTY	UNIT	U.P.	Cost	Total Activity Cost
1	Mobilize	$1,210.33	5	$6,051.66						Pickup Truck	1	$/hr	$10.00	$50.00	$6,101.66
2	Pipeline / Interference Location	$309.59	330	$100,906.82	Construction Consumables				$3,531.70	Pickup Truck	1	$/hr	$10.00	$3,302.00	$107,739.52
3	Install Silt Barrier	$356.42	2.2	$784.12	Construction Consumables				$27.44	Pickup Truck	1	$/hr	$10.00	$22.00	$1,114.17
					Silt Barrier & Stakes	420	$/100 ln ft	$35.00	$175.00	Backhoe	1	$/hr	$48.00	$105.60	
4	Paved Road Trenching				Construction Consumables					Paving Saw		$/hr	$18.00		
										Water Truck		$/hr	$30.00		
5	Clean Excavation to Pipe	$1,278.29	80	$102,263.20	Construction Consumables				$3,579.21	CAT Excavator	2	$/hr	$80.00	$12,800.00	$130,842.41
										Dump Truck	4	$/hr	$30.00	$9,600.00	
										Water Truck	1	$/hr	$30.00	$2,400.00	
6	Contaminated Soil Excavation	$1,278.29	20	$25,565.80	Construction Consumables				$894.80	CAT Excavator	2	$/hr	$80.00	$3,200.00	$32,660.80
										ERDF Box Truck	4	$/hr	$30.00	$2,400.00	
										Water Truck	1	$/hr	$30.00	$600.00	
7	Pipe Section & Remove	$697.00			Construction Consumables					CAT Excavator w/ Attachment		$/hr	$80.00		
8	Backfill, Compact, Grade	$747.38	57	$42,600.66	Construction Consumables				$1,491.02	5 CY Loader	1	$/hr	$32.00	$1,824.00	$59,880.68
					Fill Material					300-hp Dozer	1	$/hr	$65.00	$3,705.00	
										Dump Truck	5	$/hr	$30.00	$8,550.00	
										Water Truck	1	$/hr	$30.00	$1,710.00	
9	Demobilize	$829.10	10	$8,291.00						Pickup Truck	1	$/hr	$10.00	$100.00	$8,391.00
	Excavation Air Sampling														$86,132.61
	ERDF LLW Disposal														$155,036.52
	Estimating Contingency	30%													$175,710.32
	TOTAL PROJECT COST			$284,462.25					$9,699.19					$80,368.60	$761,411.38
															$761,411.38
										Calculated Cost per Linear Foot of Pipe removed:					$7,614.11

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Input		
Depth to top of pipe	15	ft
Pipe Diameter	24	in
Trench Slope	1.5	: 1
Pipe Length	100	ft

Excavation Volume Results

	ft³	CY
Contaminated Volume	17,714	656
Clean Volume	54,633	2,023
Total Volume	72,347	2,680

Input Pipe Diameter	2	ft
Slope down angle	33.7	degrees
2.5/cos(alpha)	3.00	
v	6.01	ft
z	11.01	ft
y	22.01	ft
x	1.01	ft
Total Area	726.61	sq ft
Pipe Area	3.14	sq ft
Area 3	1.53	sq ft
Area 2	181.81	sq ft
Outer contaminated Area	180.28	sq ft
Net Contaminated Area	177.14	sq ft
Non-Contaminated Area	546.33	sq ft

Excavation Duration Calculation Results

	Days	No. Boxes
Contaminated Volume	2.0	50
Clean Volume	8.0	

(for scenario Input Pipe Length)

Day 1 cans per day	4			
Day 6 cans per day	30			
yds per can	13	(bank volume)		
	CY		Days	Roundup days
Clean Volume	2,023		7.788	8.000
Total Volume,	2,680		9.471	10.000
Contaminated Volume	656		1.682	2.000

Day	Boxes Per Day	Yards Per Day	Cumulative Boxes	Cumulative Yards	Delta Yards
1	4	52	4	52	52
2	9.2	119.6	13.2	172	120
3	14.4	187.2	27.6	359	187
4	19.6	254.8	47.2	614	255
5	24.8	322.4	72	936	322
6	30	390	102	1,326	390

Net Contaminated Area

Pipe Diameter		
inch		sq ft
2	0.500	11.1
6	0.5	11.1
12	1	44.3
24	2	177.1
36	3	398.6
48	4	708.5

Calculated ERDF Disposal Cost: $236.32 /CY

Pipe Excavation Estimate

Hanford Project ID No.

Project Title: VC-24

Pipe Material: Vitreous Clay

	Activity	Crew Rate ($/Hr)	Duration (Hours)	Labor Cost	Materials	QTY	UNIT	U.P.	Cost	Equipment	QTY	UNIT	U.P.	Cost	Total Activity Cost
1	Mobilize	$1,210.33	5	$6,051.65						Pickup Truck	1	$/hr	$10.00	$50.00	$6,101.65
2	Pipeline / Interference Location	$305.59	405	$123,825.07	Construction Consumables				$4,333.88	Pickup Truck	1	$/hr	$10.00	$4,052.00	$132,210.95
3	Install Silt Barrier	$356.42	2.4	$855.41	Construction Consumables				$29.94	Pickup Truck	1	$/hr	$10.00	$24.00	$1,199.55
					Silt Barrier & Stakes	466	$/100 ln ft	$35.00	$175.00	Backhoe	1	$/hr	$48.00	$115.20	
4	Paved Road Trenching				Construction Consumables					Paving Saw		$/hr	$18.00		
										Water Truck		$/hr	$30.00		
5	Clean Excavation to Pipe	$1,278.29	120	$153,394.80	Construction Consumables				$5,368.82	CAT Excavator	2	$/hr	$80.00	$19,200.00	$196,963.62
										Dump Truck	4	$/hr	$30.00	$14,400.00	
										Water Truck	1	$/hr	$30.00	$3,600.00	
6	Contaminated Soil Excavation	$1,278.29	20	$25,565.80	Construction Consumables				$854.80	CAT Excavator	2	$/hr	$80.00	$3,200.00	$32,000.00
										ERDF Box Truck	4	$/hr	$30.00	$2,400.00	
										Water Truck	1	$/hr	$30.00	$600.00	
7	Pipe Section & Remove	$697.08			Construction Consumables					CAT Excavator w/ Attachment		$/hr	$80.00		
8	Backfill, Compact, Grade	$747.38	85	$63,527.30	Construction Consumables				$2,223.46	6 CY Loader	1	$/hr	$32.00	$2,720.00	$69,295.76
					Fill Material					300-hp Dozer	1	$/hr	$65.00	$5,525.00	
										Dump Truck	5	$/hr	$30.00	$12,750.00	
										Water Truck	1	$/hr	$30.00	$2,550.00	
9	Demobilize	$629.10	10	$6,291.00						Pickup Truck	1	$/hr	$10.00	$100.00	$6,391.00
	Excavation Air Sampling														$115,955.78
	ERDF LLW Disposal														$208,720.40
	Estimating Contingency	30%													$238,549.79
	TOTAL PROJECT COST			$379,511.03					$13,025.89					$71,286.20	$1,025,049.09
															$1,025,049.09

Calculated Cost per Linear Foot of Pipe removed: $10,250.49

Input		
Depth to top of pipe	20	ft
Pipe Diameter	24	in
Trench Slope	1.5	: 1
Pipe Length	100	ft

Excavation Volume Results

	ft³	CY
Contaminated Volume	17,714	656
Clean Volume	91,397	3,385
Total Volume	109,111	4,041

Input Pipe Diameter	2	ft
Slope down angle	33.7	degrees
2.5/cos(alpha)	3.00	
v	6.01	ft
z	11.01	ft
y	27.01	ft
x	1.01	ft
Total Area	1094.25	sq ft
Pipe Area	3.14	sq ft
Area 3	1.53	sq ft
Area 2	181.81	sq ft
Outer contaminated Area	180.28	sq ft
Net Contaminated Area	177.14	sq ft
Non-Contaminated Area	913.97	sq ft

Excavation Duration Calculation Results

	Days	No. Boxes
Contaminated Volume	2.0	50
Clean Volume	12.0	

(for scenario Input Pipe Length)

Day 1 cans per day	4
Day 6 cans per day	30
yds per can	13 (bank volume)

	CY	Days	Roundup days
Clean Volume	3,385	11.280	12.000
Total Volume,	4,041	12.962	13.000
Contaminated Volume	656	1.682	2.000

Day	Boxes Per Day	Yards Per Day	Cumulative Boxes	Cumulative Yards	Delta Yards
1	4	52	4	52	52
2	9.2	119.6	13.2	172	120
3	14.4	187.2	27.6	359	187
4	19.6	254.8	47.2	614	255
5	24.8	322.4	72	936	322
6	30	390	102	1,326	390

Net Contaminated Area

Pipe Diameter		
inch		sq ft
2	0.500	11.1
6	0.5	11.1
12	1	44.3
24	2	177.1
36	3	398.6
48	4	708.5

Calculated ERDF Disposal Cost: $318.14 /CY

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Pipeline Removal Vs. Characterization Study - Decision Support Tool

Pipe Excavation Estimate

Hanford Project ID No.
Project Title: VC-24

Pipe Material: Vitreous Clay

	Activity	Crew Rate ($/Hr)	Duration (Hours)	Labor Cost	Materials	QTY	UNIT	U.P.	Cost	Equipment	QTY	UNIT	U.P.	Cost	Total Activity Cost
1	Mobilize	$1,210.33	5	$6,051.65						Pickup Truck	1	$/hr	$10.00	$50.00	$6,101.65
2	Pipeline / Interference Location	$305.80	480	$146,744.32	Construction Consumables				$5,136.06	Pickup Truck	1	$/hr	$10.00	$4,802.00	$156,682.37
3	Install Silt Barrier	$366.42	2.8	$926.60	Construction Consumables				$32.43	Pickup Truck	1	$/hr	$10.00	$28.00	$1,319.03
					Silt Barrier & Stakes	506	5/100 ln ft	$35.00	$210.00	Backhoe	1	$/hr	$48.00	$124.80	
4	Paved Road Trenching				Construction Consumables					Paving Saw		$/hr	$18.00		
										Water Truck		$/hr	$30.00		
5	Clean Excavation to Pipe	$1,278.29	160	$204,526.40	Construction Consumables				$7,158.42	CAT Excavator	2	$/hr	$80.00	$25,600.00	$261,284.82
										Dump Truck	4	$/hr	$30.00	$19,200.00	
										Water Truck	1	$/hr	$30.00	$4,800.00	
6	Contaminated Soil Excavation	$1,278.29	20	$26,566.80	Construction Consumables				$894.80	CAT Excavator	2	$/hr	$80.00	$3,200.00	$32,069.80
										ERDF Box Truck	4	$/hr	$30.00	$2,400.00	
										Water Truck	1	$/hr	$30.00	$600.00	
7	Pipe Section & Remove	$697.06			Construction Consumables					CAT Excavator w/ Attachment		$/hr	$80.00		
8	Backfill, Compact, Grade	$747.30	119	$88,930.22	Construction Consumables				$3,112.04	5 CY Loader	1	$/hr	$32.00	$3,808.00	$126,014.06
					Fill Material					300-hp Dozer	1	$/hr	$65.00	$7,735.00	
										Dump Truck	5	$/hr	$30.00	$17,850.00	
										Water Truck	1	$/hr	$30.00	$3,570.00	
9	Demobilize	$629.10	10	$6,291.00						Pickup Truck	1	$/hr	$10.00	$100.00	$6,391.00
	Excavation Air Sampling														$147,363.61
	ERDF LLW Disposal														$295,254.49
	Estimating Contingency	30%													$300,621.76
	TOTAL PROJECT COST			$479,044.68					$16,544.55					$93,885.80	$1,302,694.29
															$1,302,694.29
										Calculated Cost per Linear Foot of Pipe removed:					$13,026.94

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Input		
Depth to top of pipe	25	ft
Pipe Diameter	24	in
Trench Slope	1.5	: 1
Pipe Length	100	ft

Excavation Volume Results

	ft³	CY
Contaminated Volume	17,714	656
Clean Volume	135,661	5,024
Total Volume	153,375	5,681

Input Pipe Diameter	2	ft
Slope down angle	33.7	degrees
2.5/cos(alpha)	3.00	
v	6.01	ft
z	11.01	ft
y	32.01	ft
x	1.01	ft
Total Area	1536.89	sq ft
Pipe Area	3.14	sq ft
Area 3	1.53	sq ft
Area 2	181.81	sq ft
Outer contaminated Area	180.28	sq ft
Net Contaminated Area	177.14	sq ft
Non-Contaminated Area	1356.61	sq ft

Excavation Duration Calculation Results

	Days	No. Boxes
Contaminated Volume	2.0	50
Clean Volume	16.0	

(for scenario Input Pipe Length)

Day 1 cans per day	4	
Day 6 cans per day	30	
yds per can	13	(bank volume)

	CY	Days	Roundup days
Clean Volume	5,024	15.483	16.000
Total Volume,	5,681	17.165	18.000
Contaminated Volume	656	1.882	2.000

Day	Boxes Per Day	Yards Per Day	Cumulative Boxes	Cumulative Yards	Delta Yards
1	4	52	4	52	52
2	9.2	119.6	13.2	172	120
3	14.4	187.2	27.6	359	187
4	19.6	254.8	47.2	614	255
5	24.8	322.4	72	936	322
6	30	390	102	1,326	390

Net Contaminated Area

Pipe Diameter		
inch		sq ft
2	0.500	11.1
6	0.5	11.1
12	1	44.3
24	2	177.1
36	3	398.6
48	4	708.5

Calculated ERDF Disposal Cost: $404.31 /CY

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Steel and Stainless Steel Pipe

Excavation/Removal Cost per Linear Foot

Estimate Scenario		Depth to Top of Pipe				
Pipe Material	Pipe Diameter (in)	5 ft	10 ft	15 ft	20 ft	25 ft
Steel	2	$2,648.38	$4,145.05	$5,804.25	$7,941.20	$10,216.67
Steel	6	$2,648.38	$4,145.05	$5,804.25	$7,941.20	$10,216.67
Steel	12	$2,907.68	$4,474.00	$6,517.31	$8,700.69	$11,045.82
Steel	24	$3,835.49	$5,855.59	$7,654.85	$10,291.23	$13,067.68
Steel	36					
Steel	48					

Estimate Assumptions

= Scenario not applicable to Hanford site.

Pipe sheared in trench with excavator-mounted hydraulic shear.

Additional labor allocated for shearing, removal, and loading pipe sections into ERDF boxes.

Pipe cut into 8 ft long sections.

Pipe NOT crushed prior to ERDF box loading.

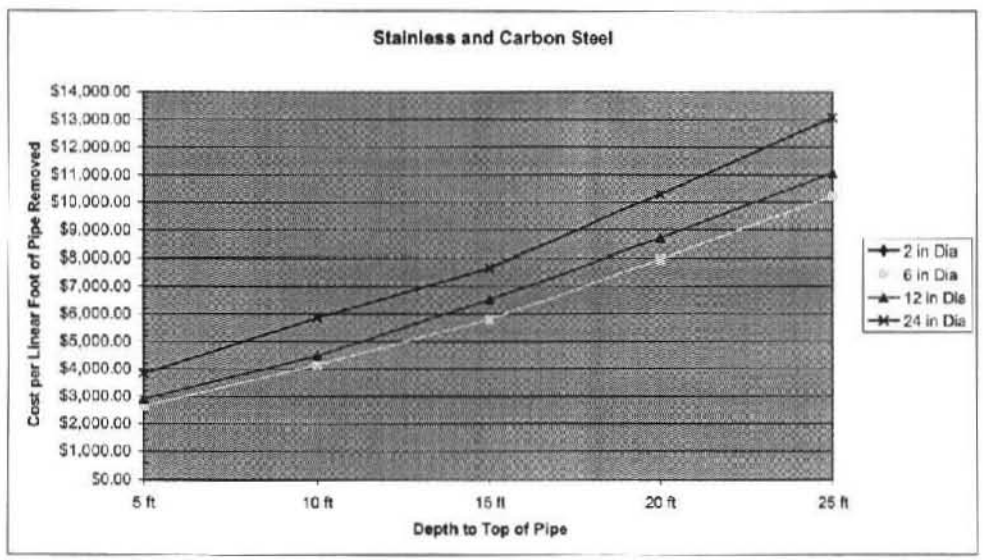
General Assumptions

Clean soil removed from trench and stockpiled close to excavation site for reuse as backfill material.

Contaminated soil loaded into lined ERDF boxes for disposal.

All scenarios do not involve any excavation of paved areas.

Silt fencing calculated based on (2.5 x L) + (8 x y), where L is the length of pipe to be removed, and y is depth from the surface to bottom of the triangle below the pipe (from geometry calcs).



Plot Data

	2 in Dia	6 in Dia	12 in Dia	24 in Dia
5 ft	$2,648.38	$2,648.38	$2,907.68	$3,835.49
10 ft	$4,145.05	$4,145.05	$4,474.00	$5,855.59
15 ft	$5,804.25	$5,804.25	$6,517.31	$7,654.85
20 ft	$7,941.20	$7,941.20	$8,700.69	$10,291.23
25 ft	$10,216.67	$10,216.67	$11,045.82	$13,067.68

Pipeline Removal Vs. Characterization Study - Decision Support Tool

Labor		
1	Supervisor	$75.00
2	General Laborer	$54.14
3	Teamster	$54.35
4	Heavy Eqpmt Operator	$64.86
5	HP Technician	$68.17
6	Burner/Pipefitter	$67.96
7	Other Craft	$67.96
8	Spare	
9	Spare	
10	Spare	

Values Used Throughout	
Estimating Contingency	30%
Labor Hours per Work Shift	10
Construction Consumables (% of direct labor)	3.5%
Excavation Air Sampling (% of total cost)	25%
ERDF LLW disposal (% of total cost)	45%
Soil Expansion Factor	25%
Pipe Rubble Factor	40%
Steel Pipe Lengths for Removal, maximum (ft)	8

Unit Prices (2007 $)

Type	Unit	Description	$$
A	each	60 feet silt brass	$500
B	per day	CAT 320 Excavator Rental	$1,500
C	each	Trench box	$550
D	per month	Forklift	$1,000
E	per month	Generators	$500
F	per month	Job Trailer	$500
G	per month	Drill Rig	$1,000
H	per day	Dump Truck	$250
I	per day	Grader	$250
J	per day	Roller	$250
K	per day	Front-end Loader	$250
L	Case	Tape - 6"	$400.00
M	Case	Tape - 2"	$180.00
N	ft	Sheeting	$4.00
O	100-ft roll	Plastic Sheeting	$650.00
P	pair	Gloves	$6.50
Q	25#b box	Rags	$130.00
R	$	Tools	$500.00
S	5-ft section	Casing	$1,000.00
T	split spoon	Split Spoons	$2,600.00
U	each	Split Spoon Liners	$20.00
V	pair	Laundry	$25.00
W	ft	Cable	$10.00
X	each	Retooling	$100.00
Y	drum	Drums	$55.35
Z	per sheet	Plywood (4'x8' 3/4 cdx exterior)	$25.00
AA	each	Drum Pallets	$35.00
AB	each	2 x 4s	$9.00
AC	$	Rope	$100.00
AD	blank	Signs	$20.00
AE	yd	Gravel	$40.00
AF	per hour	CAT 320 Excavator	$80.00
AG	per hour	Shuttle Dump Truck	$30.00
AH	per hour	Water Truck	$30.00
AI	per hour	Paving Saw	$18.00
AJ	per hour	Backhoe	$48.00
AK	100-ft roll	Silt Fencing w/ Stakes	$35.00
AL			
AM			

Type	Crew Activity	Crew Size	Crew	Rate
1	Mobilize	1	Supervisor	75.00
		6	General Laborer	54.14
		5	Teamster	54.35
		2	Heavy Eqpmt Ope	64.86
		6	HP Technician	68.17
			Burner/Pipefitter	67.96
			Other Craft	67.96
2	Pipeline / Interference Location	1	Supervisor	75.00
		3	General Laborer	54.14
			Teamster	54.35
			Heavy Eqpmt Ope	64.86
		1	HP Technician	68.17
			Burner/Pipefitter	67.96
			Other Craft	67.96
3	Install Silt Barrier	1	Supervisor	75.00
		4	General Laborer	54.14
			Teamster	54.35
		1	Heavy Eqpmt Ope	64.86
			HP Technician	68.17
			Burner/Pipefitter	67.96
			Other Craft	67.96
4	Paved Road Trenching		Supervisor	75.00
			General Laborer	54.14
			Teamster	54.35
			Heavy Eqpmt Ope	64.86
			HP Technician	68.17
			Burner/Pipefitter	67.96
			Other Craft	67.96
5	Clean Excavation to Pipe	1	Supervisor	75.00
		6	General Laborer	54.14
		5	Teamster	54.35
		2	Heavy Eqpmt Ope	64.86
		6	HP Technician	68.17
			Burner/Pipefitter	67.96
		1	Other Craft	67.96
6	Contaminated Soil Excavation	1	Supervisor	75.00
		6	General Laborer	54.14
		5	Teamster	54.35
		2	Heavy Eqpmt Ope	64.86
		6	HP Technician	68.17
			Burner/Pipefitter	67.96
		1	Other Craft	67.96
7	Pipe Section & Remove	1	Supervisor	75.00
		4	General Laborer	54.14
			Teamster	54.35
		1	Heavy Eqpmt Ope	64.86
		4	HP Technician	68.17
		1	Burner/Pipefitter	67.96
			Other Craft	67.96
8	Backfill, Compact, Grade	1	Supervisor	75.00
		4	General Laborer	54.14
		6	Teamster	54.35
		2	Heavy Eqpmt Ope	64.86
			HP Technician	68.17
			Burner/Pipefitter	67.96
			Other Craft	67.96
9	Demobilize	1	Supervisor	75.00
		4	General Laborer	54.14
			Teamster	54.35
		1	Heavy Eqpmt Ope	64.86
		4	HP Technician	68.17
			Burner/Pipefitter	67.96
			Other Craft	67.96

Type	Crew Name	Crew Rate
1	Mobilize	$1,210.33
2	Pipeline / Interference I	$365.59
3	Install Silt Barrier	$366.42
4	Paved Road Trenching	$0.00
5	Clean Excavation to Pi	$1,278.29
6	Contaminated Soil Exc	$1,278.29
7	Pipe Section & Remov	$867.06
8	Backfill, Compact, Grad	$747.38
9	Demobilize	$629.13

Activity Duration Constants		
Activity	Duration	Unit
Field (Miss Utility) Survey	20	ft² per hour
Silt Barrier Installation	220	ln ft per hour
Paving Saw Trench Cutting	50	ln ft per hour
Steel Pipe Sectioning & Removal	44	ln ft per hour
RC Pipe Sectioning & Removal	13	ln ft per hour
Backfill	80	CY per hour

Excavation Duration Calculation Basis	
CY (bank) per ERDF Box	13
Boxes per day @ Day 1	4
Boxes per day @ Day 8	30

Probable Underground Pipe Combinations at the Hanford Site

Pipeline Material	Pipe Diameter (inches) 2	6	12	24	36	48
Vitreous Clay						
Steel (stainless/carbon)						
Concrete Masonry						
Reinforced Concrete						

Legend
= Not Applicable
= Potentially Applicable
= Definitely Applicable

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Pipeline Removal Vs. Characterization Study - Decision Support Tool

Pipe Excavation Estimate

Hanford Project ID No.

Project Title: CS/SS-2

Pipe Material: Carbon / Stainless Steel

	Activity	Crew Rate ($/Hr)	Duration (Hours)	Labor Cost	Materials	QTY	UNIT	U.P.	Cost	Equipment	QTY	UNIT	U.P.	Cost	Total Activity Cost
1	Mobilize	$1,210.33	5	$6,051.65						Pickup Truck	1	$/hr	$10.00	$50.00	$6,101.65
2	Pipeline / Interference Location	$305.59	101	$30,856.27	Construction Consumables				$1,083.47	Pickup Truck	1	$/hr	$10.00	$1,013.00	$33,052.74
3	Install Silt Barrier	$356.42	1.6	$570.27	Construction Consumables				$19.98	Pickup Truck	1	$/hr	$10.00	$16.00	$823.03
					Silt Barrier & Stakes	304	$/100 ln ft	$35.00	$140.00	Backhoe	1	$/hr	$48.00	$76.80	
4	Paved Road Trenching				Construction Consumables					Paving Saw		$/hr	$18.00		
										Water Truck		$/hr	$30.00		
5	Clean Excavation to Pipe	$1,278.29	30	$38,348.70	Construction Consumables				$1,342.20	CAT Excavator	2	$/hr	$80.00	$4,800.00	$46,990.90
										Dump Truck	4	$/hr	$30.00	$3,600.00	
										Water Truck	1	$/hr	$30.00	$900.00	
6	Contaminated Soil Excavation	$1,278.29	10	$12,782.90	Construction Consumables				$447.40	CAT Excavator	2	$/hr	$80.00	$1,600.00	$16,330.30
										ERDF Box Truck	4	$/hr	$30.00	$1,200.00	
										Water Truck	1	$/hr	$30.00	$300.00	
7	Pipe Section & Remove	$607.06	2.3	$1,603.24	Construction Consumables				$56.11	CAT Excavator w/ Attachment	1	$/hr	$80.00	$184.00	$1,843.35
8	Backfill, Compact, Grade	$747.38	6	$4,484.28	Construction Consumables				$156.95	5 CY Loader	1	$/hr	$32.00	$192.00	$6,303.23
					Fill Material					300-hp Dozer	1	$/hr	$65.00	$390.00	
										Dump Truck	5	$/hr	$30.00	$900.00	
										Water Truck	1	$/hr	$30.00	$180.00	
9	Demobilize	$629.10	10	$6,291.00						Pickup Truck	1	$/hr	$10.00	$100.00	$6,391.00
	Excavation Air Sampling														$29,959.05
	ERDF LLW Disposal														$53,926.29
	Estimating Contingency	30%													$61,116.46
	TOTAL PROJECT COST			$101,088.31					$3,246.10					$16,501.80	$264,838.01
															$264,838.01
										Calculated Cost per Linear Foot of Pipe removed:					$2,648.38

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Pipeline Removal Vs. Characterization Study - Decision Support Tool

Input		
Depth to top of pipe	5	ft
Pipe Diameter	2	in
Trench Slope	1.5	:1
Pipe Length	100	ft

Excavation Volume Results

	ft³	CY
Contaminated Volume	1,107	41
Clean Volume	5,712	212
Total Volume	6,819	253

Input Pipe Diameter	0.5	ft
Slope down angle	33.7	degrees
2.5/cos(alpha)	3.00	
v	1.50	ft
z	2.75	ft
y	6.75	ft
x	0.25	ft
Total Area	68.39	sq ft
Pipe Area	0.20	sq ft
Area 3	0.10	sq ft
Area 2	11.36	sq ft
Outer contaminated Area	11.27	sq ft
Net Contaminated Area	11.07	sq ft
Non-Contaminated Area	57.12	sq ft

Excavation Duration Calculation Results

	Days	No. Boxes
Contaminated Volume	1.0	3
Clean Volume	3.0	

(for scenario Input Pipe Length)

	Vol (CY)	No. Boxes
Pipe Debris	0.1	0.031

(for scenario Input Pipe Length)

Calculated ERDF Disposal Cost: $1,312.57 /CY

Day 1 cans per day	4		
Day 6 cans per day	30		
yds per can	13	(bank volume)	
		Days	Roundup days
Clean Volume, yds	212	2.214	3.000
Total Volume	253	2.433	3.000
Contaminated Volume, yds	41	0.219	1.000

Day	Boxes Per Day	Yards Per Day	Cumulative Boxes	Cumulative Yards	Delta Yards
1	4	52	4	52	52
2	9.2	119.6	13.2	172	120
3	14.4	187.2	27.6	359	187
4	19.6	254.8	47.2	614	255
5	24.8	322.4	72	936	322
6	30	390	102	1,326	390

Net Contaminated Area

Pipe Diameter		
inch		sq ft
2	0.500	11.1
6	0.5	11.1
12	1	44.3
24	2	177.1
36	3	398.6
48	4	708.5

Box Dimensions

L (ft)	W (ft)	H (ft)	Vol (CY)
20	8	6	35.56

Box Weight Capacity

tons	lbs
20	40,000
	9,040 lbs soil bedding
	30,960 lbs Available Weight Capacity

6 inch soil bedding required for demo debris.

L (ft)	W (ft)	H (ft)	Vol (ft³)
20	8	0.5	80

Soil Density 113 lb/ft³

Based on Volume

Pipe cut to length: 8 ft

Number laid in box end-to-end: 2

Number of pipe sections that fit in box: 406

Number of boxes required for scenario pipe length: 0.031 Based on Volume capacity

Based on Weight

Number of boxes required for scenario pipe length: 0.012 Based on Weight capacity

Pipe Data from Crane Technical Manual No. 410
(Assume pipe is SCH 40)

Diameter	lb/ft
2	3.65
6	18.97
12	53.52
24	171.29
36	282.35

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Pipeline Removal Vs. Characterization Study - Decision Support Tool

Pipe Excavation Estimate

Hanford Project ID No.

Project Title: CS/SS-12

Pipe Material: Carbon / Stainless Steel

	Activity	Crew Rate ($/Hr)	Duration (Hours)	Labor Cost	Materials	QTY	UNIT	U.P.	Cost	Equipment	QTY	UNIT	U.P.	Cost	Total Activity Cost
1	Mobilize	$1,210.33	5	$6,051.65						Pickup Truck	1	$/hr	$10.00	$50.00	$6,101.65
2	Pipeline / Interference Location	$305.59	278	$84,831.78	Construction Consumables				$2,969.11	Pickup Truck	1	$/hr	$10.00	$2,778.00	$90,578.90
3	Install Silt Barrier	$356.42	2.0	$712.84	Construction Consumables				$24.96	Pickup Truck	1	$/hr	$10.00	$20.00	$993.79
					Silt Barrier & Stakes	399	$/100 ln ft	$35.00	$140.00	Backhoe	1	$/hr	$48.00	$96.00	
4	Paved Road Trenching				Construction Consumables					Paving Saw		$/hr	$18.00		
										Water Truck		$/hr	$30.00		
5	Clean Excavation to Pipe	$1,278.29	80	$102,263.20	Construction Consumables				$3,579.21	CAT Excavator	2	$/hr	$80.00	$12,800.00	$130,642.41
										Dump Truck	4	$/hr	$30.00	$9,600.00	
										Water Truck	1	$/hr	$30.00	$2,400.00	
6	Contaminated Soil Excavation	$1,278.29	10	$12,782.90	Construction Consumables				$447.40	CAT Excavator	2	$/hr	$80.00	$1,600.00	$16,330.30
										ERDF Box Truck	4	$/hr	$30.00	$1,200.00	
										Water Truck	1	$/hr	$30.00	$300.00	
7	Pipe Section & Remove	$807.06	2.3	$1,603.24	Construction Consumables				$56.11	CAT Excavator w/ Attachment	1	$/hr	$80.00	$184.00	$1,843.35
8	Backfill, Compact, Grade	$747.38	40	$29,895.20	Construction Consumables				$1,046.33	5 CY Loader	1	$/hr	$32.00	$1,280.00	$42,021.53
					Fill Material					300-hp Dozer	1	$/hr	$65.00	$2,600.00	
										Dump Truck	5	$/hr	$30.00	$9,000.00	
										Water Truck	1	$/hr	$30.00	$1,200.00	
9	Demobilize	$629.10	10	$6,291.00						Pickup Truck	1	$/hr	$10.00	$100.00	$6,391.00
	Excavation Air Sampling														$73,725.23
	ERDF LLW Disposal														$132,706.42
	Estimating Contingency	30%													$150,309.48
	TOTAL PROJECT COST			$244,431.51					$9,283.12					$42,206.00	$951,731.06
															$951,731.06
										Calculated Cost per Linear Foot of Pipe removed:					$6,517.31

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Pipeline Removal Vs. Characterization Study - Decision Support Tool

Input		
Depth to top of pipe	15	ft
Pipe Diameter	12	in
Trench Slope	1.5	: 1
Pipe Length	100	ft

Excavation Volume Results

	ft³	CY
Contaminated Volume	4,428	164
Clean Volume	46,856	1,735
Total Volume	51,285	1,899

Input Pipe Diameter	1	ft
Slope down angle	33.7	degrees
2.5/cos(alpha)	3.00	
v	3.00	ft
z	5.50	ft
y	18.50	ft
x	0.50	ft
Total Area	513.63	sq ft
Pipe Area	0.79	sq ft
Area 3	0.38	sq ft
Area 2	45.45	sq ft
Outer contaminated Area	45.07	sq ft
Net Contaminated Area	44.28	sq ft
Non-Contaminated Area	468.56	sq ft

Excavation Duration Calculation Results

	Days	No. Boxes
Contaminated Volume	1.0	13
Clean Volume	8.0	

(for scenario Input Pipe Length)

	Vol (CY)	No. Boxes
Pipe Debris	2.9	0.173

(for scenario Input Pipe Length)

Calculated ERDF Disposal Cost: $795.01 /CY

Day 1 cans per day	4		
Day 6 cans per day	30		
yds per can	13	(bank volume)	
		Days	Roundup days
Clean Volume, yds	1,735	7.050	8.000
Total Volume,	1899	7.470	8.000
Contaminated Volume, yds	164	0.421	1.000

Day	Boxes Per Day	Yards Per Day	Cumulative Boxes	Cumulative Yards	Delta Yards
1	4	52	4	52	52
2	9.2	119.6	13.2	172	120
3	14.4	187.2	27.6	359	187
4	19.6	254.8	47.2	614	255
5	24.8	322.4	72	936	322
6	30	390	102	1,326	390

Net Contaminated Area

Pipe Diameter		
inch		sq ft
2	0.500	11.1
6	0.5	11.1
12	1	44.3
24	2	177.1
36	3	398.6
48	4	708.5

Box Dimensions

L (ft)	W (ft)	H (ft)	Vol (CY)
20	8	6	35.56

Box Weight Capacity

tons	lbs
20	40,000
	9,040 lbs soil bedding
	30,960 lbs **Available Weight Capacity**

6 inch soil bedding required for demo debris.

L (ft)	W (ft)	H (ft)	Vol (ft³)
20	8	0.5	80

Soil Density 113 lb/ft³

Based on Volume

Pipe cut to length: 8 ft

Number laid in box end-to-end: 2

Number of pipe sections that fit in box: 100

Number of boxes required for scenario pipe length: 0.125 Based on Volume capacity

Based on Weight

Number of boxes required for scenario pipe length: 0.173 Based on Weight capacity

Pipe Data from Crane Technical Manual No. 410
(Assume pipe is SCH 40)

Diameter	lb/ft
2	3.65
6	18.97
12	53.52
24	171.29
36	282.35

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Reinforced Concrete Pipe

Excavation/Removal Cost per Linear Foot

Estimate Scenario		Depth to Top of Pipe				
Pipe Material	Pipe Diameter (in)	5 ft	10 ft	15 ft	20 ft	25 ft
Reinforced Concrete	2					
Reinforced Concrete	6					
Reinforced Concrete	12	$2,966.13	$4,532.45	$6,575.76	$8,759.14	$11,104.27
Reinforced Concrete	24	$3,893.94	$5,914.04	$7,713.30	$10,349.68	$13,126.13
Reinforced Concrete	36		$7,004.20	$9,617.36	$12,346.60	$15,215.92
Reinforced Concrete	48		$8,885.26	$11,230.39	$14,414.18	$17,759.71

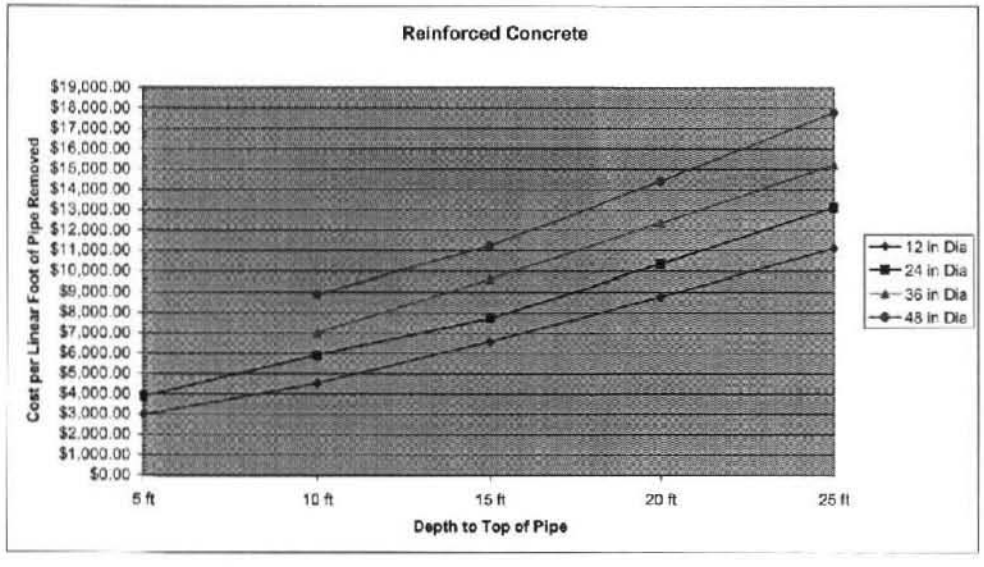
Estimate Assumptions

= Scenario not applicable to Hanford site.

Pipe demolished in trench with excavator-mounted pneumatic hammer.
Additional labor allocated for pipe demolition.
Removal of pipe debris (and loading into ERDF boxes) included in contaminated soil excavation activity labor.
Contaminated soil volume includes increased volume from pipe debris for duration calculations.
Pipe debris estimated at 40% of in-situ volume.

General Assumptions

Clean soil removed from trench and stockpiled close to excavation site for reuse as backfill material.
Contaminated soil loaded into lined ERDF boxes for disposal.
All scenarios do not involve any excavation of paved areas.
Silt fencing calculated based on (2.5 x L) + (8 x y); where L is the length of pipe to be removed, and y is depth from the surface to bottom of the triangle below the pipe (from geometry calcs).



Plot Data

	12 in Dia	24 in Dia	36 in Dia	48 in Dia
5 ft	$2,966.13	$3,893.94		
10 ft	$4,532.45	$5,914.04	$7,004.20	$8,885.26
15 ft	$6,575.76	$7,713.30	$9,617.36	$11,230.39
20 ft	$8,759.14	$10,349.68	$12,346.60	$14,414.18
25 ft	$11,104.27	$13,126.13	$15,215.92	$17,759.71

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Pipeline Removal Vs. Characterization Study - Decision Support Tool

Labor		
1	Supervisor	$75.00
2	General Laborer	$54.14
3	Teamster	$54.35
4	Heavy Eqpmt Operator	$64.86
5	HP Technician	$68.17
6	Burner/Pipefitter	$67.96
7	Other Craft	$67.96
8	Spare	
9	Spare	
10	Spare	

Values Used Throughout	
Estimating Contingency	30%
Labor Hours per Work Shift	10
Construction Consumables (% of direct labor)	3.5%
Excavation Air Sampling (% of total cost)	25%
ERDF LLW disposal (% of total cost)	45%
Soil Expansion Factor	25%
Pipe Rubble Factor	40%
Steel Pipe Lengths for Removal, maximum (ft)	8

Unit Prices (2007 $)

Type	Unit	Description	$$
A	each	50 feet slit brace	$500
B	per day	CAT 320 Excavator Rental	$1,500
C	each	Trench box	$550
D	per month	Forklift	$1,000
E	per month	Generators	$500
F	per month	Job Trailer	$500
G	per month	Drill Rig	$1,000
H	per day	Dump Truck	$250
I	per day	Grader	$250
J	per day	Roller	$250
K	per day	Front-end Loader	$250
L	Case	Tape - 6"	$400.00
M	Case	Tape - 2"	$180.00
N	ft	Sleeving	$4.00
O	100-ft roll	Plastic Sheeting	$650.00
P	pair	Gloves	$5.53
Q	25-lb box	Rags	$130.00
R	$	Tools	$600.00
S	5-ft section	Casing	$1,000.00
T	split spoon	Split Spoons	$2,600.00
U	each	Split Spoon Liners	$20.00
V	pair	Laundry	$25.00
W	ft	Cable	$10.00
X	each	Retooling	$100.00
Y	drum	Drums	$55.35
Z	per sheet	Plywood (4'x8' 3/4 cdx exterior)	$25.00
AA	each	Drum Pallets	$35.00
AB	each	2 x 4s	$9.00
AC	$	Rope	$100.00
AD	blank	Signs	$20.00
AE	yd	Gravel	$40.00
AF	per hour	CAT 320 Excavator	$80.00
AG	per hour	Shuttle Dump Truck	$30.00
AH	per hour	Water Truck	$30.00
AI	per hour	Paving Saw	$18.00
AJ	per hour	Backhoe	$48.00
AK	100-ft roll	Silt Fencing w/ Stakes	$35.00
AL			
AM			

Type	Crew Activity	Crew Size	Crew	Rate
1	Mobilize	1	Supervisor	75.00
		6	General Laborer	54.14
		5	Teamster	54.35
		2	Heavy Eqpmt Ope	64.86
		6	HP Technician	68.17
			Burner/Pipefitter	67.96
			Other Craft	67.96
2	Pipeline / Interference Location	1	Supervisor	75.00
		3	General Laborer	54.14
			Teamster	54.35
			Heavy Eqpmt Ope	64.86
		1	HP Technician	68.17
			Burner/Pipefitter	67.96
			Other Craft	67.96
3	Install Silt Barrier	1	Supervisor	75.00
		4	General Laborer	54.14
			Teamster	54.35
		1	Heavy Eqpmt Ope	64.86
			HP Technician	68.17
			Burner/Pipefitter	67.96
			Other Craft	67.96
4	Paved Road Trenching	1	Supervisor	75.00
			General Laborer	54.14
			Teamster	54.35
			Heavy Eqpmt Ope	64.86
			HP Technician	68.17
			Burner/Pipefitter	67.96
			Other Craft	67.96
5	Clean Excavation to Pipe	1	Supervisor	75.00
		6	General Laborer	54.14
		5	Teamster	54.35
		2	Heavy Eqpmt Ope	64.86
		6	HP Technician	68.17
			Burner/Pipefitter	67.96
		1	Other Craft	67.96
6	Contaminated Soil Excavation	1	Supervisor	75.00
		6	General Laborer	54.14
		5	Teamster	54.35
		2	Heavy Eqpmt Ope	64.86
		6	HP Technician	68.17
			Burner/Pipefitter	67.96
		1	Other Craft	67.96
7	Pipe Section & Remove	1	Supervisor	75.00
		4	General Laborer	54.14
			Teamster	54.35
		1	Heavy Eqpmt Ope	64.86
		4	HP Technician	68.17
		1	Burner/Pipefitter	67.96
			Other Craft	67.96
8	Backfill, Compact, Grade	1	Supervisor	75.00
		4	General Laborer	54.14
		6	Teamster	54.35
		2	Heavy Eqpmt Ope	64.86
			HP Technician	68.17
			Burner/Pipefitter	67.96
			Other Craft	67.96
9	Demobilize	1	Supervisor	75.00
		4	General Laborer	54.14
			Teamster	54.35
		1	Heavy Eqpmt Ope	64.86
		4	HP Technician	68.17
			Burner/Pipefitter	67.96
			Other Craft	67.96

Type	Crew Name	Crew Rate
1	Mobilize	$1,210.33
2	Pipeline / Interference L	$365.59
3	Install Silt Barrier	$356.42
4	Paved Road Trenching	$0.00
5	Clean Excavation to Pi	$1,278.29
6	Contaminated Soil Exc	$1,278.29
7	Pipe Section & Remov	$897.06
8	Backfill, Compact, Grad	$747.38
9	Demobilize	$829.10

Activity Duration Constants		
Activity	Duration	Unit
Field (Miss Utility) Survey	20	ft² per hour
Silt Barrier Installation	200	ln ft per hour
Paving Saw Trench Cutting	50	ln ft per hour
Steel Pipe Sectioning & Removal	44	ln ft per hour
RC Pipe Sectioning & Removal	18	ln ft per hour
Backfill	60	CY per hour

Excavation Duration Calculation Basis	
CY (bank) per ERDF Box	15
Boxes per day @ Day 1	4
Boxes per day @ Day 6	30

Probable Underground Pipe Combinations at the Hanford Site

Pipeline Material	Pipe Diameter (inches) 2	6	12	24	36	48
Vitreous Clay						
Steel (stainless/carbon)						
Concrete Masonry						
Reinforced Concrete						

Legend:
= Not Applicable
= Potentially Applicable
= Definitely Applicable

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Pipeline Removal Vs. Characterization Study - Decision Support Tool

Pipe Excavation Estimate

Hanford Project ID No.
Project Title RC-12

Pipe Material: Reinforced Concrete

	Activity	Crew Rate ($/Hr)	Duration (Hours)	Labor Cost	Materials	QTY	UNIT	U.P.	Cost	Equipment	QTY	UNIT	U.P.	Cost	Total Activity Cost
1	Mobilize	$1,210.33	5	$6,051.65						Pickup Truck	1	$/hr	$10.00	$50.00	$6,101.65
2	Pipeline / Interference Location	$305.59	128	$38,993.28	Construction Consumables				$1,364.76	Pickup Truck	1	$/hr	$10.00	$1,276.00	$41,634.05
3	Install Silt Barrier	$356.42	1.6	$570.27	Construction Consumables				$19.96	Pickup Truck	1	$/hr	$10.00	$16.00	$823.03
					Silt Barrier & Stakes	318	$/100 in ft	$35.00	$140.00	Backhoe	1	$/hr	$48.00	$76.80	
4	Paved Road Trenching				Construction Consumables					Paving Saw		$/hr	$18.00		
										Water Truck		$/hr	$30.00		
5	Clean Excavation to Pipe	$1,278.29	30	$38,348.70	Construction Consumables				$1,342.20	CAT Excavator	2	$/hr	$80.00	$4,800.00	$48,990.90
										Dump Truck	4	$/hr	$30.00	$3,600.00	
										Water Truck	1	$/hr	$30.00	$900.00	
6	Contaminated Soil Excavation	$1,278.29	10	$12,782.90	Construction Consumables				$447.40	CAT Excavator	2	$/hr	$80.00	$1,600.00	$16,330.30
										ERDF Box Truck	4	$/hr	$30.00	$1,200.00	
										Water Truck	1	$/hr	$30.00	$300.00	
7	Pipe Section & Remove	$697.06	5.6	$3,903.54	Construction Consumables				$130.62	CAT Excavator w/ Attachment	1	$/hr	$80.00	$448.00	$4,488.16
8	Backfill, Compact, Grade	$747.38	9	$6,726.42	Construction Consumables				$236.42	5 CY Loader	1	$/hr	$32.00	$288.00	$9,454.84
					Fill Material					300-hp Dozer	1	$/hr	$65.00	$585.00	
										Dump Truck	5	$/hr	$30.00	$1,350.00	
										Water Truck	1	$/hr	$30.00	$270.00	
9	Demobilize	$629.10	10	$6,291.00						Pickup Truck	1	$/hr	$10.00	$100.00	$6,391.00
	Excavation Air Sampling														$33,553.49
	ERDF LLW Disposal														$60,396.27
	Estimating Contingency	30%													$68,440.11
	TOTAL PROJECT COST			$113,667.76					$3,686.38					$16,859.80	$296,612.81
															$296,612.81
										Calculated Cost per Linear Foot of Pipe removed:					$2,966.13

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Input		
Depth to top of pipe	5	ft
Pipe Diameter	12	in
Trench Slope	1.5	: 1
Pipe Length	100	ft

Excavation Volume Results

(excluding pipe debris)	ft³	CY
Contaminated Volume	4,428	164
Clean Volume	6,342	235
Total Volume	10,771	399

Input Pipe Diameter	1	ft
Slope down angle	33.7	degrees
2.5/cos(alpha)	3.00	
v	3.00	ft
z	5.50	ft
y	8.50	ft
x	0.50	ft
Total Area	108.49	sq ft
Pipe Area	0.79	sq ft
Area 3	0.38	sq ft
Area 2	45.45	sq ft
Outer contaminated Area	45.07	sq ft
Net Contaminated Area	44.26	sq ft
Non-Contaminated Area	63.42	sq ft

Excavation Duration Calculation Results

	Days	No. Boxes
Contaminated Volume	1.0	13
Clean Volume	3.0	

(for scenario Input Pipe Length)

	Vol (CY)	No. Boxes
Pipe Debris	1.2	0.090

(for scenario Input Pipe Length)

Calculated ERDF Disposal Cost: $365.64 /CY

Day 1 cans per day	4		
Day 6 cans per day	30		
yds per can	13	(bank volume)	

	CY	Days	Roundup days
Clean Volume	235	2.338	3.000
Total Volume (including pipe debris)	400	3.162	4.000
Contaminated Volume (including pipe debris)	165	0.824	1.000

Day	Boxes Per Day	Yards Per Day	Cumulative Boxes	Cumulative Yards	Delta Yards
1	4	52	4	52	52
2	9.2	119.6	13.2	172	120
3	14.4	187.2	27.6	359	187
4	19.6	254.8	47.2	614	255
5	24.8	322.4	72	936	322
6	30	390	102	1,326	390

Net Contaminated Area

Pipe Diameter		
inch		sq ft
2	0.500	11.1
6	0.5	11.1
12	1	44.3
24	2	177.1
36	3	398.6
48	4	708.5

Pipeline Removal Vs. Characterization Study - Decision Support Tool

Pipe Excavation Estimate

Hanford Project ID No.

Project Title: RC-12

Pipe Material: Reinforced Concrete

	Activity	Crew Rate ($/Hr)	Duration (Hours)	Labor Cost	Materials	QTY	UNIT	U.P.	Cost	Equipment	QTY	UNIT	U.P.	Cost	Total Activity Cost
1	Mobilize	$1,210.33	5	$6,051.65						Pickup Truck	1	$/hr	$10.00	$50.00	$6,101.65
2	Pipeline / Interference Location	$305.59	278	$84,831.78	Construction Consumables				$2,909.11	Pickup Truck	1	$/hr	$10.00	$2,776.00	$90,576.90
3	Install Silt Barrier	$358.42	2.0	$712.84	Construction Consumables				$24.95	Pickup Truck	1	$/hr	$10.00	$20.00	$993.79
					Silt Barrier & Stakes	308	$/100 ln ft	$36.00	$140.00	Backhoe	1	$/hr	$48.00	$96.00	
4	Paved Road Trenching				Construction Consumables					Paving Saw		$/hr	$18.00		
										Water Truck		$/hr	$30.00		
5	Clean Excavation to Pipe	$1,278.29	80	$102,263.20	Construction Consumables				$3,579.21	CAT Excavator	2	$/hr	$80.00	$12,800.00	$130,642.41
										Dump Truck	4	$/hr	$30.00	$9,600.00	
										Water Truck	1	$/hr	$30.00	$2,400.00	
6	Contaminated Soil Excavation	$1,278.29	10	$12,782.90	Construction Consumables				$447.40	CAT Excavator	2	$/hr	$80.00	$1,600.00	$16,330.30
										ERDF Box Truck	4	$/hr	$30.00	$1,200.00	
										Water Truck	1	$/hr	$30.00	$300.00	
7	Pipe Section & Remove	$697.06	6.6	$3,603.54	Construction Consumables				$130.62	CAT Excavator w/ Attachment	1	$/hr	$80.00	$448.00	$4,468.10
8	Backfill, Compact, Grade	$747.38	40	$29,895.20	Construction Consumables				$1,046.33	5 CY Loader	1	$/hr	$32.00	$1,280.00	$42,021.53
					Fill Material					300-hp Dozer	1	$/hr	$65.00	$2,600.00	
										Dump Truck	5	$/hr	$30.00	$6,000.00	
										Water Truck	1	$/hr	$30.00	$1,200.00	
9	Demobilize	$629.10	10	$6,291.00						Pickup Truck	1	$/hr	$10.00	$100.00	$6,391.00
	Excavation Air Sampling														$74,386.44
	ERDF LLW Disposal														$133,895.58
	Estimating Contingency	30%													$151,748.33
	TOTAL PROJECT COST			$246,732.11					$8,343.63					$42,479.00	$957,576.09
															$957,576.09
										Calculated Cost per Linear Foot of Pipe removed:					$6,575.76

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Pipeline Removal Vs. Characterization Study - Decision Support Tool

Input		
Depth to top of pipe	15	ft
Pipe Diameter	12	in
Trench Slope	1.5	: 1
Pipe Length	100	ft

Excavation Volume Results

(excluding pipe debris)	ft³	CY
Contaminated Volume	4,428	164
Clean Volume	46,856	1,735
Total Volume	51,285	1,899

Input Pipe Diameter	1	ft
Slope down angle	33.7	degrees
2.5/cos(alpha)	3.00	
v	3.00	ft
z	5.50	ft
y	18.50	ft
x	0.50	ft
Total Area	513.63	sq ft
Pipe Area	0.79	sq ft
Area 3	0.38	sq ft
Area 2	45.45	sq ft
Outer contaminated Area	45.07	sq ft
Net Contaminated Area	44.28	sq ft
Non-Contaminated Area	468.56	sq ft

Excavation Duration Calculation Results

	Days	No. Boxes
Contaminated Volume	1.0	13
Clean Volume	8.0	

(for scenario Input Pipe Length)

	Vol (CY)	No. Boxes
Pipe Debris	1.2	0.090

(for scenario Input Pipe Length)

Calculated ERDF Disposal Cost: $810.61 /CY

Day 1 cans per day	4			
Day 6 cans per day	30			
yds per can	13	(bank volume)		
	CY		Days	Roundup days
Clean Volume	1,735		7.050	8.000
Total Volume (including pipe debris)	1,901		7.473	8.000
Contaminated Volume (including pipe debris)	165		0.424	1.000

Day	Boxes Per Day	Yards Per Day	Cumulative Boxes	Cumulative Yards	Delta Yards
1	4	52	4	52	52
2	9.2	119.6	13.2	172	120
3	14.4	187.2	27.6	359	187
4	19.6	254.8	47.2	614	255
5	24.8	322.4	72	936	322
6	30	390	102	1,326	390

Net Contaminated Area

Pipe Diameter		
inch		sq ft
2	0.500	11.1
6	0.5	11.1
12	1	44.3
24	2	177.1
36	3	398.6
48	4	708.5

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SGW-34760 Rev. 0

Concrete Masonry Pipe

Excavation/Removal Cost per Linear Foot

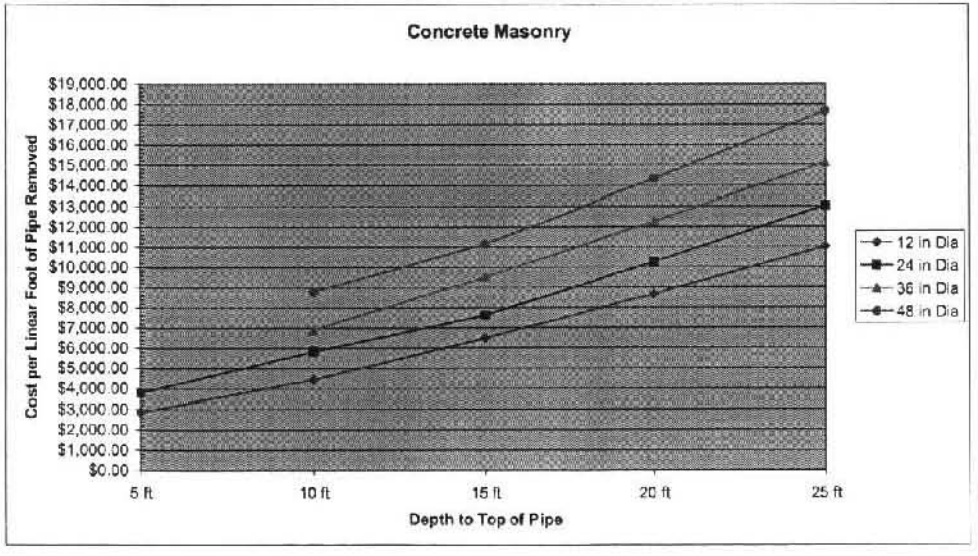
Estimate Scenario		Depth to Top of Pipe				
Pipe Material	Pipe Diameter (In)	5 ft	10 ft	15 ft	20 ft	25 ft
Concrete Masonry	2					
Concrete Masonry	6					
Concrete Masonry	12	$2,866.94	$4,433.26	$6,476.57	$8,659.96	$11,005.08
Concrete Masonry	24	$3,794.76	$5,814.85	$7,614.11	$10,250.49	$13,026.94
Concrete Masonry	36		$6,905.01	$9,518.17	$12,247.42	$15,116.74
Concrete Masonry	48		$8,786.07	$11,131.20	$14,314.99	$17,660.52

Estimate Assumptions

= Scenario not applicable to Hanford site.

Pipe demolished by excavator bucket during excavation operation.
Removal of pipe debris (and loading into ERDF boxes) included on contaminated soil excavation activity labor.
Contaminated soil volume includes increased volume from pipe debris for duration calculation.
Pipe debris estimated at 40% of in-situ volume.

General Assumptions
Clean soil removed from trench and stockpiled close to excavation site for reuse as backfill material.
Contaminated soil loaded into lined ERDF boxes for disposal.
All scenarios do not involve any excavation of paved areas.
Silt fencing calculated based on (2.5 x L) + (8 x y); where L is the length of pipe to be removed, and y is depth from the surface to bottom of the triangle below the pipe (from geometry calcs).



Plot Data

	12 in Dia	24 in Dia	36 in Dia	48 in Dia
5 ft	$2,866.94	$3,794.76		
10 ft	$4,433.26	$5,814.85	$6,905.01	$8,786.07
15 ft	$6,476.57	$7,614.11	$9,518.17	$11,131.20
20 ft	$8,659.96	$10,250.49	$12,247.42	$14,314.99
25 ft	$11,005.08	$13,026.94	$15,116.74	$17,660.52

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Pipeline Removal Vs. Characterization Study - Decision Support Tool

Labor		
1	Supervisor	$75.00
2	General Laborer	$54.14
3	Teamster	$54.35
4	Heavy Eqpmt Operator	$64.86
5	HP Technician	$68.17
6	Burner/Pipefitter	$67.96
7	Other Craft	$67.96
8	Spare	
9	Spare	
10	Spare	

Values Used Throughout	
Estimating Contingency	30%
Labor Hours per Work Shift	10
Construction Consumables (% of direct labor)	3.6%
Excavation Air Sampling (% of total cost)	25%
ERDF LLW disposal (% of total cost)	45%
Soil Expansion Factor	25%
Pipe Rubble Factor	40%
Steel Pipe Lengths for Removal, maximum (ft)	8

Unit Prices (2007 $)

Type	Unit	Description	$$
A	each	50 feet silt brace	$500
B	per day	CAT 320 Excavator Rental	$1,500
C	each	Trench box	$550
D	per month	Forklift	$1,000
E	per month	Generators	$500
F	per month	Job Trailer	$500
G	per month	Drill Rig	$1,000
H	per day	Dump Truck	$250
I	per day	Grader	$250
J	per day	Roller	$250
K	per day	Front-end Loader	$250
L	Case	Tape - 6"	$400.00
M	Case	Tape - 2"	$180.00
N	ft	Sleeving	$4.00
O	100-ft roll	Plastic Sheeting	$650.00
P	pair	Gloves	$5.53
Q	25-lb box	Rags	$130.00
R	$	Tools	$500.00
S	5-ft section	Casing	$1,000.00
T	split spoon	Split Spoons	$2,600.00
U	each	Split Spoon Liners	$20.00
V	pair	Laundry	$25.00
W	ft	Cable	$10.00
X	each	Retooling	$100.00
Y	drum	Drums	$55.35
Z	per sheet	Plywood (4'x8' 3/4 cdx exterior)	$25.00
AA	each	Drum Pallets	$35.00
AB	each	2 x 4s	$9.00
AC	$	Rope	$100.00
AD	blank	Signs	$22.00
AE	yd	Gravel	$40.00
AF	per hour	CAT 320 Excavator	$80.00
AG	per hour	Shuttle Dump Truck	$30.00
AH	per hour	Water Truck	$30.00
AI	per hour	Paving Saw	$18.00
AJ	per hour	Backhoe	$48.00
AK	100-ft roll	Silt Fencing w/ Stakes	$35.00
AL			
AM			

Type	Crew Activity	Crew Size	Crew	Rate
1	Mobilize	1	Supervisor	75.00
		6	General Laborer	54.14
		5	Teamster	54.35
		2	Heavy Eqpmt Ope	64.86
		6	HP Technician	68.17
			Burner/Pipefitter	67.96
			Other Craft	67.96
2	Pipeline / Interference Location	1	Supervisor	75.00
		3	General Laborer	54.14
			Teamster	54.35
			Heavy Eqpmt Ope	64.86
		1	HP Technician	68.17
			Burner/Pipefitter	67.96
			Other Craft	67.96
3	Install Silt Barrier	1	Supervisor	75.00
		4	General Laborer	54.14
			Teamster	54.35
		1	Heavy Eqpmt Ope	64.86
			HP Technician	68.17
			Burner/Pipefitter	67.96
			Other Craft	67.96
4	Paved Road Trenching		Supervisor	75.00
			General Laborer	54.14
			Teamster	54.35
			Heavy Eqpmt Ope	64.86
			HP Technician	68.17
			Burner/Pipefitter	67.96
			Other Craft	67.96
5	Clean Excavation to Pipe	1	Supervisor	75.00
		6	General Laborer	54.14
		5	Teamster	54.35
		2	Heavy Eqpmt Ope	64.86
		6	HP Technician	68.17
			Burner/Pipefitter	67.96
		1	Other Craft	67.96
6	Contaminated Soil Excavation	1	Supervisor	75.00
		6	General Laborer	54.14
		5	Teamster	54.35
		2	Heavy Eqpmt Ope	64.86
		6	HP Technician	68.17
			Burner/Pipefitter	67.96
		1	Other Craft	67.96
7	Pipe Section & Remove	1	Supervisor	75.00
		4	General Laborer	54.14
			Teamster	54.35
		1	Heavy Eqpmt Ope	64.86
		4	HP Technician	68.17
		1	Burner/Pipefitter	67.96
			Other Craft	67.96
8	Backfill, Compact, Grade	1	Supervisor	75.00
		4	General Laborer	54.14
		6	Teamster	54.35
		2	Heavy Eqpmt Ope	64.86
			HP Technician	68.17
			Burner/Pipefitter	67.96
			Other Craft	67.96
9	Demobilize	1	Supervisor	75.00
		4	General Laborer	54.14
			Teamster	54.35
		1	Heavy Eqpmt Ope	64.86
		4	HP Technician	68.17
			Burner/Pipefitter	67.96
			Other Craft	67.96

Type	Crew Name	Crew Rate
1	Mobilize	$1,210.33
2	Pipeline / Interference	$305.58
3	Install Silt Barrier	$366.42
4	Paved Road Trenching	$0.00
5	Clean Excavation to Pi	$1,278.29
6	Contaminated Soil Exc	$1,278.29
7	Pipe Section & Remov	$697.06
8	Backfill, Compact, Gra	$747.38
9	Demobilize	$629.10

Probable Underground Pipe Combinations at the Hanford Site

Pipeline Material	Pipe Diameter (inches) 2	6	12	24	36	48
Vitreous Clay						
Steel (stainless /carbon)						
Concrete Masonry						
Reinforced Concrete						

Legend:
= Not Applicable
= Potentially Applicable
= Definitely Applicable

Activity Duration Constants		
Activity	Duration	Unit
Field (Miss Utility) Survey	20	ft² per hour
Silt Barrier Installation	200	ln ft per hour
Paving Saw Trench Cutting	50	ln ft per hour
Steel Pipe Sectioning & Removal	44	ln ft per hour
RC Pipe Sectioning & Removal	18	ln ft per hour
Backfill	60	CY per hour

Excavation Duration Calculation Basis	
CY (bank) per ERDF Box	13
Boxes per day @ Day 1	4
Boxes per day @ Day 5	30

Pipeline Removal Vs. Characterization Study - Decision Support Tool

Pipe Excavation Estimate

Hanford Project ID No.
Project Title: CM-12

Pipe Material: Concrete Masonry

	Activity	Crew Rate ($/Hr)	Duration (Hours)	Labor Cost	Materials	QTY	UNIT	U.P.	Cost	Equipment	QTY	UNIT	U.P.	Cost	Total Activity Cost
1	Mobilize	$1,210.33	5	$6,051.65						Pickup Truck	1	$/hr	$10.00	$50.00	$6,101.65
2	Pipeline / Interference Location	$305.59	128	$38,993.28	Construction Consumables				$1,364.76	Pickup Truck	1	$/hr	$10.00	$1,270.00	$41,634.05
3	Install Silt Barrier	$356.42	1.6	$570.27	Construction Consumables				$10.06	Pickup Truck	1	$/hr	$10.00	$16.00	$823.03
					Silt Barrier & Stakes	318	$/100 ln ft	$35.00	$140.00	Backhoe	1	$/hr	$48.00	$76.80	
4	Paved Road Trenching				Construction Consumables					Paving Saw		$/hr	$18.00		
										Water Truck		$/hr	$30.00		
5	Clean Excavation to Pipe	$1,278.29	30	$38,348.70	Construction Consumables				$1,342.20	CAT Excavator	2	$/hr	$80.00	$4,800.00	$48,990.90
										Dump Truck	4	$/hr	$30.00	$3,600.00	
										Water Truck	1	$/hr	$30.00	$900.00	
6	Contaminated Soil Excavation	$1,278.29	10	$12,782.90	Construction Consumables				$447.40	CAT Excavator	2	$/hr	$80.00	$1,600.00	$16,330.30
										ERDF Box Truck	4	$/hr	$30.00	$1,200.00	
										Water Truck	1	$/hr	$30.00	$300.00	
7	Pipe Section & Remove	$697.06			Construction Consumables					CAT Excavator w/ Attachment		$/hr	$80.00		
8	Backfill, Compact, Grade	$747.38	9	$6,726.42	Construction Consumables				$235.42	5 CY Loader	1	$/hr	$32.00	$288.00	$9,454.84
					Fill Material					300-hp Dozer	1	$/hr	$66.00	$888.00	
										Dump Truck	5	$/hr	$30.00	$1,350.00	
										Water Truck	1	$/hr	$30.00	$270.00	
9	Demobilize	$629.10	10	$6,291.00						Pickup Truck	1	$/hr	$10.00	$100.00	$6,391.00
	Excavation Air Sampling														$32,431.45
	ERDF LLW Disposal														$58,376.60
	Estimating Contingency	30%													$66,160.16
	TOTAL PROJECT COST			$109,764.23					$3,549.76					$16,411.80	$286,693.98
															$286,693.98
										Calculated Cost per Linear Foot of Pipe removed:					$2,866.94

SGW - 31760 Rev. 0

Pipeline Removal Vs. Characterization Study - Decision Support Tool

Input		
Depth to top of pipe	5	ft
Pipe Diameter	12	in
Trench Slope	1.5	: 1
Pipe Length	100	ft

Excavation Volume Results

(excluding pipe debris)	ft³	CY
Contaminated Volume	4,428	164
Clean Volume	6,342	235
Total Volume	10,771	399

Input Pipe Diameter	1	ft
Slope down angle	33.7	degrees
2.5/cos(alpha)	3.00	
v	3.00	ft
z	5.50	ft
y	8.50	ft
x	0.50	ft
Total Area	108.49	sq ft
Pipe Area	0.79	sq ft
Area 3	0.38	sq ft
Area 2	45.45	sq ft
Outer contaminated Area	45.07	sq ft
Net Contaminated Area	44.28	sq ft
Non-Contaminated Area	63.42	sq ft

Excavation Duration Calculation Results

	Days	No. Boxes
Contaminated Volume	1.0	13
Clean Volume	3.0	

(for scenario Input Pipe Length)

	Vol (CY)	No. Boxes
Pipe Debris	1.2	0.090

(for scenario Input Pipe Length)

Calculated ERDF Disposal Cost: $353.42 / CY

Day 1 cans per day	4	
Day 6 cans per day	30	
yds per can	13	(bank volume)

	CY	Days	Roundup days
Clean Volume	235	2.338	3.000
Total Volume (including pipe debris)	400	3.162	4.000
Contaminated Volume (including pipe debris)	165	0.824	1.000

Day	Boxes Per Day	Yards Per Day	Cumulative Boxes	Cumulative Yards	Delta Yards
1	4	52	4	52	52
2	9.2	119.6	13.2	172	120
3	14.4	187.2	27.6	359	187
4	19.6	254.8	47.2	614	255
5	24.8	322.4	72	936	322
6	30	390	102	1,326	390

Net Contaminated Area

Pipe Diameter		
inch		sq ft
2	0.500	11.1
6	0.5	11.1
12	1	44.3
24	2	177.1
36	3	398.6
48	4	708.5

SAW - 34760 Rev. 0

Pipeline Removal Vs. Characterization Study - Decision Support Tool

Pipe Excavation Estimate

Hanford Project ID No.
Project Title CM-12

Pipe Material: Concrete Masonry

	Activity	Crew Rate ($/Hr)	Duration (Hours)	Labor Cost	Materials	QTY	UNIT	U.P.	Cost	Equipment	QTY	UNIT	U.P.	Cost	Total Activity Cost
1	Mobilize	$1,210.33	5	$6,051.65						Pickup Truck	1	$/hr	$10.00	$50.00	$6,101.65
2	Pipeline / Interference Location	$305.59	278	$84,831.78	Construction Consumables				$2,969.11	Pickup Truck	1	$/hr	$10.00	$2,776.00	$90,576.90
3	Install Silt Barrier	$356.42	2.0	$712.84	Construction Consumables				$24.06	Pickup Truck	1	$/hr	$10.00	$20.00	$993.79
					Silt Barrier & Stakes	398	$/100 ln ft	$35.00	$140.00	Backhoe	1	$/hr	$48.00	$96.00	
4	Paved Road Trenching				Construction Consumables					Paving Saw		$/hr	$18.00		
										Water Truck		$/hr	$30.00		
5	Clean Excavation to Pipe	$1,278.29	80	$102,263.20	Construction Consumables				$3,579.21	CAT Excavator	2	$/hr	$80.00	$12,800.00	$130,042.41
										Dump Truck	4	$/hr	$30.00	$9,600.00	
										Water Truck	1	$/hr	$30.00	$2,400.00	
6	Contaminated Soil Excavation	$1,278.29	10	$12,782.90	Construction Consumables				$447.40	CAT Excavator	2	$/hr	$80.00	$1,600.00	$16,330.30
										ERDF Box Truck	4	$/hr	$30.00	$1,200.00	
										Water Truck	1	$/hr	$30.00	$300.00	
7	Pipe Section & Remove	$697.06			Construction Consumables					CAT Excavator w/ Attachment		$/hr	$80.00		
8	Backfill, Compact, Grade	$747.38	40	$29,895.20	Construction Consumables				$1,048.33	5 CY Loader	1	$/hr	$32.00	$1,280.00	$42,021.53
					Fill Material					300-hp Dozer	1	$/hr	$65.00	$2,600.00	
										Dump Truck	5	$/hr	$30.00	$6,000.00	
										Water Truck	1	$/hr	$30.00	$1,200.00	
9	Demobilize	$629.10	10	$6,291.00						Pickup Truck	1	$/hr	$10.00	$100.00	$6,391.00
	Excavation Air Sampling														$73,264.40
	ERDF LLW Disposal														$131,876.91
	Estimating Contingency	30%													$149,459.37
	TOTAL PROJECT COST			$242,828.57					$8,207.01					$42,022.00	$647,657.25
															$647,657.25
										Calculated Cost per Linear Foot of Pipe removed:					$6,476.57

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Pipeline Removal Vs. Characterization Study - Decision Support Tool

Input		
Depth to top of pipe	15	ft
Pipe Diameter	12	in
Trench Slope	1.5	: 1
Pipe Length	100	ft

Excavation Volume Results

(excluding pipe debris)	ft³	CY
Contaminated Volume	4,428	164
Clean Volume	46,856	1,735
Total Volume	51,285	1,899

Input Pipe Diameter	1	ft
Slope down angle	33.7	degrees
2.5/cos(alpha)	3.00	
v	3.00	ft
z	5.50	ft
y	18.50	ft
x	0.50	ft
Total Area	513.63	sq ft
Pipe Area	0.79	sq ft
Area 3	0.38	sq ft
Area 2	45.45	sq ft
Outer contaminated Area	45.07	sq ft
Net Contaminated Area	44.28	sq ft
Non-Contaminated Area	468.56	sq ft

Excavation Duration Calculation Results

	Days	No. Boxes
Contaminated Volume	1.0	13
Clean Volume	8.0	

(for scenario Input Pipe Length)

	Vol (CY)	No. Boxes
Pipe Debris	1.2	0.090

(for scenario Input Pipe Length)

Calculated ERDF Disposal Cost: $798.39 / CY

Day 1 cans per day	4			
Day 6 cans per day	30			
yds per can	13	(bank volume)		
		CY	Days	Roundup days
Clean Volume		1,735	7.050	8.000
Total Volume (including pipe debris)		1,901	7.473	8.000
Contaminated Volume (including pipe debris)		165	0.424	1.000

Day	Boxes Per Day	Yards Per Day	Cumulative Boxes	Cumulative Yards	Delta Yards
1	4	52	4	52	52
2	9.2	119.6	13.2	172	120
3	14.4	187.2	27.6	359	187
4	19.6	254.8	47.2	614	255
5	24.8	322.4	72	936	322
6	30	390	102	1,326	390

Net Contaminated Area

Pipe Diameter		
inch		sq ft
2	0.500	11.1
6	0.5	11.1
12	1	44.3
24	2	177.1
36	3	398.6
48	4	708.5

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