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Evaluation of Trenchless Installation Technologies for Radioactive Wastewater Piping Applications

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ACRONYMS

AHP	Analytical Hierarchy Process
CCTV	closed circuit television
CD	critical decision
CIPP	cured-in-place pipe
D&D	decontamination and decommissioning
DOE	U.S. Department of Energy
EM	DOE Office of Environmental Management
EPA	U.S. Environmental Protection Agency
ETR	external technical review
F&E	fused and expanded
FFA	Federal Facility Agreement (for the Oak Ridge Reservation, October 30, 1996)
HAB	horizontal auger boring
HDD	horizontal directional drilling
HEB	horizontal earth boring
HPDE	high density polyethylene
IFDP	Integrated Facility Disposition Program
LLLW	liquid low-level waste
MSL	modified sliplining
MT	microtunneling
ORNL	Oak Ridge National Laboratory
PB	pipe bursting
PE	polyethylene
PJ	pipe jacking
PR	pipe ramming
PTMT	pilot-tube microtunneling
PVC	polyvinyl chloride
PWTC	Process Waste Treatment Complex (ORNL)
ROD	Record of Decision
SL	sliplining
TCM	trenchless construction method
TDEC	Tennessee Department of Environment and Conservation
ThP	thermoformed pipe
TRM	trenchless renewal method
TWPC	transuranic waste processing center
UT	utility tunneling

WAC	waste acceptance criteria

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FOREWORD

Information for this report was gathered from a variety of sources, including publicly available literature, trenchless technology vendors, utility staff, and engineering construction managers. The data-gathering activities were limited by time, scope, degree of participation, and the boundaries imposed on the subject area. As a result, the report may not fully capture all viewpoints. Although efforts were made to incorporate a broad range of views, some valid ideas may have been excluded based on judgments made in combining and prioritizing information to produce a final report.

EXECUTIVE SUMMARY

This report evaluates the technical risks, benefits, and economics of using trenchless technologies for installing new and rehabilitating existing piping for radioactive applications within the U.S. Department of Energy (DOE) complex. The report was initiated in response to an external technical review group for the Oak Ridge Reservation Integrated Facility Disposition Program (IFDP) recommendation that trenchless techniques be considered as an alternative to open trench installation methods in applications for long runs of pipeline through contaminated areas.

Several different trenchless installation technologies have been developed over the last 20 years for a range of pipeline installation applications. While trenchless technologies have been used extensively in the sanitary sewer and natural gas pipeline industries, the use of trenchless technologies in contaminated environments has been limited. Therefore, a full range of trenchless installation technologies was reviewed for general applicability for replacing long runs of existing contaminated piping and/or installing new pipelines in potentially contaminated areas. About half the trenchless technologies are not applicable to the contaminated environments typical of DOE sites because of restrictions such as worker entry requirements, pipe size limitations, etc. For applications that could include very short runs of piping (e.g., across roads and repairing broken pipelines) or in uncontaminated areas, some of the technologies eliminated from consideration in this study might be applicable. This study did not consider combining methods for a single run, which might result in lower costs depending on specific conditions.

Two trenchless horizontal earth boring technologies were considered potentially viable installation methods for new construction pipelines in contaminated environments: horizontal directional drilling for pressurized piping and pilot-tube microtunneling for gravity and pressurized lines that require high degrees of line and grade accuracy. Four renewal methods were considered potentially viable for extending the life of existing pipelines: cured-in-place pipe, thermoformed pipe, sliplining, and pipe bursting. Though considered acceptable for general DOE applications, pilot-tube microtunneling was not considered for Oak Ridge National Laboratory- (ORNL-) specific applications because of geological conditions.

The Analytical Hierarchy Process decision modeling tool was used to develop a methodology for evaluating pipeline installation technologies for a specific application using weighted criteria in the areas of environment, safety, and health (ES&H); project cost and schedule; and technical operability. Site-specific weighting factors were developed for ORNL using a pair-wise comparison technique. The methodology was used to evaluate pipeline installation techniques for three specific ORNL pipeline applications. Although the detailed evaluation results obtained for the ORNL example are applications specific, the evaluation methodology developed in this report should be useful for feasibility level engineering alternatives analyses that may be performed at other DOE sites in the future.

The installation methods evaluated for the three specific ORNL applications included gravity drained singly contained 6 in. pipeline, pressurized singly contained 6 in. pipeline, and pressurized doubly contained 2 in. pipeline. Three piping materials were considered: high density polyethylene (HDPE), cathodically-protected carbon steel, and cathodically-protected stainless steel. Investigations indicated that most vendors have experience installing HDPE piping by trenchless methods, but few if any install carbon and stainless pipe by these methods. In addition, certain piping materials are incompatible with some specific trenchless installation techniques, particularly for the renewal technologies. Also, some installation methods cannot be used for gravity drained pipelines. Traditional open trench pipeline installation was the only method that was applicable to all three ORNL applications evaluated.

Evaluations of the three ORNL-specific applications indicate that the selection of a replacement pipeline installation technology will be application specific and will be impacted by the relative importance of drivers such as cost and schedule, operability, and ES&H. The study results showed that open trench installation methods have advantages over horizontal earth boring for new pipeline installations in hazardous congested industrial environments where ES&H issues could have significant regulatory, environmental, and worker safety impacts. Renewal techniques offer advantages over open trench and trenchless construction technologies because they do not require digging in potentially contaminated environments and avoid the associated installation risks. If leaving potentially contaminated shards of the original pipeline in the ground is acceptable, pipe bursting should be considered for replacement of vitrified clay pipe, particularly in congested areas with significant risk of existing contaminated soil. If operability of a pipeline is of prime importance, open trench installation of new pipelines would be the technology of choice over trenchless installation methods. If costs and schedule are the over arching drivers and the operability and ES&H risks are low, trenchless installation technologies would be preferred over traditional open trench methods.

The results of this study indicate that trenchless installation technologies have potential for application in contaminated environments. Due to their limited use in the past for DOE applications, they are considered to be unproven technologies, particularly with respect to impact of the installation method on pipeline integrity and design life. The standard piping materials typically used in radioactive DOE applications (e.g., carbon and stainless steel) offer technical challenges for renewable installation technologies and some are considered to be incompatible with some of the installation techniques, at least with the maturity level of the technology today. In addition, for the ORNL applications evaluated in this study, the costs of installing pipelines are impacted more by the type of piping material than the installation technology. This finding is generally not true for applications in urban environments where more costly piping materials such as carbon and stainless steels are not standard materials of construction for trenchless applications. This indicates that future studies to evaluate the compatibility of a range of piping materials with DOE waste stream compositions should be the first step towards not only significantly reducing costs for pipeline installation projects in general, but also increasing the applicability of trenchless installation technologies for contaminated waste applications. Demonstrations of the installation technologies should be conducted within the DOE environment with enhanced ES&H oversight to reduce any risk associated with these technologies. Initial demonstrations could begin with short pipeline installations using standard piping materials, and future demonstrations could expand to include more challenging installation applications with nontraditional (for radioactive environments) piping materials. Technology development areas could include new pipe bursting heads capable of bursting ductile piping.

The major benefits historically cited for use of trenchless horizontal earth boring technologies instead of open trench pipeline installation in traditional applications were based on congested suburban environments where rehabilitation of surfaces, rerouting roads, etc. significantly increase the cost of projects. For the ORNL-specific applications evaluated in this study, trenchless construction techniques were considered to be less desirable than open trench installation in congested areas. The areas with significant numbers of obstructions (buildings, roads, etc.) also have significant uncertainties associated with location of underground utilities, hazardous waste pipelines, and historical soil contamination. Therefore, the ES&H risks associated with underground drilling in such areas outweighed potential benefits from reduced above ground disruptions. Technology demonstrations could reduce the uncertainties associated with the technologies, as could the development of better three dimensional underground mapping techniques to identify underground obstructions. These demonstrations and technology developments would validate trenchless technologies for wider applications involving radiological waste systems in the DOE complex.

1. INTRODUCTION

The U.S. Department of Energy (DOE) Office of Environmental Management (EM) cleanup mission at Oak Ridge National Laboratory (ORNL) includes dispositioning facilities, contaminated legacy materials/waste, and contamination sources and remediation of soil under facilities, groundwater, and surface water to support final Records of Decision (RODs). The Integrated Facilities Disposition Project (IFDP) is a roughly $15B project for completion of the EM mission at Oak Ridge, with a project duration of up to 35 years. The IFDP Mission Need Statement—Critical Decision–0 (CD-0)—was approved by DOE in July 2007, and the IFDP Alternative Selection and Cost Range—Critical Decision–1 (CD-1)—was approved in November 2008.

The IFDP scope includes reconfiguration of waste collection and treatment systems as needed to complete the IFDP remediation and decontamination and decommissioning (D&D) missions in a safe and cost-effective manner while maintaining compliance with all governing regulations and bodies and preserving the support of continuing operations at ORNL. A step in the CD-1 approval process included an external technical review (ETR) of technical approaches proposed in the CD-1 document related to the facility reconfiguration for the ORNL radioactive waste and liquid low-level waste management systems. The ETR team recommended that the IFDP team consider the use of trenchless technologies for installing pipelines underground in and around contaminated sites as part of the alternatives evaluations required in support of the CD-2 process. The team specifically recommended evaluating trenchless technologies for installing new pipes in existing underground pipelines as an alternative to conventional open trench installation methods. Potential benefits could include reduction in project costs, less costly underground piping, fewer disruptions of ongoing and surface activities, and lower risk for workers.

While trenchless technologies have been used extensively in the sanitary sewer and natural gas pipeline industries, they have been used far less in contaminated environments. Although trenchless technologies have been used at ORNL in limited applications to install new potable water and gas lines, the technologies have not been used in radioactive applications. This study evaluates the technical risks, benefits, and economics for installing gravity drained and pressurized piping using trenchless technologies compared to conventional installation methods for radioactive applications under ORNL geological conditions.

A range of trenchless installation technologies was reviewed for this report for general applicability for replacing existing contaminated piping and/or installing new pipelines in potentially contaminated areas. Installation methods that were determined to have potential for use in typical ORNL contaminated environments were then evaluated in more detail for three specific ORNL applications. Each feasible alternative was evaluated against the baseline conventional open trench installation method using weighted criteria in the areas of environment, safety, and health (ES&H); project cost and schedule; and technical operability.

The formulation of alternatives for evaluation, the development of selection criteria, and the scoring of alternatives were performed by ORNL staff with input from vendors and consultants. A description of the evaluation methodology and the evaluation results are documented in the following sections of this report.

2. PIPELINE INSTALLATION METHODS

There are two general categories of technologies used to install underground pipelines: the traditional open trench method and newer trenchless installation methods. Several different trenchless installation technologies have been developed over the last 20 years for a range of applications. The various pipeline installation techniques are reviewed below, and their general applicability for contaminated environments was assessed using information gained primarily through literature reviews and discussions with vendors. The more promising technologies were then evaluated for three specific ORNL applications as described in the remainder of the report.

2.1 DESCRIPTION OF PIPELINE INSTALLATION METHODS

Figure 2.1 shows the types of underground pipeline installation methods considered in this study. Each installation method is described in more detail below.

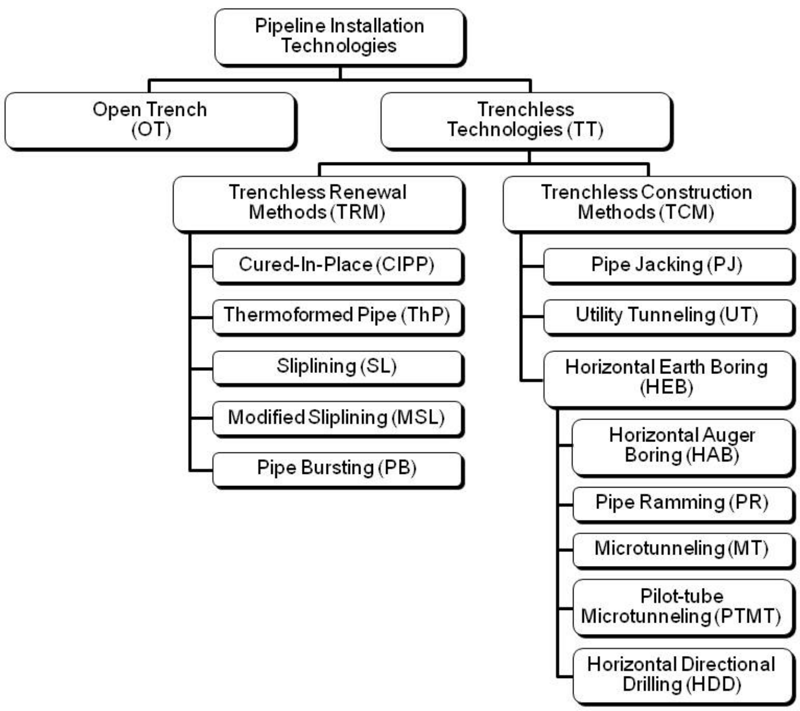

Figure 2.1. Underground pipeline installation methods.

2.1.1 Open Trench

Open trench construction is the traditional method for installing or replacing an existing pipeline for most applications, including radioactively contaminated environments. The method involves excavating the ground along the entire length of the pipeline. When the proper depth is reached, bedding material is placed into the bottom of the trench. The new pipe is laid onto the bedding, and the open trench is backfilled. The surface and infrastructure around the pipeline area is repaired as needed.

Advantages of the open trench technologies include that the amount of preplanning and engineering time required before construction is minimal compared to trenchless technologies for pressurized lines; this is not necessarily true for gravity fed pipelines where any obstruction could be problematic. With open trench methods, the location of underground obstructions such as utility lines can be identified without having to rely completely on drawings that could be inaccurate. During the installation process, the condition of any existing pipeline can be visually and physically inspected along with the quality of the new pipe once it is installed. Since open trench is one of the oldest pipeline installation methods, the experience level of contractors is the highest for all types of applications, including radioactively contaminated environments.

A disadvantage of the open trench method is that it requires excavation along the entire length of the pipeline. In an industrial setting, this can become inconvenient for the day-to-day activities around the pipeline area. Because of the large amount of excavation, the exposed work area could become large. This can create a hazardous work place for workers and the surrounding environment and increases potential environmental impacts from storm water runoff from excavated materials and trench water removal. The technique can incur extensive costs in repairing the surface and infrastructure impacted by the excavation.

2.1.2 Trenchless Technologies

Trenchless technology is a general term that describes a group of methods that are used to install or renew underground pipelines with minimum excavation (Favre 2002; Lee, Mohammad, and Matthys 2007; Mohamed, Najafi, and Hashemi 2008; Rajani, Zhao, and Rajani 2002; Parker 2007; and Purdue University). Compared to the traditional open trench method the amount of excavation is very minor, thus leading to the name "trenchless." Trenchless methods originated in the United Kingdom and some have been in practice for more than 100 years. However, trenchless technology was not officially introduced into the United States until 1986. Since then trenchless technologies have been used extensively in the sanitary sewer and natural gas pipeline industries but much less extensively in contaminated environments.

Trenchless technology methods are divided into two groups: trenchless construction methods (TCMs) and trenchless renewal methods (TRMs). The key word "construction" in TCM indicates that these methods are primarily used when a pipeline does not exist and one is needed. The term "renewal" in TRM indicates methods which are used to extend the design life of an existing pipeline.

2.1.2.1 Trenchless Renewal Methods

Cured-in-place pipe (CIPP). The CIPP renewal method consists of several steps. The first step is to inspect the pipeline with closed circuit television (CCTV) and clean/remove any debris remaining in the pipe. The condition and length of each installation is measured and recorded with CCTV. These measurements are used to manufacture segments of tube required for the specific project. The second step involves inserting a thermoset resin-impregnated tube into the existing pipeline. Hydrostatic pressure or air pressure is used to invert the tube inside the pipe. The tube can also be pulled into the pipeline with a winch. The third step is to cure the resin with hot water, steam, or UV light. The last step is to drain the pipeline of any waste material from the process.

The CIPP method is applicable for existing pipelines with 4 in. diameters and up. Before the resin is cured the tube is flexible, allowing this method to be used on pipelines with varying cross sections and multiple bends. The maximum installation length can be up to 1,500 ft. Existing manholes can be used as entry and exit pits. If there are no manholes available, the excavation pit needed for a 6 in. diameter pipeline would be about 4 ft by 6 ft. The diameter reduction of the existing pipeline is typically less than 10%. The hydraulic capacity is increased due to the smooth continuous surface of the cured resin. Service laterals and valves can be reconnected remotely.

Although the CIPP method is the most widely used trenchless technology for pipeline renewal, it has limitations. It is not recommended for pipelines with diameters smaller than 4 in. Also, pipelines transporting product at temperatures greater than about 130 ºF can cause problems for the resin. The resin can vary depending on the contractor, so it is important to verify that the resin has the required physical properties before installation. The cost of the CIPP method is typically more than other renewal methods such as sliplining (SL) and thermoformed pipe (ThP).

Thermoformed pipe (ThP). There are two main types of installation options for ThP. The first step for both options is to inspect the pipeline with CCTV and clean/remove any debris remaining in the pipe. The condition and length of each installation is measured and recorded with CCTV. ThP renewal of existing pipeline is typically performed using high density polyethylene (HDPE) or polyvinyl chloride (PVC) pipe, although PVC is more commonly used. Vendors tend to have less experience with this installation method than CIPP and SL renewal methods.

One option of ThP is called “fold and form.” The cross section of a thin walled pipe is reduced by folding it at the factory. The folded pipe is delivered to the work site in coils and then preheated with steam before installation. The preheating makes the pipe flexible, allowing it to be pulled through bends in the pipeline using a winch. Once the pipe is in place, it is pressurized with steam to form the pipe tightly inside the existing pipe.

Another variety of ThP is called “fused and expanded” (F&E). The outer diameter of the pipe is designed to be smaller than the internal diameter of the existing pipe. The pipe is butt-welded together at the job site, then inserted similarly to SL. Once the pipe is in position, hot liquid and high pressures are used to increase the diameter of the pipe to form it against the inner diameter of the existing pipeline.

ThP can be used in existing pipelines with diameters ranging from 6 in. up to 30 in. or greater depending on the application. With ThP, the pipe is manufactured at the factory and its physical properties can be verified before it arrives at the job site. Installation lengths vary depending on the maximum acceptable coil size. Typically, a 6 in. diameter pipe coil can allow up to about 500 ft of installation. With the F&E option, installation lengths can be as long as 1,500 ft due to the pipe being butt-welded in the field. Entry and exit can take place through existing manholes. If there are no manholes, pits have to be excavated. The pit size needed for a 6 in. diameter pipe will be about 4 ft by 6 ft.

A large work area is needed to lay out continuous strings of welded pipe if the F&E option is used. Although ThP can accommodate large bends, it is not recommended if there are multiple bends within a segment of installation. For multiple bends, excavation of installation pits is required to install fittings, negating some of the benefits of the trenchless technology.

Sliplining (SL). The SL method involves inserting a new pipe into an existing pipe. The first step is to inspect the pipeline with CCTV and clean/remove any debris. The condition and length of each installation is measured and recorded with CCTV. The new pipe must have a smaller diameter than the minimum internal diameter of the existing pipe. The new pipe is installed by pushing or pulling. If applicable, the new pipe can be inserted as a continuous run or in segments. With either case, after the pipe is installed the annulus space between the two pipes is grouted. If the grade is important, then spacers are used to prevent the pipe from shifting during the grouting process.

The experience level among the contractor community is high for this installation method, and the overall cost of installation tends to be relatively less than other renewal methods. This method can be used for gravity or pressurized lines.

A limitation of SL is the loss of cross-sectional area of the pipeline; the requirements for hydraulic capacity must be evaluated before choosing SL as a renewal method. SL also requires pits for entry and exit; however, existing manholes can be used. Severe bends can usually not be negotiated. Therefore, excavation of installation pits is required for these bends, and this negates some of the benefits of the trenchless technology.

Excavation will also be needed to reconnect service laterals. If the existing pipeline has misalignments or joint settlements, SL is not recommended. If the pipeline has multiple bends, steel pipe is not recommended for installation using this technology.

Modified sliplining (MSL). This is an SL method where the new pipe fits closely with the shape of the existing pipe, and the method is specifically designed for large diameter gravity sewers.

Pipe bursting (PB). The PB method consists of bursting an existing pipe underground while simultaneously pulling a new replacement pipe through the enlarged cavity. The bursting action can be pneumatic, static, or hydraulic depending on the application. With all cases, the head is sized to be slightly larger than the existing pipe. As the head advances through the pipeline, the existing pipe bursts. The broken pipe fragments are displaced into the surrounding soil while the replacement pipe is pulled in place behind the head. PB requires the excavation of an entry and exit pit. Within the pits, proper shoring must be installed to ensure the pit walls can withstand the thrust loads of the PB equipment.

PB is most applicable when an existing pipeline needs to be upsized. It is common to increase the replacement pipe as much as three pipe sizes. PB does not require cleaning of the existing pipe or removal of small debris.

PB is not recommended for existing pipelines made of steel or other ductile materials. Any point repairs made with ductile materials, concrete casings, or service laterals will require excavation at those points. If the pipeline area has expansive soils, then significant surface heave can occur when upsizing pipes. If other pipelines are in close proximity to the line being renewed, these pipelines may be damaged by the PB process.

2.1.2.2 Trenchless Construction Methods

Pipe jacking (PJ). PJ involves thrusting segments of pipe into the earth from a drive shaft. The jacking equipment consists of hydraulic jacks and tracks. Pipe segments are placed on the tracks and the pipe is thrust into the excavated earth through a cyclic process. The spoil is removed through the pipe and disposed of out the drive shaft. This is repeated until the full length of the pipeline has been jacked into place. Worker entry is required for the pipe face excavation and the spoil removal process. This typically prevents PJ being used on pipe sizes less than 42 in. With PJ, the pipe provides the structural support needed for temporary ground support while the workers are inside.

Utility tunneling (UT). UT is similar to PJ in that the same equipment is used and worker entry is required for the pipe face excavation and spoils removal process. With UT, the tunneling shield is the only thing that is jacked through the earth along the entire pipeline route. Special liners are installed in place as the shield advances to provide temporary ground support as the new pipe is installed. Once the new pipe is installed, grouting is typically required to fill the annular space between the liner and the new pipe.

Horizontal earth boring (HEB). HEB involves boring a hole underground along the centerline of a proposed path for a new pipeline. The hole is bored with equipment and worker entry is not required during installation. HEB can be used in soil or rock, but mixed phase soils can be problematic. Under these conditions, the bore could be deflected by a phase change and potentially would have to be corrected. One consideration when using HEB techniques is that a failure in the boring equipment requires an open excavation to free or repair the bore head. The equipment and process used to bore the hole varies depending on the application.

The variations of HEB are described below.

Horizontal auger boring (HAB) and pipe ramming (PR). HAB and PR involve excavating an entry/exit pit and jacking a steel casing into the earth. The spoil is removed from inside the casing with an auger or compressed air. The steel casing provides the structural support as a new product pipe is inserted into the casing. HAB and PR are primarily used for road and railway crossings. They are not typically used solely on pipeline installations.

Microtunneling (MT). MT involves drilling a bore hole with a steerable drill head. The diameter of the drill head is as large as or larger than the new pipe being installed. A laser is the most commonly used system to steer the drill head. As the drill head advances, the new product pipe is pulled behind the drill head into place. Due to the size of the equipment and the steering system, MT is limited to pipe sizes 10 in. or larger.

Pilot-tube microtunneling (PTMT). PTMT is a similar technology to MT, but it uses a guided pilot tube followed by upsizing to install the product pipe. PTMT is applicable to pipe diameters from 4 in. to 10 in. PTMT was introduced in the 1990s and is typically used to install house connections directly from main collection sewers. The same type of drilling head as in MT is used, but with the steering system of horizontal directional drilling (HDD). The complex equipment used for PTMT improves its accuracy. The skill level needed to operate the PTMT equipment plus the increased complexity of the equipment increases the cost of the technology vs. that of other HEB technologies. This technology can only be used in soft soils at relatively shallow depths and with jacking distances under 300 ft.

Horizontal directional drilling. The HDD method consists of steering a small diameter drill head (2–4 in.) underground from point “A” to point “B” along the proposed path of the new pipeline. The diameter of the bore hole is gradually increased to the desired size of the new pipe by back reaming the bore hole. During the reaming process the new pipe is pulled into the bore hole. Entry and exit pits are not required if it is suitable for the pipe to enter/exit the ground at an angle. Typically the HDD equipment will sit on top of the surface and the drilling rig will be angled between 8º and 15º. The required angle depends on the stiffness of the pipe material and the overall depth of installation.

The pipe diameter can range from 2 in. up to 48 in. The typical length of installation for a 2 in. pipe can be up to 600 ft. The type of pipe that is installed needs to be able to withstand the tensile stresses created while the pipe is pulled through the bore. The pipe also needs to be able to be fused or welded together to form a continuous length. HDD can be used in a variety of soil conditions. Although HDD is not preferred for rocky soil, it can be done with additional cost. The accuracy of HDD depends largely on the skill level of the operators and the frequency with which location readings of the drill head are taken. A higher frequency gives more accuracy but requires more time and money. Some contractors claim that they can steer the head within a 1 ft by 1ft area 90% of the time. Others use the ballpark figure of 1% of the installation length as an accuracy benchmark.

HDD is not recommended for gravity fed lines due to the unknown accuracy between location readings of the head. With HDD, a significant amount of engineering time is needed in the planning stages of a project to survey and gather information about the subsurface conditions of the pipeline area. If all obstacles are known at the beginning of installation, then less time will be spent and lower costs will be incurred preparing for the pipeline installation by this method.

HDD is considered the best of the HEB technologies for installation of long runs of piping.

2.2 APPLICABILITY OF TRENCHLESS TECHNOLOGIES TO INSTALLATION OF LONG RUNS OF PIPING IN RADIOACTIVELY CONTAMINATED ENVIRONMENTS

The trenchless installation technologies described above were evaluated for applicability in radioactively contaminated environments typical of DOE sites. General applicability requirements included the following.

- Worker entry inside the pipeline must not be required.
- The technology must be applicable to pipelines in the 2 to 6 in. diameter size range often used within the DOE complex for transporting radioactively contaminated wastewater.
- The technology must be applicable for installing significant lengths of piping (i.e., it is not primarily used for road crossings).

The following technologies were dropped from further consideration because they failed to meet one or more of the general applicability requirements, as indicated.

- Pipe jacking and utility tunneling require worker entry during installation.
- Modified Sliplining is used on pipelines with 8 in. or larger diameter, which is outside the 2 to 6 in. diameter size range considered for this study.
- Horizontal auger boring and pipe ramming are primarily used for road and railway crossings. They are not typically used solely on pipeline installations.
- Microtunneling is limited to pipe diameters of 10 in. or larger. This is outside the 2 to 6 in. diameter piping size range typically used on DOE facilities for transporting wastewater.

Figure 2.2 summarizes the pipeline installation methods determined to be applicable for transporting radiological contaminated wastewaters. Table 2.1 shows the main characteristics of each method, and Table 2.2 highlights the advantages and disadvantages of each.

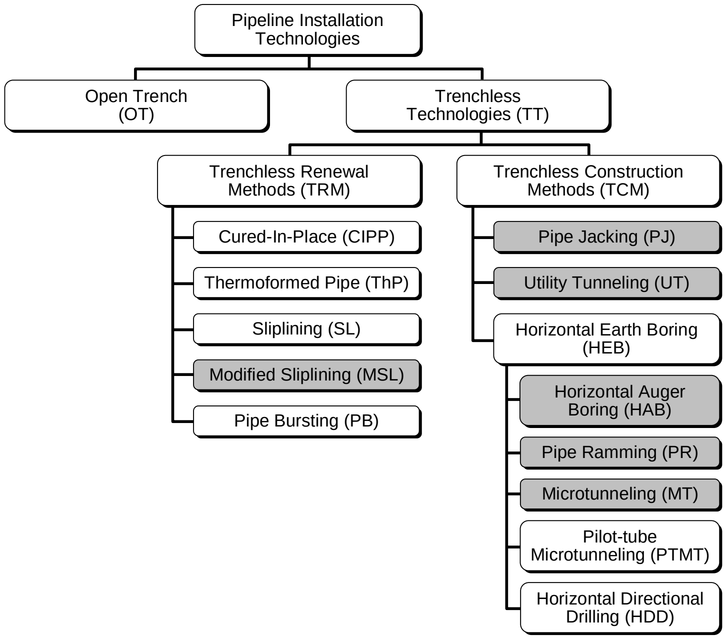

Figure 2.2. Pipeline installation technologies considered for radioactive environments. (Technologies shown in gray are considered not applicable.)

Table 2.1 Characteristics of Trenchless Pipeline Installation Methods Suitable for Radioactive Applications

Method	Min. Diameter (in.)	Max. Installation Length (ft)	Pipe/or Liner Material	Typical Application	Vendor Experience Level[a]
Cured-in-place pipe	4	1,500	thermoset resin/fabric composite	pressure and gravity pipe	high
Thermoformed pipe	6	1,500	HDPE, PVC	pressure and gravity pipe	medium
Sliplining	4	1,000	HDPE, PP, PE/EPDM, PVC	pressure and gravity pipe	high
Pipe bursting	4	1,500	HDPE, PP, PVC, GRP	pressure and gravity pipe	medium
Pilot-tube microtunneling	4	300	RCP, GRP, VCP, Steel, PCP	pressure and gravity pipe	medium
Horizontal directional drilling	2	600	HDPE, Steel, PVC, VCP, FRP	pressure pipe	high

Abbreviations: HDPE = high density polyethylene, PVC = polyvinyl chloride, PP = polypropylene, PE = polyethylene, EPDM = ethylene propylene dimonomer, GRP = glass-reinforced pipe, RCP = reinforced concrete pipe, VCP = vitrified clay pipe, PCP = polymer concrete pipe, FRP = fiberglass-reinforced plastic

[a]high = more than 20 years experience in municipal sector, medium = more than 10 years but less than 20 years experience in municipal sector

Table 2.2. Comparison of Pipeline Installation Methods Suitable for Radioactive Applications

Trenchless Methods	Advantages	Disadvantages
Open trench	• Ability to evaluate the condition of existing pipe and new pipe once installed • High experience level by vendor community, including radioactive environments • Less engineering design compared to other methods	• Quantity of excavation required • Large exposed work area = safety hazard • Double handling of soil • High cost to restore surface and infrastructure impacted. • Increased storm water runoff
Cured-in-place pipe	• Most widely used renewal method • High experience level by vendor community • No joints and smooth internal surface • Applicable for pipes with bends and deformations • Able to enter/exit through manhole • Internal reconnection of laterals and valves	• Carrier tube must be manufactured specially for each project • Sealing may be required at ends • Higher costs compared to other trenchless renewal methods • Temperature of material being transported must be less than about 130ºF
Thermoformed pipe	• Pipe manufactured at factory = good quality • Start/stop capability, reducing excavation for entry/exit pits • New pipe is capable of handling large radius bends	• Large working area above ground is required to lay out butt-fused pipe before insertion • Excavation required for reconnection of laterals and valves • Temperature of material being transporting must be less than about 130ºF • Not recommended for pipelines with multiple bends
Sliplining	• Simple technique = no specialized equipment needed • High experience level by vendor community • Relatively low installation costs	• Cross-sectional area typically reduced 10% or more • Excavation required for entry/exit pits • Excavation required for reconnection of laterals and valves • Grouting required • Excavation required for every bend • Not recommended for pipes with misalignments or joint settlements • Steel piping not recommended for applications with multiple bends
Pipe bursting	• New pipe will follow alignment of the existing pipe • The existing pipe is left underground eliminating the need for its disposal • Ability to upsize the existing pipes	• Excavation required for entry/exit pits • Large working area above ground is required to lay out continuous lines of pipe before insertion • Excavation required for reconnection of laterals and valves • Possible surface heave • Not recommended for existing pipes made of ductile materials such as steel • Steel piping not recommended for installation by this method
Pilot-tube microtunneling	• High accuracy in both line and grade • Can be used on small diameter gravity lines	• Can only be used in soft soils and at relatively shallow depths • Is the most expensive horizontal earth boring technology • Requires high skill level to operate
Horizontal directional drilling	• Steering capability for flexible pipeline materials • Can launch from the ground surface; therefore, no drive and reception pits are required	• Disposal of slurry removed from bore hole required • Significant amount of engineering design required before installation begins • Possible surface heave • Not recommended for gravity fed lines • Bore head could be deflected by a phase change in soils or bedrock • Method limited to straight line installation for stiff piping materials such as steel

3. ORNL WASTEWATER TRANSPORT APPLICATIONS

The scope of the IFDP project includes the upgrade/replacement of portions of the ORNL process wastewater treatment system and the Liquid Low-Level Waste (LLLW) System to support the remediation and decontamination and decommissioning (D&D) missions in a safe and cost-effective manner, while preserving the support of continuing operations at ORNL. This scope may include replacement of and/or installation of new underground piping systems. This study selected three potential IFDP pipeline reconfiguration tasks at ORNL for evaluation with respect to potential use of open trench and trenchless installation technologies.

3.1 ORNL LIQUID WASTE TREATMENT SYSTEMS OVERVIEW

Liquid waste is generated and collected throughout the ORNL site within a complex array of building drains, piping, manholes, pump stations, and tanks. ORNL currently has the following three radioactive liquid waste treatment facilities in operation:

- Process Waste Treatment Complex (PWTC) for treatment of process wastewater and groundwater;
- LLLW System for collection, concentration, and storage of radioactive LLLW; and
- Transuranic Waste Processing Center (TWPC) for solidification of LLLW.

The process waste system accepts wastewater from laboratories, contaminated groundwater, and other waste treatment systems that have a maximum total radiological concentration of the ingestion dose equivalent of 1×10^4 Becquerels per liter (Bq/L) strontium-90 (^{90}Sr). The PWTC treats waste water for radionuclides, heavy metals, and organics and discharges it to the environment via National Pollutant Discharge Elimination System permitted discharge points. The waste acceptance criteria (WAC) for the PWTC are given in Appendix A.

The LLLW System treats aqueous radioactive waste solutions from research laboratories, nuclear reactor facilities, and waste management operations. The LLLW Systems WAC administratively limit the wastes that can be added to the system to a total radionuclide concentration of the ingestion dose equivalent of 2×10^{10} Bq/L ^{90}Sr. It is treated via evaporation, and the concentrate is ultimately sent to storage in one of many large on-site tanks.

The TWPC further processes the concentrated liquids (and resultant sludges) for eventual disposal as solid waste.

The ORNL liquid waste collection and treatment systems were primarily constructed between 1950 and 1989. The existing LLLW collection and transport lines are doubly contained stainless steel lines (typically 2 in. pipe inside a 3 in. pipe) installed in the 1980s. Process waste lines have been installed at ORNL since the early 1950s and consist of a variety of materials based on the standard practices at the time of installation and composition of the liquids expected to be transported through the lines. The piping materials included vitreous clay (oldest piping), carbon steel, stainless steel, and PVC. The majority of the piping installed since the 1980s has been cathodically protected singly contained carbon steel piping for collection of process wastewater. A singly contained HDPE line was installed in 2006 for transport of contaminated groundwater, and a singly contained stainless steel pipeline was installed in this same timeframe to transport research facility process wastewater.

The ORNL liquid waste collection and treatment systems are reaching the end of their safe operating life. Also, a significant portion of the systems is primarily located in what is known as the Central Campus, the main location of the IFDP remediation zone, and will require D&D to accomplish the cleanup mission of IFDP. As a result, process and LLLW collection/transfer lines have the potential to be upgraded or replaced under IFDP.

3.2 ORNL WASTEWATER TRANSPORT APPLICATIONS CONSIDERED IN EVALUATIONS

Three ORNL wastewater transport applications were selected for evaluations of pipeline installation technologies in this study. They are representative of categories of radiological pipelines in contaminated environments that could potentially be installed or upgraded at ORNL in the future. The potential applications are described below.

1. Existing Gravity Drained Process Waste Line: Replace/upgrade 6 in. singly contained vitrified clay pipe to extend the design life by 30 years. Line begins inside research building 7920 and extends to the first manhole located about 270 ft from the building. The pipeline has minimum bends and contains straight segments of pipe from manhole to manhole. This application is located in a congested area with underground utilities and roads and buildings in the area. For the purposes of this study, it was assumed that the pipeline would follow the original installation route. Both renewal and new pipeline installation technologies could be considered for this application.
2. Existing Pressurized Process Waste Line: Replace/upgrade about 5,600 ft of 6 in. singly contained carbon steel pipe running from the building 7961 wastewater collection tanks to building 2600 treatment plant feed tanks to extend the design life by 30 years. The pipeline is connected to tank systems at each end, is located in both congested and "open field" areas, and requires multiple bends. For the purposes of this study, it was assumed that the pipeline would follow the original installation route. Both renewal and new pipeline installation technologies could be considered for this application.
3. New Pressurized LLLW Line: Install a new, roughly 6,000 ft, doubly contained LLLW pipeline from the research area collection tank in building 7966 to the building 7830 treatment plant feed tanks with a 30-year design life. The pipeline is connected to tank systems at each end, is located in both congested and open field areas, and requires multiple bends. For the purposes of this study, the pipeline was assumed to take a more direct route than the existing line and would therefore be considered for new pipeline installation technologies.

The specifications for each ORNL application studied in this report are given in Table 3.1 and the locations of the pipelines are shown in Figure 3.1.

Table 3.1. Select ORNL Wastewater Pipeline Applications

	Application		
Specification	**1**	**2**	**3**
Type of waste transported	Process	Process	Low level
Head type	Gravity	Pressurized	Pressurized
Existing pipe material	Vitrified clay	Carbon steel	Stainless steel
Containment	Single	Single	Double
Inner pipe size (in.)	6	6	2
Outer pipe size (in.)	N/A	N/A	3
Length of existing route (ft)	~270	~5,600	~10,500[a]
Average depth (ft)	4	Varies	4
Length of new route (ft)	N/A	N/A	~6,000[b]
Pipeline area	Congested	Congested and open field	Congested and open field

[a]Existing route (shown in Fig. 3.1 as Application 3-A)
[b]Proposed new route (shown in Fig. 3.1 as Application 3-B)

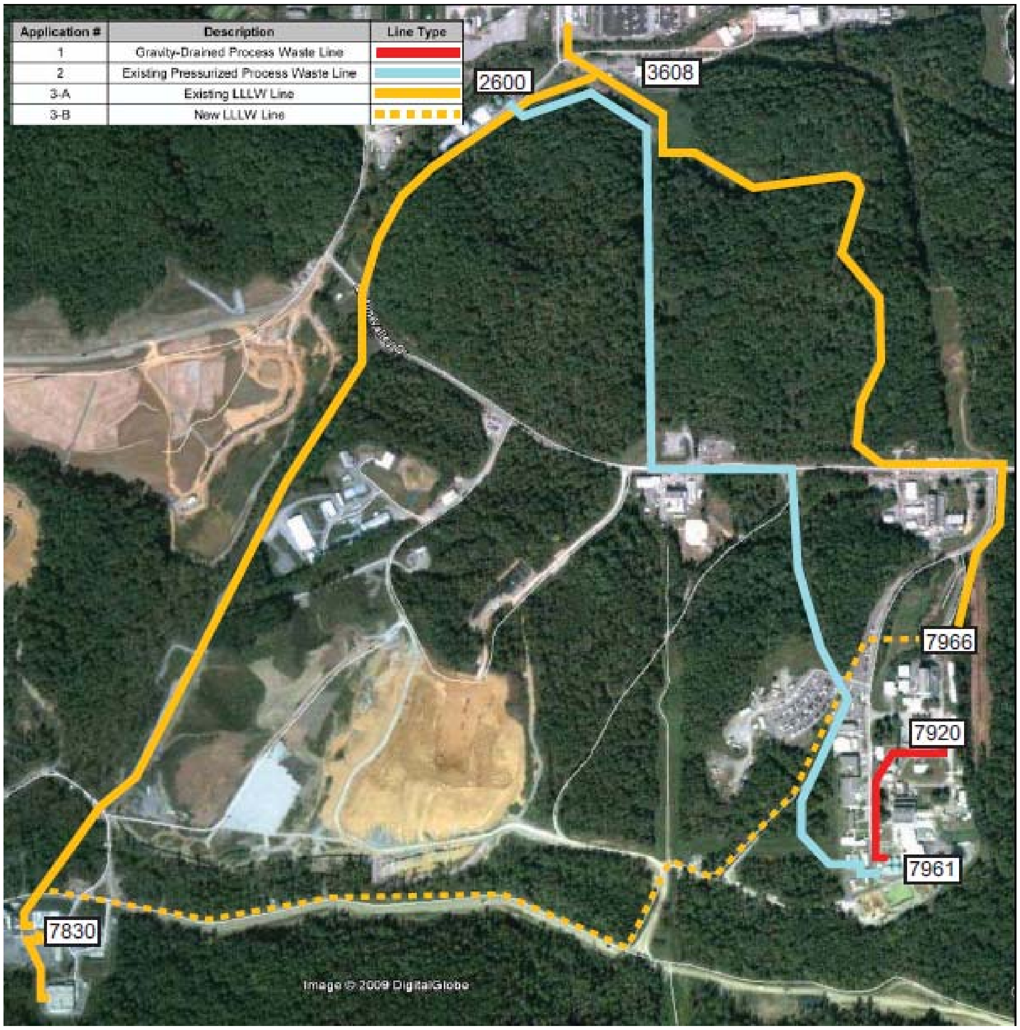

Figure 3.1. Select ORNL wastewater pipeline locations.

3.3 PIPELINE SELECTION CONSIDERATIONS FOR ORNL APPLICATIONS

Pipelines considered for replacement/upgrade in this study must comply with all environmental regulations, DOE orders and guidelines, and applicable codes and standards. The ORNL liquid waste system is regulated by the U.S. Environmental Protection Agency (EPA), DOE, and the Tennessee Department of Environment and Conservation (TDEC). Wastewater composition and classification defines how the stream must be managed in terms of the design and operation of collection, transfer, and treatment processes. The two primary documents governing the design of radioactive liquid waste systems are DOE O 435.1 and its companion manual DOE M 435.1-1,which specifies general confinement and leak detection requirements for the design of radioactive waste systems and additional requirements for systems containing high activity and high hazard materials (DOE 1999 and DOE 1999a). For the purposes of this study, ORNL process wastewater was assumed to fall below the threshold for high activity and high hazard, and the LLLW system above the threshold. Another "governing document," the Federal Facility Agreement for the Oak Ridge Reservation (FFA) between DOE, EPA, and TDEC, contains design requirements for leak detection and double containment for LLLW tank systems.

For the purposes of this study, a range of potential pipeline materials was considered for replacing the three specific ORNL wastewater pipeline applications described above. Because of DOE O 435.1 design requirements for high activity-high hazard systems and the FFA, it was assumed that doubly contained stainless steel piping was the only material of construction that should be considered for the LLLW application evaluated in this study. It was also assumed that a range of piping materials could potentially be considered for transporting process wastewater within the composition range given in Appendix A. New materials of construction considered in this study included carbon steel, stainless steel, and HPDE. However, the performance requirements of the pipeline based on the expected chemical and radiological composition of future wastewater must be used to select the piping materials for a given pipeline installation project during the detailed design process.

It was also assumed that a variety of leak detection methods could be considered for these process waste lines, some of which would require doubly contained pipelines. Therefore, the piping options for process wastewater evaluated both singly contained and doubly contained pipelines.

In the case of pipe replacement, this study assumed that existing pipelines would be emptied, flushed, and abandoned in place, but these costs were not included in the cost comparison. The ROD for ultimate remediation of the area will determine the final requirements for pipeline closure. These options could range from digging up the pipes to grouting them in place to no additional action. Costs associated with these future actions were not considered in this evaluation.

3.4 GEOLOGICAL CONSIDERATIONS FOR THE ORNL RESERVATION

The ORNL reservation is typically mantled by clayey residual soils derived from in-place weathering of shaley and calcareous siltstone and limestone bedrock. The soils vary from soft to very hard consistency, with much of the soil profile varying from stiff to very stiff consistency, and contain fragments of sandstone and chert. The bedrock surface is highly irregular and at some locations at ORNL rock pinnacles project upward to the ground surface. Also, "floating" rock boulders within the soil profile and weathered rock layers may be encountered at shallow depths (Hatcher, R. D., et al. 1992).

4. APPLICABILITY OF TRENCHLESS TECHNOLOGIES TO ORNL APPLICATIONS

The underground piping installation techniques described in Section 2 that were thought to be generally applicable to radiologically contaminated environments are shown in Figure 2.2. These installation techniques were evaluated for applicability to the three specific ORNL applications described in Section 3 of this report. The resulting matrix shown in Table 4.1 summarizes the alternatives that were viable for further evaluation. Several of the proposed installation technologies, shown in yellow in Figure 4.1, were dropped from consideration for a specific ORNL application because of the technical reasons described below. The open trench technique was the only installation technology that was considered applicable to all three ORNL applications.

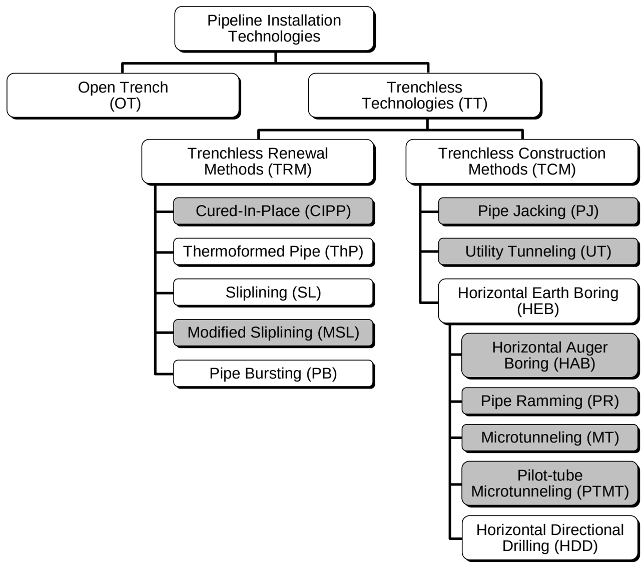

Figure 4.1. Pipeline installation technologies considered for three specific ORNL applications. (Technologies shown in gray were deemed not applicable for the three specific cases considered.)

The existing pipelines in the three specific ORNL applications listed in Table 4.1 include 6 in. singly contained vitrified clay or carbon steel piping for process waste and 2 in. piping inside 3 in. piping for doubly contained LLLW piping. For the replacement piping alternatives listed in Table 4.1, process piping was assumed to be replaced with 6 in. singly contained HDPE, coated carbon steel, or 304 L stainless steel piping; 6 in. and 8 in. doubly contained carbon or stainless steel piping; or 6 in. and 10 in. HDPE doubly contained piping. LLLW piping was assumed to be replaced with 2 in. and 3 in. doubly contained stainless steel piping. All steel piping was assumed to have cathodic protection. Sliplined singly contained pipes were assumed to be 4 in. diameter pipes.

ThP renewal of existing pipeline is performed using HDPE and PVC pipe. It is not considered a viable option for steel pipe or doubly contained pipes.

CIPP techniques are not applicable to the three piping materials considered for the ORNL-specific applications.

SL of existing pipes is traditionally performed using HDPE, polypropylene, PE/ethylene propylene dimonomer, or PVC pipe. Although vendors do not routinely install steel piping using this technology, it may be technically feasible for short segments of pipe with few bends. Therefore, it was considered as a potential method in Table 4.1 for the existing gravity drained process waste line. It was not considered for the existing pressurized process waste line because the stiffness of the steel would make it too difficult to install in pipelines with multiple bends without adding numerous open excavations to install fittings, thus negating the benefits of the trenchless technology. SL process waste pipes with doubly contained piping was not considered to be a practical option because reducing the size of the pipeline from 6 in. to 2 to 3 in. would cause operational problems for the process waste system.

PB is not recommended for use when the existing pipes are made of ductile material. Therefore, it was only considered for the existing gravity drained process waste pipe that is made of vitrified clay pipe. It was not considered for the carbon steel pressurized process waste line. Steel is also not recommended for the material of construction for the new piping using the PB installation technology.

HDD installation technology is not recommended for gravity drained pipelines because of the unknown accuracy between location readings. Therefore, this installation technology was only considered for the two pressurized line applications. It should be noted that mixed phase soils such as those found at ORNL can be problematic for this technology. The bore could be deflected by a phase change between soil and bedrock. This could require an open excavation to free or repair the bore head.

PTMT use is limited to soft soils and relatively shallow depths. The technique is not applicable for rocky soil conditions such as those found at ORNL.

Table 4.1. Pipeline Installation Techniques Considered for Specific ORNL Applications

Application Name	Existing Pipe Material	New Pipe Material	Pipeline Installation Method				
			Open Trench[a]	Horizontal Directional Drilling[a]	Thermoformed Pipe[b]	Sliplining[b]	Pipe Bursting[b]
Existing gravity drained process waste line	VC	Singly contained CS (coated and cathodically protected)		N/A[c]	N/A[d]		N/A[d]
		Singly contained HDPE		N/A[c]			
		Doubly contained CS (coated and cathodically protected)		N/A[c]	N/A[d]	N/A[e]	N/A[d]
		Doubly contained HDPE		N/A[c]	N/A[e]	N/A[e]	
		Singly contained SS[f] (cathodically protected)		N/A[c]	N/A[d]		N/A[d]
		Doubly contained SS[f] (cathodically protected)		N/A[c]	N/A[d]	N/A[e]	N/A[d]
Existing pressurized process waste line	CS	Singly contained CS (coated and cathodically protected)			N/A[d]	N/A[g]	N/A[d,h]
		Singly contained HDPE					N/A[d,h]
		Doubly contained CS (coated and cathodically protected)			N/A[d]	N/A[e,g]	N/A[d,h]
		Doubly contained HDPE			N/A[e]	N/A[e]	N/A[d,h]
		Singly contained SS[f] (cathodically protected)			N/A[d]	N/A[g]	N/A[d,h]
		Doubly contained SS[f] (cathodically protected)			N/A[d]	N/A[e,g]	N/A[d,h]
New pressurized LLLW line	SS	Doubly contained SS[f] (cathodically protected)			N/A[d]	N/A[e,g]	N/A[d,h]

Abbreviations: VC = vitrified clay, CS = carbon steel, N/A = not applicable, HDPE = high density polyethylene, SS= stainless steel, LLLW =

[a]Technology is applicable to new installations and renewal of existing pipelines.

[b]Technology is only applicable to renewal of existing pipelines.

[c]Method is not recommended for gravity drained pipelines because of the unknown accuracy between location readings.

[d]Steel piping is not recommended as the material of construction for this pipeline installation method.

[e]Double containment inside of an existing pipe of this size significantly reduces the hydraulic capacity.

[f]304 L SS

[g]Existing pipeline has multiple bends, and steel piping is not recommended as the material of construction because of its high stiffness.

[h]Method is not recommended if the existing piping is steel because of its ductility.

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5. ALTERNATIVES ANALYSES METHOLOGY

To further evaluate the viable trenchless technologies identified in Table 4.1, an analysis of the potential installation technologies was performed for each of the three ORNL test cases. The alternative analyses were performed with the Analytical Hierarchy Process (AHP) using a decision modeling method developed at the University of Pennsylvania Wharton School of Business by Dr. Thomas L. Saaty (Saaty 1977). This model provides a structured framework that allows for comparison of both qualitative and quantitative selection criteria. The relative importance of the selection criteria was developed using a pair-wise comparison technique. This method has been implemented within the federal government and many Fortune 500 companies and is used in project management software tools such as Primavera.

Three key selection criteria and several subcriteria were identified for ranking alternative options.

1. *Cost and Schedule*—Considers installation cost, operating cost, impact on project schedule, and cost of obtaining project planning data.
2. *Operability*—Considers impact on ongoing operations, maturity of the installation technology, integrity of the pipeline, and expected pipeline design life.
3. *Environment, Safety, and Health*—Considers likelihood of ES&H impact from environmental releases during installation, potential to contaminate installation equipment, and risk of disrupting existing underground utilities during the installation process.

These three criteria were compared using AHP. The pair-wise comparison technique was used to determine the relative importance of the selection criteria for each option (e.g., how does one weight "Cost and Schedule" as a criterion relative to "ES&H"?). This approach provides decision makers with the ability to focus solely on the two decision criteria being evaluated in isolation, without the distraction or confusing impact of other criteria. The results are shown in Appendix B, Table B.1, and the weighted selection criteria are summarized in Figure 5.1.

Five ratings were used to determine how well an option met a given subcriterion: 5—Strong, 4—Moderate-Strong, 3—Moderate, 2—Low, 1—None. Definitions were developed for the ratings for each subcriterion. The criteria and subcriteria definitions used for evaluating and scoring the pipeline installation options are given in Appendix B, Table B.2.

Each alternative in the options analysis was given a rating between 1 and 5 for each subcriterion, and weighted ratings were obtained by multiplying the rating by the appropriate weighting factor from Figure 5.1. The ratings were made by the evaluation team based on experience guided by the subcriterion definitions. In some cases actual data (i.e., cost estimates for the proposed pipeline installation option) were used to calculate ratings based on criterion definitions. An overall score for each alternative was obtained by summing the weighted ratings. The highest possible score that can be obtained by this process is 100.

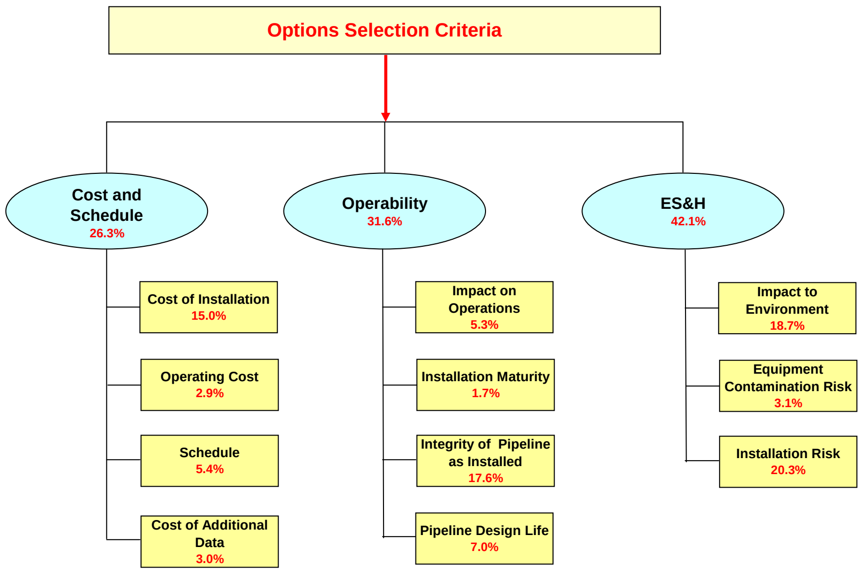

Figure 5.1. Alternative analysis selection criteria.

6. EVALUATION OF ORNL-SPECIFIC OPTIONS

The underground piping installation techniques that were thought to be generally applicable to radiologically contaminated environments are described in Section 2. These installation techniques were evaluated for applicability to three specific ORNL applications described in Section 4. Each pipeline installation technology that was considered to be technically viable for each ORNL application (as shown in Table 4.1) was scored using the criteria and methodology described in Section 5. The results of the evaluation of alternatives are summarized in Table 6.1 and discussed below.

6.1 EVALUATION OF ALTERNATIVES

Piping installation and materials options for each of the three ORNL applications evaluated were scored by the process described in Section 5. A rating between 1 and 5 was given for each subcriterion, and a weighted score was obtained for each piping option by multiplying the rating by the appropriate weighting factor. The resulting score could range between 0 and 100, with the higher score being the preferred alternative. The piping options for each ORNL application are listed in the order of descending scores in Table 6.1.

The alternatives analyses showed a similar trend for selection of pipeline installation technologies for the three ORNL applications evaluated. Renewal technologies such as SL, ThP techniques, and PB received the highest scores in the cases where these techniques were considered viable. For installation of new pipelines, the technologies ranked in the following order: open trench and HDD. However, the open trench technology was the only technique that was applicable to all three applications.

Information used to obtain a rating for each subcriterion is described below.

<u>Installation Costs.</u> Linear foot cost comparison estimates used in the alternatives evaluation are given in Appendix C. These estimates were developed for relative comparison purposes only as needed for AHP, described in Section 5; they should not be considered as complete or total costs for installation of a pipeline at ORNL. As shown in Table C.1, the cost of installation of underground piping in these applications was impacted more by the materials of construction than the pipeline installation method. In most industry applications the pipeline method impacts cost more than pipeline materials; however, in DOE applications the wide spread in cost between HDPE and carbon and stainless steels is larger than in industrial applications where less expensive materials with a narrower cost spread can be used.

<u>Operating Costs.</u> It was assumed that the major differences between operating costs for various piping systems would be due to the different methods used to meet leak detection requirements for DOE O 435.1 (DOE 1999 and DOE 1999a) and pipeline inspection requirements. It was assumed that leak detection for doubly contained lines would be accomplished by routine pressure monitoring of the pressurized annulus between piping systems, and manpower intensive mass balances would be performed with each transfer for singly contained lines. It was assumed that singly contained lines would require more frequent inspections for continued life expectancy, and additional costs were assumed for inspection of lines that are cathodically protected.

<u>Schedule Impacts</u>. Potential impacts on schedule took into account how complicated the installation process was expected to be and the level of experience vendors would likely have with installation techniques using a given piping option. Renewal techniques were rated high because there would not be complications due to unknowns associated with unexpected

underground obstructions and there are many experienced installation vendors. Open trench rated high because it is a widely used installation technique that historically has not resulted in significant schedule delays. HDD was rated lower because of potential complications for drilling in areas with underground interferences. HDPE was assumed to be the easiest piping material to install followed by singly contained piping and then doubly contained piping. Cathodic protection was assumed to potentially complement the installation process. SL with catholically protected steel pipelines was rated low because of the complications associated with installing these materials by this method and the lack of vendors experienced in installation of the materials by this method.

<u>Quantity of Data/Planning</u>. Costs of providing preplanning data included the amount of information needed on the underground environment as well as that required to develop the engineering specifications packages for piping and installation. The required information on the underground environment was expected to increase from renewal technologies to open trench to HDD. More information is required for installation of rigid piping such as steel than for flexible piping such as HDPE. The time required to develop the engineering specification packages before procurement was expected to increase from HDPE to carbon steel to stainless steel.

<u>Impacts on Operations</u>. Renewal techniques received low scores for impact on operations because the pipeline must be out of service for the duration of the project compared to just for final pipe tie-ins for techniques used to install new pipelines. Installations in highly congested areas received lower scores that those in mainly open field areas.

<u>Installation Maturity</u>. Open trench and ThP were considered to be the most mature technologies. SL and HDD with HDPE piping and PB were considered to be mature technologies. SL and HDD with steel pipelines were considered to be the least well developed installation techniques with the fewest number of experienced vendors.

<u>Integrity of Pipeline as Installed</u>. The open trench technique allows full inspection. The integrity of an outer pipe cannot be verified using any trenchless technologies. HDD, PB, and SL allow for preinspection but do not allow for visual inspection after installation. ThP does not allow for direct preinspection or postinspection of the piping. All inner piping can be inspected postinstallation by camera, although these costs are not included in this analysis.

<u>Expected Pipeline Design Life</u>. This is a long-term measure of the installation damage to the pipeline. Open trench received the highest score because it is the most controlled installation technique. SL, PB, and HDD received medium scores. Plastic piping installed by these techniques was considered more vulnerable to damage and thus received a lower score than steel piping. The ThP method received the lowest score because the piping cannot be seen during installation.

<u>Impact to the Environment</u>. Renewal techniques that do not require digging received the highest ratings. Within the renewal category, PB received a slightly lower score because it exposes the soils and groundwater to potentially contaminated shards of piping and potentially impacts nearby pipelines. Open trench received a lower rating than HDD because it results in the removal of more dirt and in more storm water runoff.

<u>Potential to Contaminate Equipment</u>. Renewal technologies received the highest scores because they involve the least expensive equipment potentially being exposed to contamination during the installation process. Open trench and PB received medium ratings because the equipment used is more expensive. HDD received the lowest score because the drill head, shaft, and cabling would

be the most expensive items that could potentially be contaminated by installation in contaminated areas.

Installation Risk. Renewal techniques received the highest score because they do not involve digging. Open trench technology was given a medium score because historical experience with this technique f in areas with unknown utilities has shown it to be a low risk option. This installation technique was given a lower score for use in highly congested environments compared to mainly open field areas. HDD was rated lower because of potential complications for drilling in areas with underground interferences.

6.2 SENSITIVITY ANALYSIS

A sensitivity analysis was performed to understand the impacts of weighting factors and ratings on the results shown in Table 6.1.

In the baseline evaluation, the main criteria were weighted: cost and schedule ~26%, operability ~32%, and ES&H ~42%. The weighting factor for each main criterion was changed to be 5 times the other criteria to determine the impact on overall scores. When costs and schedule were emphasized, the relative rankings of the various installation technologies did not change. However, the material of construction begins to impact overall rankings more than the pipeline installation technique when the cost weighting is increased.

When operability was emphasized, installation of new piping using open trench technology ranked higher than all other installation technologies, and the relative rankings between installation technologies changed to open trench, followed by SL/ PB/HDD, which all received similar scores, followed by ThP.

Because ES&H was emphasized heavily in the base case, increasing the ES&H emphasis did not impact the overall rankings of installation technologies.

Because various levels of information were available for scoring each subcriterion, the sensitivity to subcriterion ratings was evaluated by systematically changing the rating of each individual subcriterion to a value of 5, implying there was no discernable difference between piping installation options for that subcriterion. The overall rankings of the pipeline installation technologies were not impacted by changes in the ratings for any subcriterion except for "installation risk." This is the result of the technologies originally receiving ratings that spanned the full 1–5 range and the subcriterion having the high weighting factor of 20%. When the differences in installation risk subcriterion were not taken into account, the open trench installation technique for HDPE piping became as attractive as renewal technologies. The gaps between the overall scores for open trench and HDD techniques were also reduced.

The results of the sensitivity analysis indicate that the selection of piping installation method is sensitive to the installation environment and the priority of the drivers for a project. The results of the detailed analysis given above are applicable to the three ORNL applications of interest. The overall methodology developed in this study for evaluating pipeline installation options will be useful at other sites inside and outside of ORNL. However, each evaluation must be application specific and rankings of various technologies must reflect those environments.

Table 6.1. Alternatives Analysis for ORNL-Specific Wastewater Transport Applications

Installation Method	Piping Option	Total Project Score	Cost of Installation	Operating Cost	Schedule	Quantity of Data/Planning	Impact on Operations	Installation Maturity	Integrity of Pipeline as Installed	Expected Pipeline Design Life	Impact to Environment	Potential to Contaminate Equipment	Installation Risk
ORNL Application 1: Existing Pressurized Process Waste Line (Carbon Steel)													
Sliplining	Singly contained high density polyethylene	80	5	3	5	5	1	4	4	4	4	3	5
Thermoformed pipe	High density polyethylene	73	5	3	5	5	1	5	3	2	4	3	5
Open trench	Singly contained high density polyethylene	69	5	3	5	5	3	5	5	5	2	2	3
Open trench	Doubly contained high density polyethylene	68	5	5	3	5	3	5	5	5	2	2	3
Open trench	Singly contained carbon steel[a]	61	4	1	3	5	3	5	5	5	2	2	3
Open trench	Singly contained stainless steel[b]	61	4	2	3	4	3	5	5	5	2	2	3
Open trench	Doubly contained carbon steel[a]	56	2	4	3	5	3	5	5	5	2	2	3
Horizontal directional drilling	Singly contained high density polyethylene	52	5	3	3	3	4	4	4	3	3	1	1
Horizontal directional drilling	Doubly contained high density polyethylene	52	5	5	2	3	4	4	4	3	3	1	1
Open trench	Doubly contained stainless steel[b]	50	1	4	2	4	3	5	5	5	2	2	3
Horizontal directional drilling	Singly contained carbon steel[a]	46	4	1	2	2	4	2	4	4	3	1	1
Horizontal directional drilling	Singly contained stainless steel[b]	46	4	2	2	1	4	2	4	4	3	1	1
Horizontal directional drilling	Doubly contained carbon steel[a]	44	3	4	2	2	4	1	4	4	3	1	1
Horizontal directional drilling	Doubly contained stainless steel[b]	34	1	4	1	1	4	1	4	4	3	1	1
ORNL Application 2: Existing Gravity Drained Process Line (Vitrified Clay)													
Sliplining	Singly contained high density polyethylene	79	5	3	5	5	1	4	4	3	4	3	5
Thermoformed pipe	High density polyethylene	73	5	3	5	5	1	5	3	2	4	3	5
Sliplining	Singly contained carbon steel[a]	72	5	1	1	5	1	1	4	4	4	3	5
Sliplining	Singly contained stainless steel[b]	69	4	2	1	5	1	1	4	4	4	3	5
Pipe bursting	Singly contained high density polyethylene	65	5	5	2	5	1	4	4	3	3	1	4
Pipe bursting	Doubly contained high density polyethylene	65	5	3	3	5	1	4	4	3	3	1	4
Open trench	Singly contained high density polyethylene	62	5	3	5	4	2	5	5	5	2	2	2
Open trench	Doubly contained high density polyethylene	61	5	5	3	4	2	5	5	5	2	2	2
Open trench	Singly contained carbon steel[a]	54	4	1	3	3	2	5	5	5	2	2	2
Open trench	Singly contained stainless steel[b]	54	4	2	3	2	2	5	5	5	2	2	2
Open trench	Doubly contained carbon steel[a]	48	2	4	3	3	2	5	5	5	2	2	2

Installation Method	Piping Option	Total Project Score	Cost of Installation	Operating Cost	Schedule	Quantity of Data/Planning	Impact on Operations	Installation Maturity	Integrity of Pipeline as Installed	Expected Pipeline Design Life	Impact to Environment	Potential to Contaminate Equipment	Installation Risk
Open trench	Doubly contained stainless steel[b]	42	1	4	2	2	2	5	5	5	2	2	2
ORNL Application 3: New Pressurized Liquid Low-Level Waste Line (Stainless Steel)													
Open trench	Doubly contained stainless steel[b]	52	1	5	3	4	3	5	5	5	2	2	3
Horizontal directional drilling	Doubly contained stainless steel[b]	51	5	5	2	1	4	1	4	4	3	1	1

[a]Coated and cathodically protected
[b]Cathodically protected 304 L stainless steel

7. SUMMARY AND CONCLUSIONS

The purpose of this study was to address the IFDP External Technical Review's recommendation to evaluate trenchless technologies for installing underground pipelines as an alternative to conventional open trench installation methods under conditions at ORNL, including radioactive applications. The scope of the study included evaluation of the technical risks, benefits, and economics of installing new and rehabilitating existing gravity drained and pressurized piping using trenchless technologies compared to conventional installation methods. It should be noted that the conclusions in this study are applicable for installing long runs of piping in contaminated areas as directed by the technical review. Applications using shorter runs of piping (e.g., across roads or repairing broken pipelines) or in uncontaminated areas could result in a preference for other methods.

A range of trenchless installation technologies was reviewed for general applicability for replacing long runs of existing contaminated piping and/or installing new pipelines in potentially contaminated areas. It was concluded that pipe jacking, utility tunneling, modified sliplining, horizontal auger boring, pipe ramming, and microtunneling trenchless technologies are not applicable for radioactive environments for the following reasons: (1) the technologies require worker entry into the pipeline; (2) the technologies are not applicable to pipelines in the 2 to 6 in. diameter size range often used within the DOE complex for transporting radioactively contaminated wastewater; and/or (3) the technologies are only used for road crossings, not for installing significant lengths of piping.

Open trench, cured-in-place, thermoformed, sliplining, pipe bursting, pilot-tube microtunneling, and horizontal directional drilling installation methods are considered potentially viable alternatives for radioactive environments. It was determined that CIPP and PTMT were not feasible in the ORNL-specific applications considered. The remaining options were evaluated in more detail for the three specific ORNL applications considered: gravity drained process waste pipeline, pressurized process waste pipeline, and pressurized LLLW pipeline. Each feasible pipeline installation method was evaluated against the baseline conventional open trench installation method using weighted criteria in the areas of ES&H, project cost and schedule, and technical operability.

Open trench technology was the only pipeline installation technique that could be applied to all three ORNL scenarios. The results indicated that renewal technologies such as SL and ThP processes should be considered if it is desirable and technically feasible to extend the life of an existing radioactively contaminated pipeline. For the ORNL applications evaluated, the baseline open trench technology scored higher than the trenchless HDD technology. PB could only be considered for replacement of the gravity drained vitrified clay pipeline.

Conclusions from the evaluation of the ORNL specific applications indicate that open trench installation methods have advantages over HDD for new pipeline installations in hazardous industrial environments where ES&H issues could have very serious regulatory, environmental, and worker safety impacts. If leaving potentially contaminated shards of the original pipeline in the ground is acceptable, PB should be considered for replacement of technically viable pipes such as vitrified clay pipe, particularly in congested areas with significant risk of contaminated soil. If long-term operability of a pipeline is of prime importance, open trench installation of new pipelines would be the technology of choice over trenchless installation methods. If costs and schedule are the over arching drivers and the operability and ES&H risks are low, trenchless installation technologies such as HDD would be preferred over traditional open trench methods.

The results of this study indicate that trenchless installation technologies have potential for application in contaminated environments. Due to their limited use in the past for DOE applications, they are considered to be unproven technologies, particularly with respect to impact of the installation method on pipeline integrity and design life. The piping materials typically used in DOE radioactive applications, carbon or stainless steels, offer technical challenges for renewable installation technologies, and some of these materials are considered incompatible with some of the installation techniques, at least with the maturity level of the technology today. In addition, for the ORNL applications evaluated in this study, it was found that the costs of installing pipelines are impacted more by the type of piping material than the installation technology. This indicates that future studies to evaluate the compatibility of a range of piping materials with DOE waste stream compositions should be the first step towards not only significantly reducing costs for pipeline installation projects in general, but also increasing the applicability of trenchless installation technologies for contaminated waste applications. Demonstrations of the installation technologies should be conducted within the DOE environment with enhanced ES&H oversight to reduce the risks associated with these technologies. Initially short pipeline installations with currently used piping materials could be demonstrated, and future demonstrations could expand to include more challenging installation applications with nontraditional (for radioactive environments) piping materials. Technology development areas could include new PB heads capable of bursting ductile piping.

The major benefits historically given for using trenchless HEB technologies instead of open trench pipeline installation in traditional applications were based on congested suburban environments where rehabilitation of surfaces, rerouting roads, etc. significantly increase the cost of projects. For the ORNL-specific applications evaluated in this study, trenchless construction techniques were considered to be less desirable than open trench installation in congested areas. The areas with significant numbers of building, road, and related obstructions also have significant uncertainties associated with the location of underground utilities, hazardous waste pipelines, and historical soil contamination. Therefore, the ES&H risks associated with underground drilling in such areas outweighed potential benefits from reduced above ground disruptions. Technology demonstrations could reduce the uncertainties associated with the technologies, as could the development of better three dimensional underground mapping techniques to identify underground obstructions.

Such demonstrations and technology developments would validate trenchless technologies for wider use involving radiological waste systems in the DOE complex.

8. REFERENCES

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APPENDIX A. ORNL WASTE ACCEPTANCE CRITERIA

Table A.1. Maximum Allowable Concentrations of Contaminants for Discharge to the ORNL Waste Treatment Complex System

Contaminant	**Concentration**
Radionuclides:	
Gross Alpha	175 Bq/L
Gross Beta	10,000 Bq/L
^{90}Sr	10,000 Bq/L
^{137}Cs	400 Bq/L
Metals:	
As	4.0 mg/L
B	40.0 mg/L
Ba	120.0 mg/L
Be	0.2 mg/L
Cd	0.3 mg/L
Cr	7.5 mg/L
Cu	2.5 mg/L
Ni	65.0 mg/L
Pb	30.0 mg/L
Sb	65.0 mg/L
Se	3.0 mg/L
Zn	60.0 mg/L
Other:	
Br	100 ppm
Cl	20 ppm
Cyanide (CN)	0.2 ppm
Nitrate (NO_3)	10 ppm
Oil and Grease	100 ppm
pH	>6.0 units
Phosphate (PO_4)	5 ppm
Sulfate (SO_4)	3,000 ppm
Total organic carbon	150 ppm
Total suspended solids	1,000 ppm
Total toxic organics	100 ppm

Reference: Bechtel Jacobs Company, LLC, *Waste Acceptance Criteria for Liquid Waste Systems Operated by Liquid and Gaseous Waste Operations Project at ORNL, WM_LWS-WAS* (Rev. 6), Bechtel Jacobs, May 2007.

APPENDIX B. ALTERNATIVE ANALYSES DEFINITIONS

Table B.1. Pair Wise Selection Criteria

Main Criteria	Cost and Schedule	Operability	ES&H	Total	Weight
Cost and Schedule	1.00	1.00	0.50	2.5	26.32%
Operability	1.00	1.00	1.00	3.0	31.58%
ES&H	2.00	1.00	1.00	4.0	42.11%
			Total	9.5	100.00%

Cost and Schedule	Cost of Installation	Operating Cost	Schedule	Cost of Additional Data	Total	Weight	Relative Weight
Cost of Installation	1.00	4.00	4.00	5.00	9.0	57.0%	14.99%
Operating Cost	0.25	1.00	0.50	1.25	1.8	11.1%	2.91%
Schedule	0.25	2.00	1.00	1.25	3.3	20.6%	5.41%
Cost of Additional Data	0.20	0.80	0.80	1.00	1.8	11.4%	3.00%
				Total	15.8	100.0%	26.32%

Operability	Impact to Operations	Installation Maturity	Integrity of pipeline as installed	Pipeline Design Life	Total	Weight	Relative Weight
Impact to Operations	1.00	4.00	0.15	0.33	5.5	16.7%	5.27%
Installation Maturity	0.25	1.00	0.15	0.33	1.7	5.3%	1.66%
Integrity of pipeline as installed	6.67	6.67	1.00	4.00	18.3	55.8%	17.64%
Pipeline Design Life	3.00	3.03	0.25	1.00	7.3	22.2%	7.00%
				Total	32.8	100.0%	31.58%

ES&H	Impact to Environment	Potential to Contaminate	Installation Risk	Total	Weight	Relative Weight
Impact to Environment	1.00	6.00	1.00	8.0	44.5%	18.73%
Potential to Contaminate	0.17	1.00	0.15	1.3	7.3%	3.08%
Installation Risk	1.00	6.67	1.00	8.7	48.2%	20.29%
			Total	18.0	100.0%	42.11%

Table B.2. Definitions for Rating Alternative Options

Main Criteria	Subcriteria	Definition	5—Strong	4—Moderate–Strong	3—Moderate	2—Low	1—None
Cost and Schedule	**Cost of installation**	Estimated project cost ($/ft) for the actual installation of the selected piping material. Project cost includes design and construction cost. CL—lowest cost, CH—highest cost; Range = CH–CL.	Cost in lowest 20% of cost range	Cost in lowest 20%–40% of cost range	Cost in lowest 40%–60% of cost range	Cost in lowest 60%–80% of cost range	Cost in highest 20% of cost range
	Operational Cost	Estimated operating cost ($K/year) for all maintenance / inspections required by the option determine pipeline integrity. CL—lowest cost CH—highest cost; Range = CH–CL	Cost in lowest 20% of cost range	Cost in lowest 20%–40% of cost range	Cost in lowest 40%–60% of cost range	Cost in lowest 60%w80% of cost range	Cost in highest 20% of cost range
	Schedule	Measures of the uncertainty in meeting the established project schedule. This identifies the potential for delays based on unknowns associated with unexpected underground obstructions. Factors in the ability of approach to deal with variations in soil and terrain.	High confidence the project completed >4 weeks ahead of schedule.	High confidence the project completed 2–4 weeks ahead of schedule.	High confidence the project schedule will be met.	Project expected to be delayed by 2–4 weeks.	Project expected to be delayed by >4 weeks.
	Quantity of data/ planning required	Cost of providing the data with the fidelity required on the existing underground environment needed to ensure successful installation without surprises. Also includes the specification package for the piping and installation.	All data currently exists. Cost in lowest 20% of cost range	Only updated ground contamination data needed. Cost in lowest 20%–40% of cost range	New analysis of existing data required, possible core samples. Cost in lowest 40%–60% of cost range	Significant new data needed, utilities must be mapped to higher precision than currently exists. Cost in lowest 60%–80% of cost range	Extensive data requirements, multiple coring, GP radar mapping. Cost in highest 20% of cost range

Main Criteria	Subcriteria	Definition	5—Strong	4—Moderate–Strong	3—Moderate	2—Low	1—None
Operability	**Impact to Operations**	Measures option’s impact on the ongoing operations at ORNL. This includes impacts during any required construction and start-up.	Ongoing operations are not impacted. Some scheduling/ coordination required to accommodate tie-ins. Final configuration provides better synergy than current situation.	Ongoing operations will be impacted slightly (<5 days). Careful scheduling/ coordination required to avoid significant impacts. Final configuration provides similar working configuration to current operations.	Moderate impacts to multiple operations. Periodic suspensions of work lasting more than 5 days each. Final configuration requires personnel to routinely work at multiple locations.	Incompatible with ongoing operations. Requires shutdown of one operation for more than 90 days.	Incompatible with ongoing operations. Requires shutdown of two or more operations for more than 180 days.
	Installation maturity	Measure the maturity of the proposed installation technology for the selected piping type.	Fully mature, no specialized tools required, in routine use locally.	Fully mature, some specialized equipment required, demonstrated locally.	Limited experience available in state but has been demonstrated within DOE complex.	Limited experience available in U.S.	Requires demonstration.
	Integrity of pipeline as installed	Measures the assurance of installing the pipeline undamaged.	Method allows complete testing and inspection of piping during installation.	Method allows complete testing of piping prior to use but only preinstallation inspection.	Method allows complete testing of piping prior to use.	Limited testing only.	Pipe can not be tested.
	Expected pipeline design life	Measures the impact of the installation method on the design life of pipeline. This is a long-term measure of the installation damage to the pipeline when compared to the most controlled approach.	No reduction likely.	2% design life lost compared to most controlled approach.	<5% design life lost compared to most controlled approach.	<10% reduction in design life expected.	>10% design life lost compared to most controlled approach.

Main Criteria	Subcriteria	Definition	5—Strong	4—Moderate–Strong	3—Moderate	2—Low	1—None
ES&H	**Impact to environment**	Measures likelihood of environmental release. This includes contaminated soil generated during excavation and residual contaminated materials left in the ground. Assumes existing pipes will be abandoned in place.	Highly robust provisions and conditions for preventing environmental release.	Moderate to strong provisions and conditions for preventing environmental release.	Adequate provisions and conditions for preventing environmental release with minor future concerns.	Adequate provisions for preventing environmental release but some future concerns.	Adequate current provisions for preventing environmental release but significant future concerns.
	Potential to contaminate installation equipment	Measures the likelihood of contaminating the equipment during the installation process that would involve the cost of decontamination and possible purchase.	Minimal risk of contaminating vendor equipment.	Some risk of contaminating vendor equipment. Costs less than $10,000.	Moderate risk of contaminating vendor equipment. Costs greater than $10,000 but less than $25,000.	High risk of contaminating vendor equipment. Costs greater than $25,000 less than $100,000.	Very high risk of contaminating vendor equipment. Costs greater than $100,000.
	Installation risk	Measures the risk of hitting/ disrupting existing utilities during the installation.	Installation present minimal concern for potential accident disruption of utilities in general area of installation pathway.	Installation present moderate concern for potential accident disruption of utilities in general area of installation pathway.	Installation present significant concern for potential accident disruption of utilities in general area of installation pathway and/or installation presents low concern for potential accident doses or injury to public and/or workers.	Installation presents some concern for potential accident doses or injury to public and/or workers.	Installation present moderate concern for potential accident doses or injury to public and/or workers.

APPENDIX C. COST ESTIMATES FOR ORNL-SPECIFIC APPLICATIONS

Cost estimates per linear foot of piping were prepared for each selected combination of piping materials and installation techniques. Table C.1 contains these costs estimates normalized to a baseline of singly contained high density polyethylene (HDPE) pipe installed by open trenching in the Oak Ridge National Laboratory (ORNL) gravity drained process line application. These estimates do not reflect the entire cost for installing pipe using one of these methods. The estimates are for fixed price construction costs only and do not reflect the costs for design, management, field support and oversight, tie-in inside active facility, waste disposal, etc. Another cost that was not considered is the actual "in building footprint" work that would be required to fully install one of these pipe systems. This work is usually performed at ORNL with on-site staff and would be basically the same cost for each type of pipe.

Table C.1. Relative Costs for Installation of Underground Piping

ORNL Application	New Piping Material	Relative Costs for Installation (by Method)				
		OT	HDD	ThP	SL	PB
Existing Gravity Drained Process Waste Line (VC)	Singly contained CS (coated and cathodically protected)	4.1	N/A	N/A	2.5	N/A
	Singly contained HDPE	1.0	N/A	1.3	1.3	2.5
	Doubly contained CS (coated and cathodically protected)	9.1	N/A	N/A	N/A	N/A
	Doubly contained HDPE	2.3	N/A	N/A	N/A	2.8
	Singly contained SS[a] (cathodically protected)	5.5	N/A	N/A	3.8	N/A
	Doubly contained SS[a] (cathodically protected)	12.5	N/A	N/A	N/A	N/A
Existing Pressurized Process Waste Line (CS)	Singly contained CS (coated and cathodically protected)	3.7	3.3	N/A	N/A	N/A
	Singly contained HDPE	1.0	1.4	1.3	1.3	N/A
	Doubly contained CS (coated and cathodically protected)	8.6	7.9	N/A	N/A	N/A
	Doubly contained HDPE	2.1	2.2	N/A	N/A	N/A
	Singly contained SS[a] (cathodic ally protected)	5.4	4.6	N/A	N/A	N/A
	Doubly contained SS[a] (cathodically protected)	12.3	10.9	N/A	N/A	N/A
New Pressurized LLLW Line (SS)	Doubly contained SS[a] (cathodically protected)	5.8	4.8	N/A	N/A	N/A

Abbreviations: OT = open trench, HDD = horizontal directional drilling, ThP = thermoformed pipe, SL = sliplining, PB = pipe bursting, CS = carbon steel, N/A = not applicable, HDPE = high density polyethylene, VC = vitrified clay, SS = stainless steel, LLLW = liquid low-level waste

[a]304 L SS

Estimates were prepared using the current FY 2009–10 construction labor rates for work at ORNL, standard estimating guides like R. S. Means and Richardson's, and vendor quotes for various items. Costs are shown in current year dollars. Each installation technique and type of pipe material was priced out. The estimates generically assume installation of 1,000 linear ft of pipe to determine cost per foot. In that given 1,000 ft, assumptions were made for various items like road crossings; number of manholes; number of pull pits; size of excavation; number of valves, fittings, and cleanouts; etc. Other typical construction costs for mobilization, demobilization, submittals, materials, shop support and quality assurance, material handling, surveying, and general conditions were added. Overhead and profit were also included.

For renewal technologies costs, camera inspections and cleaning of existing lines were included. For each selected renewal technology, a vendor was contacted and a general discussion was conducted on installation techniques and access requirements. Job-specific variables like number of access pits, since there are no manholes in some existing lines, and number of manholes to be installed were assumed and priced out. Because these technologies use existing pipes, no rock excavation was included.

For open trench estimates, a standard depth of 4 ft was used. The width of the trench varied depending on the flexibility and size of the pipe. An allowance for rock excavation was added based on 10% of the excavated volume. Larger steel pipes that have to be welded in place require a much wider excavation than installing flexible butt-fused HDPE. Steel pipe, A-53, schedule 40, was used for the steel pipe options and assumed to be welded. For the stainless steel pipe, pedigreed 304 L, schedule 40, welded pipe was assumed. Fittings were assumed to be needed for every 100 ft of pipe. Additional costs were added for quality requirements for the pedigreed stainless steel pipe. For gravity pipelines, a manhole and a cleanout were assumed every 300 ft. For pressurized pipes, manholes and valves were installed at road crossings and at each end of the pipe run. Two road crossings were assumed in the open trench estimates. For doubly contained lines, annulus monitoring was added to the costs. For all steel pipe, cathodic protection was included in the estimate. When installing HDPE pipe, sand pipe bedding was assumed to be required.

For horizontal boring, the horizontal directional drilling method was estimated. All three pipe types are able to be installed with this technique. Assumptions had to be made for additional drilling pits and for “sight holes” at points of intersection with other utilities. Based on vendor input only pressurized systems were assumed viable, so manholes and valves were assumed at each road crossing and both ends of the line. An allowance for rock excavation was added based on 10% of the total linear feet. Steel pipe, A-53, schedule 40, was used for the steel pipe options and assumed to be welded. For the stainless steel pipe, pedigreed 304 L, schedule 40, welded pipe was assumed. The HDPE pipe was assumed to be butt fused. Fittings were assumed to be needed for every 100 ft of pipe. Additional costs were added for quality requirements for the pedigreed stainless steel pipe. For all steel pipe, cathodic protection was included in the estimate.