Evaluation of Trenchless Technologies for Installation of Pipelines in Radioactive Environments – 10249

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ABSTRACT

Several 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. 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 Oak Ridge National Laboratory (ORNL) applications 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.

INTRODUCTION

The U.S. Department of Energy (DOE) Office of Environmental Management (EM) cleanup mission at ORNL includes the dispositioning of facilities, contaminated legacy materials/waste, and contamination sources and the remediation of soil under facilities, groundwater, and surface water to support final Records of Decision (RODs). The Integrated Facilities Disposition Program (IFDP) scope includes reconfiguration of waste collection and treatment systems as needed to complete 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.

The IFDP is a roughly $14 billion project for completion of the EM mission at Oak Ridge. 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

Prepared by Oak Ridge National Laboratory, P.O. Box 2008, Oak Ridge, Tennessee 37831-6285, managed by UT-Battelle, LLC, for the U.S. Department of Energy under contract DE-AC05-00OR22725.

approved in November 2008. 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 (LLLW) management systems. The review 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 present study was performed to address the ETR recommendation and is limited to reviewing a range of trenchless technologies for general applicability for replacing long runs of existing contaminated piping and/or installing new pipelines in potentially contaminated areas. It should be noted that some of the technologies eliminated from consideration in this study might be appropriate for applications that could include very short runs of piping (e.g., across roads and repairing broken pipelines) or in uncontaminated area. Also, this study did not consider combining methods for a single run, which might result in lower costs depending on specific conditions.

The results of the trenchless installation technology review are given in ORNL/TM-2009/203 [1] and are summarized in this paper.

POTENTIAL PIPELINE INSTALLATION METHODS

Figure 1 shows the types of underground pipeline installation methods considered in this study. Open trench construction is the traditional method for installing or replacing an existing pipeline, 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 are repaired as needed.

Trenchless technology is a general term that describes a group of methods used to install or renew underground pipelines with minimum excavation [2–7]. Compared to the traditional open trench method, the amount of excavation is very minor, thus leading to the name “trenchless.” Trenchless technology methods are divided into two groups: trenchless construction methods and trenchless renewal methods. The key word “construction” in trenchless construction methods indicates that these methods are primarily used when a pipeline does not exist and one is needed. The term “renewal” in trenchless renewal methods indicates methods used to extend the design life of an existing pipeline.

APPLICABILITY OF TRENCHLESS TECHNOLOGIES TO INSTALLATION IN RADIOACTIVELY CONTAMINATED ENVIRONMENTS

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

- Worker entry inside the pipeline must not be required.

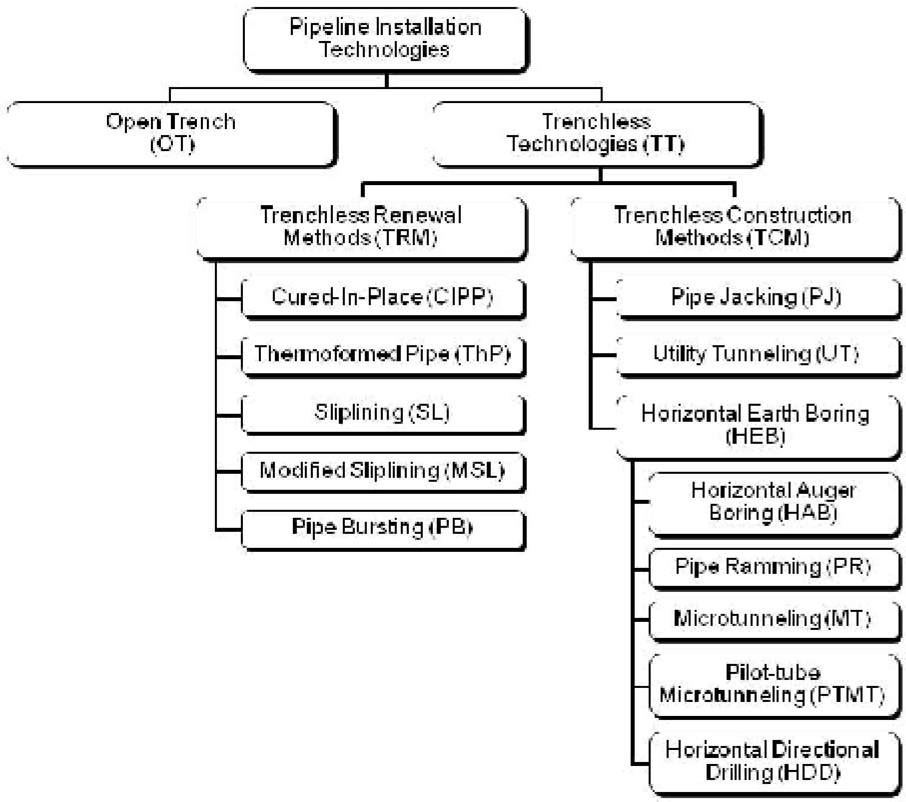

Fig. 1. Underground pipeline installation methods.

- The technology must be applicable to pipelines in the 5.08 to 15.24 cm (2 to 6 in.) diameter size range often used within the DOE complex for transporting radioactive 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 20.32 cm (8 in.) or larger diameter, which is outside the 5.08 to 15.24 cm (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 25.4 cm (10 in.) or larger. This is outside the 5.08 to 15.24 cm (2 to 6 in.) diameter piping size range typically used at DOE facilities for wastewater transport.

Figure 2 summarizes the pipeline installation methods determined applicable for transporting radioactive wastewaters. Table I shows the main characteristics of each method, and Table II highlights the advantages and disadvantages of each.

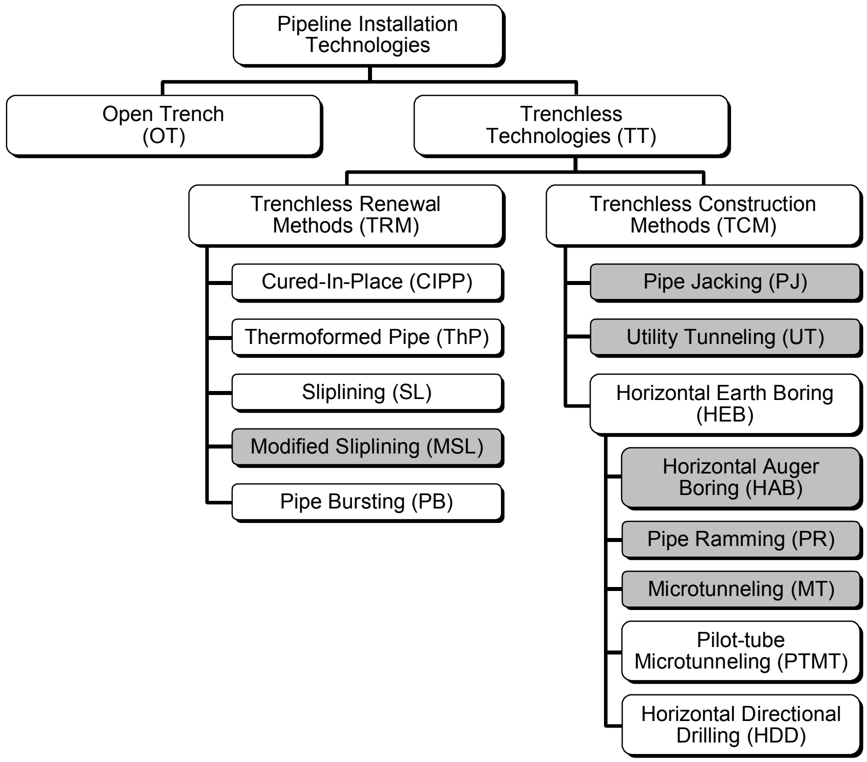

Fig. 2. Pipeline installation technologies considered for radioactive environments. (Technologies shown in gray are considered not applicable.)

Table I. Characteristics of Trenchless Pipeline Installation Methods Suitable for Radioactive Applications.

Method	Min. Diameter [cm (in.)]	Max. Installation Length [m (ft)]	Pipe/or Liner Material[a]	Typical Application	Vendor Experience Level[b]
Cured-in-place pipe	10.16 (4)	457.2 (1,500)	Thermoset resin/fabric composite	Pressure and gravity pipe	High
Thermoformed pipe	15.24 (6)	457.2 (1,500)	HDPE, PVC	Pressure and gravity pipe	Medium
Sliplining	10.16 (4)	304.8 (1,000)	HDPE, PP, PE/EPDM, PVC	Pressure and gravity pipe	High
Pipe bursting	10.16 (4)	457.2 (1,500)	HDPE, PP, PVC, GRP	Pressure and gravity pipe	Medium
Pilot-tube microtunneling	10.16 (4)	91.44 (300)	RCP, GRP, VCP, Steel, PCP	Pressure and gravity pipe	Medium
Horizontal directional drilling	5.08 (2)	182.88 (600)	HDPE, Steel, PVC, VCP, FRP	Pressure pipe	High

[a]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.
[b]High = more than 20 years' experience in municipal sector; medium = 10–20 years' experience in municipal sector.

Table II. 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 • 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

ORNL ALTERNATIVES EVALUATED

Three ORNL wastewater transport applications were selected for evaluations of pipeline installation technologies. They are representative of categories of radiological pipelines in contaminated environments that could potentially be installed or upgraded at ORNL in the future. The installation methods evaluated for the three specific ORNL applications included gravity drained singly contained 15.24 cm (6 in.) pipeline, pressurized singly contained 15.24 cm (6 in.) pipeline, and pressurized doubly contained 5.08 cm (2 in.) pipeline. The specifications for each ORNL application studied in this report are given in Table III.

Table III. Select ORNL Wastewater Pipeline Applications.

	Application		
Specification	**1**	**2**	**3**
Type of waste transported	Process	Process	Liquid Low Level Waste
Head type	Gravity	Pressurized	Pressurized
Existing pipe material	Vitrified clay	Carbon steel	Stainless steel
Containment	Single	Single	Double
Inner pipe size, cm (in.)	15.24 (6)	15.24 (6)	5.08 (2)
Outer pipe size, cm (in.)	N/A	N/A	7.62 (3)
Length of existing route, m (ft)	~82 (~270)	~1,707 (~5,600)	~3,200 (~10,500)
Average depth, m (ft)	1.22 (4)	Varies	1.22 (4)
Length of new route, m (ft)	N/A	N/A	~1,829 (~6,000)
Pipeline area	Congested	Congested and open field	Congested and open field
Soil conditions	Soft to hard with fragments of sandstone and and chert and bedrock outcroppings	Soft to hard with fragments of sandstone and and chert and bedrock outcroppings	Soft to hard with fragments of sandstone and and chert and bedrock outcroppings

It was assumed that the pipelines considered for replacement/upgrade 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 define 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 [8, 9]. ORNL process wastewater falls below the threshold for high activity and high hazard, and the LLLW system falls above the threshold. The Federal Facility Agreement for the Oak Ridge Reservation (FFA) between DOE, EPA, and TDEC also contains design requirements for leak detection and double containment for LLLW tank systems.

A range of potential pipeline materials was considered for replacing the three specific ORNL wastewater pipeline applications described above. Based on the DOE O 435.1 design requirements for high activity–high hazard systems and the FFA, doubly contained stainless steel piping was the only material of construction considered for the LLLW application evaluated in this study. Materials of construction considered for transporting process wastewater included carbon steel, stainless steel, and HPDE. A variety of leak detection methods were considered suitable for monitoring the 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.

The underground piping installation techniques thought generally applicable to radioactively contaminated environments (see Fig. 2) were evaluated for applicability against the three specific ORNL applications in Table III. As a result, several of the proposed installation technologies, shown in gray in Fig. 2, were dropped from consideration for a specific ORNL application.

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 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 doubly contained process waste piping was not considered a practical option because reducing the size of the pipeline 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.

The open trench technique was the only installation technology considered applicable to all three ORNL applications. Trenchless technologies were not considered applicable to the LLLW lines because none of the applicable methods could be used for doubly contained stainless steel lines that have multiple bends. One trenchless horizontal earth boring technology was considered a potentially viable installation method for a subset of piping materials for new construction pipelines in contaminated environments: horizontal directional drilling is applicable for pressurized piping but not gravity fed pipelines. Three renewal methods were considered potentially viable for extending the life of existing pipelines: thermoformed pipe, sliplining, and pipe bursting.

EVALUATION OF ORNL ALTERNATIVES

An alternatives analysis was performed for each applicable installation technology shown in Fig. 3 for the three ORNL applications listed in Table III. The analysis was performed using the Analytical Hierarchy Process (AHP), with a decision-modeling method developed at the Wharton School of Business at the University of Pennsylvania by Dr. Thomas L. Saaty [10].

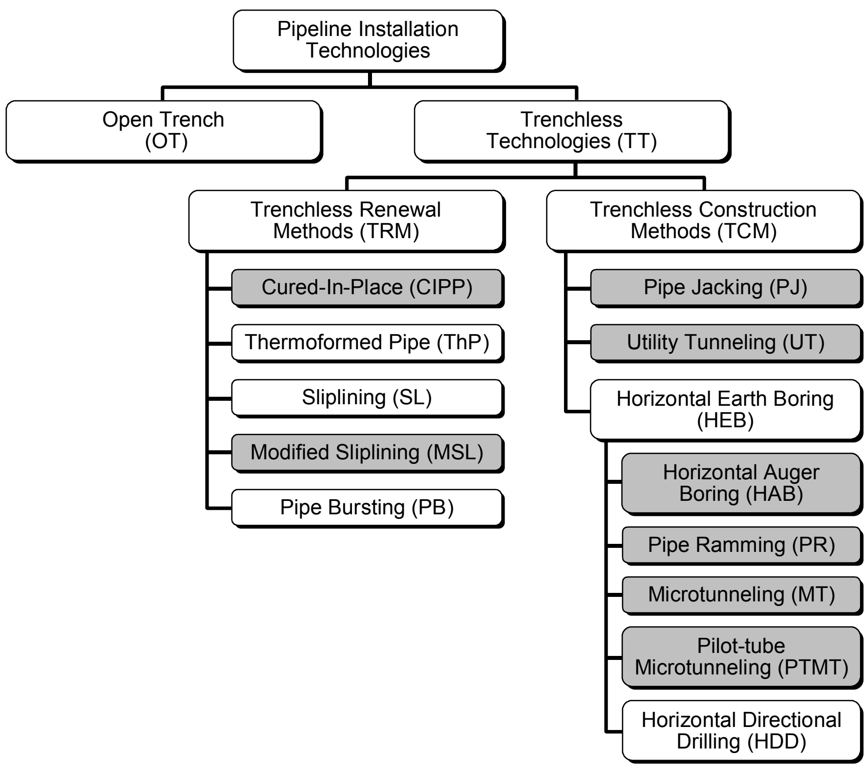

Fig. 3. Pipeline installation technologies considered for three specific ORNL applications. (Technologies shown in gray were deemed not applicable for the three specific cases considered.)

The three key criteria and several subcriteria given in Fig. 3 were identified for ranking alternative options:

1. Cost and Schedule (26.3%)—Considers installation cost (15.0%), operating cost (2.9%), impact on project schedule (5.4%), and cost of obtaining project planning data (3.0%).
2. Operability (31.6%)—Considers impact on ongoing operations (5.3%), maturity of the installation technology (1.7%), integrity of the pipeline (17.6%), and expected pipeline design life (7.0%).
3. Environment, Safety, and Health (42.1%)—Considers likelihood of ES&H impact from environmental releases during installation (18.7%), potential to contaminate installation equipment (3.1%), and risk of disrupting existing underground utilities during the installation process (20.3%).

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

Installation Costs. The cost of installing underground piping 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.

Operating Costs. 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 [8, 9] 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 that 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.

Schedule Impacts. 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 cathodically 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.

Quantity of Data/Planning. 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.

Impacts on Operations. Renewal techniques require that the pipeline must be out of service for the duration of the project compared with only for final pipe tie-ins for techniques used to install new pipelines.

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

Integrity of Pipeline as Installed. 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.

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

Impact to the Environment. Renewal techniques that do not require digging were considered the best technologies. Within the renewal category, PB was slightly less desirable because it exposes the soils and groundwater to potentially contaminated shards of piping and potentially impacts nearby pipelines. Open trench was less desirable than HDD because it results in the removal of more dirt and in more storm water runoff.

Potential to Contaminate Equipment. Renewal technologies were the most desirable because they involve the least expensive equipment potentially being exposed to contamination during the installation process. HDD was the least desirable 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 are the most desirable because they do not involve digging. Open trench technology was medium because historical experience with this technique in areas with unknown utilities has shown it to be a low risk option. This installation technique was less desirable for use in highly congested environments compared to mainly open field areas. HDD was least desirable because of potential complications for drilling in areas with underground interferences.

Conclusions from the evaluation of the ORNL-specific applications indicate that open trench installation methods have advantages over horizontal directional drilling 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, pipebursting 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 overarching drivers and the operability and ES&H risks are low, trenchless installation technologies such as horizontal directional drilling 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 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 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.

CONCLUSIONS AND RECOMMENDATIONS

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 ORNL-specific applications because of geological conditions.

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 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 aboveground 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.

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.

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