DOE/EM-0425

Innovative Technology
Summary Report

Pipe Inspection Using the Pipe Crawler

Deactivation and Decommissioning Focus Area

Prepared for
U.S. Department of Energy
Office of Environmental Management
Office of Science and Technology

May 1999

INNOVATIVE TECHNOLOGY

Summary Report

Pipe Inspection Using the Pipe Crawler

OST Reference #1810

Deactivation and Decommissioning Focus Area

Demonstrated at

Fernald Environmental Management Project – Plant 1

Fernald, Ohio

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INNOVATIVE TECHNOLOGY
Summary Report

Purpose of this document

Innovative Technology Summary Reports are designed to provide potential users with the information they need to quickly determine if a technology would apply to a particular environmental management problem. They are also designed for readers who may recommend that a technology be considered by prospective users.

Each report describes a technology, system, or process that has been developed and tested with funding from DOE's Office of Science and Technology (OST). A report presents the full range of problems that a technology, system, or process will address and its advantages to the DOE cleanup in terms of system performance, cost, and cleanup effectiveness. Most reports include comparisons to baseline technologies as well as other competing technologies. Information about commercial availability and technology readiness for implementation is also included. Innovative Technology Summary Reports are intended to provide summary information. References for more detailed information are provided in an appendix.

Efforts have been made to provide key data describing the performance, cost, and regulatory acceptance of the technology. If this information was not available at the time of publication, the omission is noted.

All published Innovative Technology Summary Reports are available on the OST Web site at http://OST.em.doe.gov under "Publications."

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SECTION 1

SUMMARY

Introduction

The United States Department of Energy (DOE) continually seeks safer and more cost-effective remediation technologies for use in the decontamination and decommissioning (D&D) of nuclear facilities. To this end, the Deactivation and Decommissioning Focus Area (DDFA) of the DOE's Office of Science and Technology sponsors Large-Scale Demonstration and Deployment Projects (LSDDPs) in which developers and vendors of improved or innovative technologies showcase products that are potentially beneficial to the DOE's projects and to others in the D&D community. Benefits sought include decreased health and safety risks to personnel and the environment, increased productivity, and decreased cost of operation.

In several of the buildings at the Fernald Site, there is piping that was used to transport process materials. As the demolition of these buildings occur, disposal of this piping has become a costly issue. Currently, all process piping is cut into ten-foot or less sections, the ends of the piping are wrapped and taped to prevent the release of any potential contaminants into the air, and the piping is placed in roll off boxes for eventual repackaging and shipment to the Nevada Test Site (NTS) for disposal. Alternatives that allow for the onsite disposal of process piping are greatly desired due to the potential for dramatic savings in current offsite disposal costs.

Current regulatory commitments require that a visual inspection be performed prior to the disposal of process piping into the On Site Disposal Facility (OSDF). According to the Plant 1 Area D&D Performance Specification 01517 1.8.A.1, "To remove equipment, material or debris from a local containment or enclosure, or to containerize, surfaces shall be free of visible process material as determined by a Fernald representative. The definition of visible process material is: Visible process residues (green salt, yellow cake, etc.) on the interior or exterior surfaces of materials that is obvious to the eye and if rubbed, would be easily removed. Stains, rust, corrosion, and flaking do NOT qualify as visible process material. If an item fails visual inspection the item shall be deemed a Category C item and encapsulated or wrapped. All equipment, material, and debris are still considered to be radiologically contaminated." No means is currently employed to allow for the adequate inspection of the interior of piping, and consequently, process piping has been assumed to be internally contaminated and thus routinely disposed of at NTS.

The overall objective of this demonstration was to determine if an effective, cost reducing method for the inspection of piping could be found. The Pipe Crawler is an effective technology for radiological inspection of pipe but is not recommended for use at Fernald and other sites to *visually* inspect process piping.

Technology Summary

Problem

Current site policy requires that all process piping to be disposed of at the OSDF be visually inspected to ensure the absence of process residues. For larger pieces of piping (such as twelve inch diameter or greater), visual inspection is easily accomplished. However, for smaller diameter pieces of piping, visual inspection is not readily performed. Fluor Daniel Fernald (FDF), the primary contractor at the Fernald site, does not currently employ any techniques to inspect smaller diameter piping (twelve inch diameter or less) and in practice, does not inspect larger diameter piping either. As a result, process piping is assumed to be contaminated and is placed in white metal boxes for eventual shipment and disposal at the NTS.

How it Works

For this demonstration, a system provided by Radiological Services, Inc. was used. The Pipe Crawler consists of a visual inspection system (a high-resolution micro color camera with lightheads, a monitor, and a video recorder) along with radiological detectors coupled to a ratemeter. Pipe Crawlers are available for 1.5", 2", 3", 4", 6", 8", 10", 12", and 24" pipe sizes. The crawler/detector is capable of visually and radiologically inspecting the inside of pipes and pinpointing where in the pipe contamination exists. Individual detectors can be isolated for separate readings if necessary. The system is well suited for inspecting the interior of most types of piping.

The camera and detectors are pulled through a pipe using fish tape and a fiberglass rod and reel. They can also be mounted on a push-pull fiberglass rod. As the assembly is pulled through the pipe to be inspected (Figure 1), the operator at the console (Figure 2) looks for the presence of visual contamination and monitors the ratemeter for radiological contamination. The operator at the console can give the camera operator directions about the required movements in the pipe in order to properly inspect the entire interior.

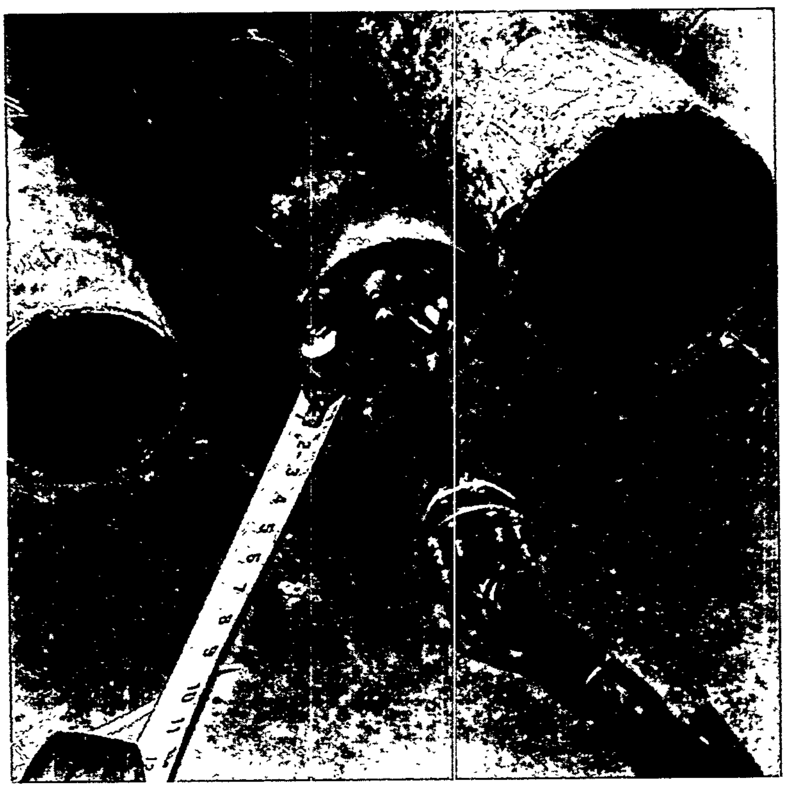

Figure 1. The Pipe Crawler's camera and detector assembly entering a pipe.

A crew of six workers would typically be used for pipe inspection with the Pipe Crawler. Two workers would move the pieces of pipe into position for the camera and would segregate the pieces based on the inspection results, one worker would operate the crawler, and one would operate the video unit. A fork lift operator and a rad tech would also provide support, either part-time or full-time. Figure 3 shows workers inspecting a pipe with the Pipe Crawler.

The capital cost of the Pipe Crawler, including all components, is approximately $130,000. Based on information from the vendor, the expected life of the equipment is 8,350 hours of operation, after which there will be a salvage value of 10% of the purchase price. Operation costs are approximately $0.08 per hour for electricity usage.

Figure 2. The video monitor and recording unit.

Figure 3. Workers inspecting a pipe with the Pipe Crawler.

Potential Markets

The Pipe Crawler is fully developed, commercially available, and currently used in a variety of commercial and nuclear power industry applications. The technology can be transferred to other sites for similar applications. Aside from verifying the presence or absence of process materials, the Pipe Crawler can be used to inspect inaccessible pipes (e.g., underground lines). However, this technology is not very well suited to perform the pipe inspection requirements at Fernald because of its additional capabilities that are not required for OSDF acceptance. The added cost of the radiological detectors and ratemeter make the technology too expensive for the visual-only requirement at the site. If other DOE facilities require a radiological inspection, then the technology may be more applicable.

Advantages over the Baseline

The current baseline practice is to send all removed process piping to NTS for disposal, due to lack of a means of visually inspecting the inside of the pipe. Because the Pipe Crawler allows visual inspection to see if the acceptance criteria are met, some piping can be disposed of on site. From the piping removed from Plant 1 at Fernald, 45% was diverted from NTS to the OSDF. This measurement was made on a per pipe basis with pipes of varying sizes, but in general should correspond to a similar reduction in volume of waste to NTS.

However, the Pipe Crawler does not offer cost savings, even though disposal costs at the OSDF are less expensive than at NTS. The average cost for disposal at NTS is $46.38 a pipe, and the cost for disposal at the OSDF is only $16.03 per pipe, but the inspection cost using the Pipe Crawler is $33.19 per pipe in addition to the disposal costs. This high cost prevents any cost savings from diverting pipes to the OSDF. The Pipe Crawler is made more expensive by its radiological detectors and ratemeter, which are not required for OSDF acceptance at Fernald.

Demonstration Summary

The system chosen to perform this demonstration is designed and manufactured by Radiological Services, Inc. The technology is fully developed and is used in commercial applications. The specific system used for this demonstration, the Pipe Crawler, consists of a high-resolution color camera placed on the end of a cable (which is coupled to a monitor and VCR) and multiple radiological detectors connected to an Eberline ESP-2 ratemeter. The crawler/detector is manipulated manually through the pipe using fish tape and a fiberglass rod and reel. For this demonstration, the Pipe Crawler was required to inspect a series of piping with varying internal diameters of 4 to 18 inches. The Pipe Crawler was demonstrated in November 1996. This report covers the period of November 1996 to January 1997.

Process piping taken from Plant 1 at Fernald was cut into 10-foot (or less) sections, end-wrapped and taped, and placed into a roll off box. For this demonstration, the roll off box was moved to the Plant 7 pad which was used as a staging area. Piping was then selected from the box, unwrapped, inspected, and re-wrapped. Pipes were selected at random; however, if loose process residue was heard inside the pipe during movement, it was assumed it would not meet OSDF requirements and was not inspected with the Pipe Crawler. These rejected pipes are not counted in this demonstration. FDF Hazardous Waste Workers were used to move the piping as well as manipulate the camera through the piping. An FDF Construction Manager was responsible for viewing the inspection results and determining if the piping was free of process residues. Once complete, piping that passed inspection was segregated for eventual disposal in the OSDF. Piping that did not pass inspection was returned to a roll off box for repackaging and shipment to NTS for disposal.

The objectives of the demonstration were:

- to determine whether the Pipe Crawler would provide sufficient *visual* inspection for the inside of process piping (there was no requirement for a radiological survey), and
- to determine if a significant percentage of process piping could be diverted from disposal at NTS to the OSDF.

Key Results

The key results of the demonstration were:

- The Pipe Crawler allowed for the visible inspection of the inside of pipes that would otherwise have been impossible with the human eye. This inspection met the requirements to allow materials to be placed in the OSDF. The equipment also provided a radiological survey of the pipes, although this was not required by the OSDF acceptance criteria.

- Based on the piping inspected in this demonstration, a significant percentage of piping can be diverted to the less expensive OSDF rather than shipping to NTS. 45% of the inspected pipes from Plant 1 were diverted to the OSDF.

- The Pipe Crawler is somewhat delicate, particularly the wiring harness, and workers must be careful when moving the crawler around and starting it through a pipe.

- The cost per pipe when disposed of at NTS is $46.38/pipe. The cost per pipe for visual inspection and disposal at the OSDF is $56.15/pipe. Based on the diversion rate observed for Plant 1 (see Table 1), the effective cost per pipe for this demonstration (with some disposal at the OSDF, some at NTS) is $72.77/pipe. Because the added cost of inspection always makes the Pipe Crawler more expensive to use, there is no break-even point for cost recovery of buying the system.

- No expendables are generated during operation besides disposable PPE.

Table 1 lists the key performance factors that were measured or determined during the demonstration.

Table 1. Summary of key performance factors

Number of Pipes Inspected	42
Number of Pipes Sent to NTS	23
Number of Pipes Diverted to OSDF	19
Average Inspection Time per Pipe	15 min.
Break-Even Point[1]	Never breaks even.

[1]This is the number of pipes inspected to recover the cost of using the Pipe Crawler.

Regulatory Considerations

FDF carried out the Pipe Crawler demonstration with D&D laborers from the site. No regulatory permits or licenses were required for demonstrating the technology, aside from a Fernald work permit.

The demonstration involved working in radiologically controlled areas. FDF provided technical support in the areas of radiation protection, health and safety, and regulatory compliance.

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Other

All published ITSRs are available at http://em-50.em.doe.gov. The Technical Management System, also available through the EM50 Web site, provides information about OST programs, technologies, and problems. The OST Reference # for Pipe Inspection Using the Pipe Crawler is 1810.

The FEMP Internet web site address is http://www.fernald.gov.

SECTION 2

TECHNOLOGY DESCRIPTION

Overall Process Definition

The Pipe Crawler demonstrated at the Fernald Environmental Management Project (FEMP) consists of a high-resolution color camera placed on the end of a cable (which is coupled to a monitor and VCR) and multiple radiological detectors connected to an Eberline ESP-2 ratemeter. The crawler/detector is manipulated manually through the pipe using fish tape and a fiberglass rod and reel. This technology was investigated as a means of allowing the *visual* inspection of the inside of process piping to determine if it meets the criteria to be disposed of in the FEMP's OSDF. The Pipe Crawler also provides radiological measurement of contamination inside the pipe, although these results are not required for acceptance at the OSDF. The current baseline approach for process piping is to not visually inspect it, assume that it does not meet the criteria for the OSDF, and ship it to NTS in Nevada for disposal. This approach, however, significantly increases the cost of disposal. In addition, landfill space at NTS is unnecessarily used up and packaging and transportation costs are added to the disposal costs.

Figure 4 illustrates the setup of the Pipe Crawler.

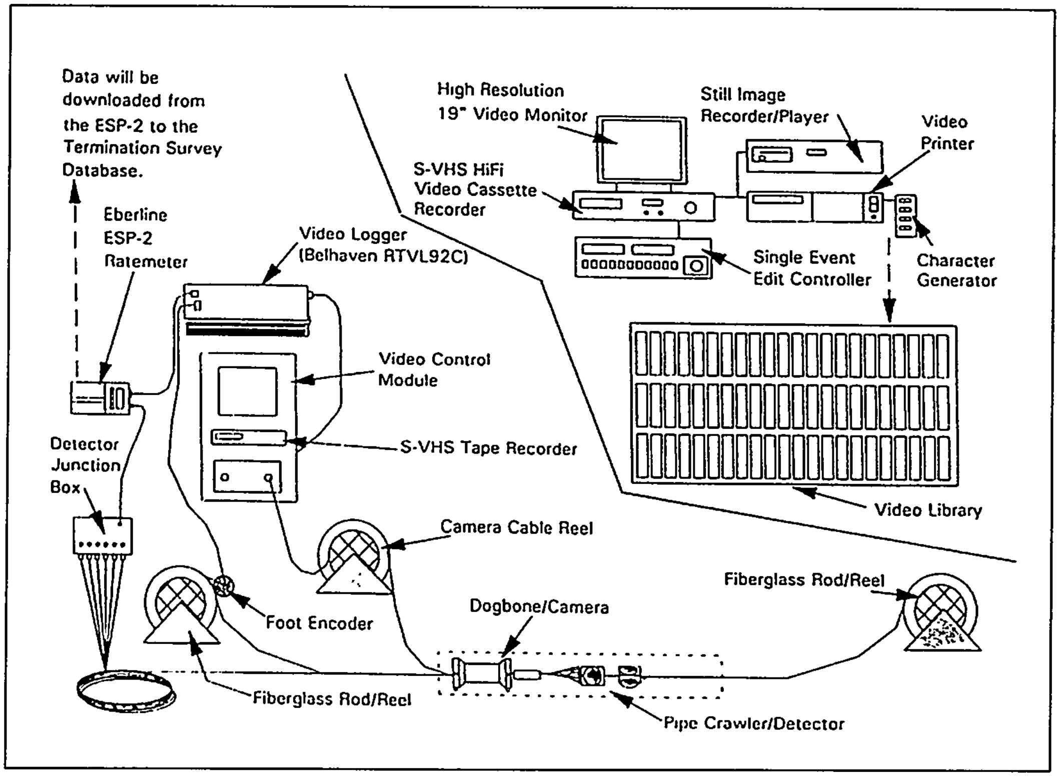

Figure 4. Schematic of the Pipe Crawler.

System Operation

The system is designed to be used in various sizes of pipes by using one of several sizes of crawler/ detectors. Operation should be in dry pipes that are free of obstructions. Calibration of the detectors and rate meter are required prior to surveying to ensure proper measurement of radioactivity. The system is portable and can be operated in most locations that have a 120V standard power supply. Some basic training is required to operate the system, and there are no expendables generated during the operation of the system.

Table 2 summarizes the operational parameters and conditions of the Pipe Crawler demonstration.

Table 2. Operational parameters and conditions of the Pipe Crawler demonstration

Working Conditions	
Work Area Location	Concrete pad outside Plant 7.
Work Area Description	Outdoor area with several sea-land containers and roll-off boxes used for storage of pipe and other materials and equipment.
Work Area Hazards	Limited room due to storage boxes and equipment in the area. Pinch hazards from storage box doors. Manual lifting of heavy pipes.
Labor, Support Personnel, Specialized Skills, Training	
Work Crew	Two workers to handle the pipes, one to operate the camera, one to operate the video console, one fork truck operator, and one rad tech. (The fork truck operator and the rad tech may be part-time.)
Additional Support Personnel	Full-time demonstration data taker.
Training	No additional training was required, as the D&D laborers were already working at the site.
Equipment Specifications, Operational Parameters, and Portability	
Equipment Design Purpose	Visual and radiological inspection of the interior of process piping.
Dimensions	Crawlers available for 1.5", 2", 3", 4", 6", 8", 10", 12", and 24" pipe sizes.
Materials Used	
Personal Protective Equipment	Tyvek disposable suit. Rubber shoe covers. Safety glasses.
Utilities/Energy Requirements	
Utilities	120V power supply.

SECTION 3

PERFORMANCE

Demonstration Plan

Demonstration Site Description

All process piping removed from Plant 1 was cut into approximately ten-foot sections, capped on both ends, and placed in roll off boxes. A sampling of piping was selected from the roll off boxes for the demonstration. To facilitate operations during the demonstration, and to minimize the impact to the D&D contractor performing work on Plant 1, the demonstration was conducted on the Plant 7 pad. All process piping used for the demonstration was from Plant 1.

The roll off boxes were moved from Plant 1 to the Plant 7 pad prior to the initiation of the demonstration. Pipes, with varying IDs, were selected from the roll off boxes and inspected using the Pipe Crawler. Pipes were selected at random; however, if loose process residue was heard inside the pipe during movement, it was assumed it would not meet OSDF requirements and was not inspected with the Pipe Crawler. These rejected pipes are not counted in this demonstration. The ends of the pipe were opened, and the crawler was inserted into the pipe to perform the demonstration. An FDF Construction Manager viewed the inspection video while the inspections were being performed to determine if process residues were present. Once the inspection was completed, the ends were re-wrapped and the piping was segregated based on the inspection results. Piping that passed inspection was retained for disposition at the OSDF; all other piping was sent for repackaging and eventual disposal at NTS.

All piping selection, manipulation, and handling was performed by FDF Hazardous Materials Workers. All inspections were performed by FDF technicians with oversight by FDF Construction Management.

Demonstration Objectives

The main objective of the demonstration was to assess visual inspection of pipes using the Pipe Crawler to determine if piping met OSDF disposal requirements as an alternative to the baseline of assuming contamination and sending it to NTS. This investigation assessed the Pipe Crawler based on its performance in achieving the following demonstration objectives:

- the ability to inspect pipes visually in an acceptable manner for OSDF acceptance,
- reduced disposal costs, and
- reduced volume of waste to NTS.

Demonstration Boundaries

The demonstration of the Pipe Crawler evaluated the percentage of pipes diverted to the OSDF based on the pipes inspected from Plant 1 at Fernald. Although the percentage diverted from this demonstration may be typical of other facilities, it can also be highly dependent on what the process piping in a building was used for and how it was abandoned. Also, this demonstration evaluated costs on a per pipe basis, not on weight, volume, or linear feet of piping.

Results

The actual inspection of piping took place over four days. During that time, a total of 42 different pieces of pipe were inspected. Nominal diameters of the schedule 40 carbon steel piping ranged from 4" to 18". Pipe lengths generally ranged from 4 to 6 feet, with some piping cut to the standard 10-foot length.

Crews were made up of two hazardous materials workers to move and manipulate the piping, one technician to operate the Pipe Crawler, one technician to operate the console, one fork lift operator, and one rad tech. This crew size should be typical of normal operations using the Pipe Crawler inspection process, although the fork lift operator and the rad tech could be part-time, depending on site conditions.

Performance relative to demonstration objectives

Table 3 summarizes the overall performance results of the baseline and Pipe Crawler technologies for each of the demonstration objectives listed above.

Table 3. Performance Comparison between Baseline and Inspection Technologies

Performance Factor	Disposal at NTS (Baseline)	Inspection with Pipe Crawler (Innovative)
Ability to Visually Inspect Pipes	Not required	Able to visually inspect pipes in an acceptable manner for OSDF acceptance. Also able to inspect pipes radiologically, although not required for the OSDF.
Cost for Disposal	\$46.38/pipe	\$16.03/pipe
Cost for Inspection	Not required	\$40.12/pipe (\$33.19 inspection + \$6.93 PPE)
Effective Cost	\$46.38/pipe	\$72.77/pipe[1]
Number of Pipes Sent to NTS	All 42 would have been sent to NTS.	Only 23 of 42 sent to NTS.

[1]This is the overall cost per pipe for this demonstration based on the 45% diversion rate to the OSDF.
[(42 x \$40.12 inspection) + (19 x \$16.03 OSDF) + (23 x \$46.38 NTS)]/42 pipes = \$72.77/pipe

Ability to Visually Inspect Pipes

The OSDF acceptance criteria require that no visible process residue that can easily be removed be present on materials. The Pipe Crawler provides an acceptable way to visually inspect the interior of process piping and thus see if the acceptance criteria are satisfied. However, the Pipe Crawler also provides a radiological survey of the pipe's interior, although not required for OSDF acceptance.

Reduced Costs

The Pipe Crawler does not offer cost savings, even though disposal costs at the OSDF are less expensive than at NTS. The average cost for disposal at NTS is \$46.38 a pipe, and the cost for disposal at the OSDF is only \$16.03 per pipe. However, the inspection cost using the Pipe Crawler is \$33.19 per pipe in addition to the disposal costs. This high cost prevents any cost savings from diverting pipes to the OSDF. The Pipe Crawler is made more expensive by its radiological detectors and ratemeter, which are not required for OSDF acceptance at Fernald.

Reduced Volume of Waste to NTS

The current baseline practice is to send all removed process piping to NTS for disposal, due to lack of a means of visually inspecting the inside of the pipe. Because the Pipe Crawler allows visual inspection to see if the acceptance criteria are met, some piping can be disposed of on site. From the piping removed from Plant 1 at Fernald, 45% was diverted from NTS to the OSDF. This measurement was made on a per pipe basis with pipes of varying sizes, but in general should correspond to a similar reduction in volume of waste to NTS.

A reduced volume of waste to NTS also means reduced transportation risk. An incident during transportation can cause significant safety and financial impacts, including a DOE-wide stoppage of waste shipments until problems are resolved.

SECTION 4

TECHNOLOGY APPLICABILITY AND ALTERNATIVES

Competing Technologies

Several technologies are available to perform this same type of inspection work as well as technologies only equipped with cameras. Some of these technologies include (but are not limited to) the Pipe Explorer by Science and Engineering Associates and the BTX-II System by Visual Inspection Technologies. Other less sophisticated systems could be fabricated from off-the-shelf components for less money, as the inspection requirements at Fernald are relatively low-tech.

Innovative Technology Summary Reports have been prepared for the Pipe Explorer for in-situ inspection of pipe at Chicago Pile 5 (CP-5) Research Reactor, the BTX-II for ex-situ inspection of pipe at Fernald, and the RSI Pipe Crawler for in-situ pipe inspection at CP-5 Research Reactor.

Radiological Services, Inc. is the sole manufacturer of the Pipe Crawler. They maintain all commercial rights to the system.

Technology Applicability

The Pipe Crawler is a mature and commercialized technology for visually and radiologically inspecting the inside of pipes. The post-demonstration assessment of the Pipe Crawler is summarized below.

- Visual inspection is adequately accomplished using the Pipe Crawler. This inspection is able to meet the criteria for acceptance at the OSDF. However, the Pipe Crawler also provides information on radiological contamination that is not required for the OSDF.
- The equipment is somewhat delicate, and care is needed when inspecting pipes.
- The Pipe Crawler allowed the diversion of 45% of the pipes inspected to the OSDF, saving the high costs of disposal at NTS.

This technology is not very well suited to perform the pipe inspection requirements at Fernald because of its additional capabilities that are not required for OSDF acceptance. The added cost of the radiological detectors and ratemeter make the technology too expensive for the visual-only requirement at the site. If other DOE facilities require a radiological inspection, then the technology could be evaluated differently. The Pipe Crawler is fully developed, commercially available, and currently used in a variety of commercial and nuclear power industry applications. The technology can be transferred to other sites for similar applications. Aside from verifying the presence or absence of process materials, the Pipe Crawler can be used to inspect inaccessible pipes (e.g., underground lines).

Patents/Commercialization/Sponsor

The technology has been patented by the technology developer, Radiological Services, Inc., from which it can be purchased. The Pipe Crawler has been used in the commercial and nuclear power industries worldwide. There are no issues related to patents, commercialization, or sponsorship.

SECTION 5

COST

Introduction

A cost analysis was performed to evaluate and summarize the Pipe Crawler and a "no inspection" baseline and to estimate the potential cost savings the Pipe Crawler may offer. The objective is to assist decision makers who are selecting from among competing technologies. This analysis strives to develop realistic estimates that represent actual D&D work within the DOE weapons complex. However, this is a limited representation of actual cost, because the analysis uses only data observed during the demonstration. Some of the observed costs were eliminated or adjusted to make the estimates more realistic. These adjustments were allowed only when they would not distort the fundamental elements of the observed data (i.e. does not change the productivity rate, quantities, work element, etc.,) and eliminated only those activities which are atypical of normal D&D work. Descriptions contained in later portions of this analysis document any changes to the observed data.

Methodology

The cost analysis compares two approaches: the Pipe Crawler and a "no inspection" baseline. The Pipe Crawler was demonstrated at Fernald Plant No. 1 to inspect the interior of process piping removed from the interior of Plant No. 1. Under the baseline, piping designated as process piping is placed into metal boxes for shipping to NTS for disposal without visual inspection of the interior of process piping to determine if it meets the waste acceptance criteria (WAC) for the OSDF. The WAC allows debris wastes which pass a visual inspection for loose surface contamination to be placed in the OSDF. The innovative inspection technology allows such an inspection to be performed and should reduce the amount of process piping that must be shipped to NTS.

The baseline technology is a no-inspection scenario and was not actually demonstrated. The Pipe Crawler was rented from the vendor for the duration of the demonstration. The Pipe Crawler was operated by D&D contractor personnel.

Cost and performance data were collected for the Pipe Crawler during the demonstration. Costs for the baseline technology are based on packaging, shipping, and disposing of all process piping at the NTS. The following cost elements were identified from the *Hazardous, Toxic and Radioactive Waste Remedial Action Work Breakdown Structure and Data Dictionary* (HTRW RA WBS) (US Army Corps of Engineers, February 1996), prior to the demonstration. Data was collected to support a cost analysis based on those elements:

- mobilization (including necessary training)
- inspection
- disposal (OSDF)
- disposal (NTS)
- demobilization (including equipment decontamination)
- personal protective equipment

Mobilization costs included the cost of transporting equipment to the site, costs for training the crew members on use of the equipment, installation of temporary work areas, and installation of temporary utilities.

Segments of process piping that had been previously removed from the interior of Plant No. 1 were inspected during the demonstration. This piping had been stored in metal boxes pending shipment to the NTS for disposal.

Disposal (OSDF) includes the cost for disposal of process piping which meets the OSDF WAC and can be placed in the OSDF.

Disposal (NTS) includes the cost for disposal of process piping which does not meet the OSDF WAC and must be shipped to the NTS.

Demobilization included removal of temporary work areas and utilities, decontamination of equipment, disposal of wastes generated by removal of temporary work areas, and removal of equipment from the site.

PPE costs include all clothing, respirator equipment, etc., required for protection of crew members during the demonstration. It was assumed that four changes of reusable PPE clothing items per day were required for each crew member. Reusable PPE items were assumed to have a life expectancy of 200 hours. The cost of laundering reusable PPE clothing items is included in the analysis. It was assumed that four changes of disposable PPE clothing items per day were required for each crew member. Disposable PPE items were assumed to have a life expectancy of 10 hours (the shift length).

Cost Analysis

Data were collected during the demonstration for the cost elements. Work was measured and unit costs determined on the number of pieces of process piping inspected. For each element, detailed costs were determined from the data collected. For inspection of process piping, a production rate was calculated from the performance data and used in the cost analysis. The calculated average production rate is considered reasonable, and no further analysis was performed on the production rate. Because there is no corresponding activity for the "no inspection" baseline, production rate cannot be used as a technology comparison factor.

Labor rates used in the analysis were those actually in effect at the FEMP. Crews for the various activities were based on the data collected. Contractor indirect costs were omitted from the analysis, since overhead rates can vary greatly among contractors. Engineering, quality assurance, administrative costs and taxes were also omitted from the analysis. The unit costs determined by the analysis can be modified by adding site specific indirect costs to produce a site-specific unit cost that includes indirect costs.

Equipment costs were based on the cost of ownership. For the Pipe Crawler, an hourly equipment rate was calculated using a spreadsheet based on the methodology outlined in EP 1110-1-8, *Construction Equipment Ownership and Operating Expense Schedule* (US Army Corps of Engineers, September 1997). The hourly rate is based on the $130,000 capital cost of the Pipe Crawler, a discount rate of 5.6%, equipment life of 8,350 operating hours as advised by the vendor, estimated yearly usage of 1,040 hours, and estimated operating and repair costs.

Costs for disposal, both in the OSDF and at NTS, were provided by the Integrating Contract Team (ICT). Since the OSDF was not in place during the demonstration, the ICT provided estimated unit costs for solid waste disposal. Costs for disposal at NTS are based on historical data. These disposal costs are costs per cubic foot of waste. For an analysis based on the number of pipes inspected, disposal costs had to be calculated per pipe.

For inspection using the Pipe Crawler, the cost data was entered into an MCACES Gold project database. Supporting databases for labor, equipment and crews were created for the Fernald Plant No. 1 LSTD. Laborers, equipment pieces and crews were added to these supporting databases. The project database was priced from the supporting databases. A hard copy of the MCACES Gold cost estimate can be found in the Detailed Technology Report.

The following modification was made to the cost data for the Pipe Crawler to reflect a more typical technology deployment. The data package showed that a total of 10 personnel were trained for four hours each in the use of the Pipe Crawler. Personnel training costs in the analysis were set at six personnel, 10 hours each, which is the typical technology training/familiarization time observed at the FEMP.

Fixed cost elements (independent of the quantity of inspection work) were calculated as lump sum costs. Unit cost elements were based on the quantity of inspection work performed. Comparative unit costs are direct costs with no indirect costs included. This is standard practice in commercial unit price guides such as those published by the R. S. Means Company.

Cost Conclusions

A comparison of the major cost elements from the MCACES cost estimate is shown in Table 4.

Table 4. Summary Cost Comparison

Inspection Using the Pipe Crawler (Innovative)			**No Inspection** (Baseline)		
Cost Element	**Unit Cost**	**Production Rate**	**Cost Element**	**Unit Cost**	**Production Rate**
Mobilization[1]	$5,604	N/A	Mobilization[1]	$0	N/A
Inspection	$33.19/pipe	5 pipes/hr	Inspection	$0	N/A
Disposal (NTS)	$46.38/pipe	N/A	Disposal (NTS)	$46.38/pipe	N/A
Disposal (OSDF)	$16.03/pipe	N/A	Disposal (OSDF)	$0	N/A
Demobilization[1]	$45	N/A	Demobilization[1]	$0	N/A
PPE	$6.93/pipe	N/A	PPE	$0	N/A

[1] These are fixed costs that are independent of the quantity of inspection work.

Mobilization costs were higher for the Pipe Crawler because the equipment had to be transported to the site. The Pipe Crawler also requires some time for training and equipment familiarization. There are no such mobilization costs for the "no inspection" baseline.

Inspection of process piping interiors using the Pipe Crawler is an additional work activity that the "no inspection" baseline does not require. The cost of this additional activity is the cost of using the Pipe Crawler technology equipment.

Waste disposal costs may be lower for the Pipe Crawler, because its use may reduce the amount of process piping that must sent to NTS for disposal.

Demobilization costs were higher for the Pipe Crawler due to the cost of equipment decontamination. There are no demobilization costs for the "no inspection" baseline.

Because use of the Pipe Crawler is an additional work activity not required for the baseline, PPE costs were higher for the Pipe Crawler. There are no PPE costs for the "no inspection" baseline.

The comparative unit costs for the two technologies for the demonstrated application are:

$46.38/pipe - no inspection (all piping disposal at NTS)

$56.15/pipe - Pipe Crawler (inspection and disposal for piping diverted to OSDF)

$86.50/pipe - Pipe Crawler (inspection and disposal for piping inspected but still sent to NTS)

The demonstration consisted of inspecting 42 pipes using the Pipe Crawler system at a cost of $40.12/pipe ($33.19 inspection + $6.93 PPE). Nineteen of these pipes were found not to contain visible contamination and were able to be disposed of in the OSDF at a cost of $16.03/pipe, while 23 of the pipes contained visible contamination requiring their disposal at NTS at $46.38/pipe. Based on demonstration results that showed that 45% of the pipe could be disposed of in the OSDF, the average cost to inspect and dispose of pipe was $72.77/pipe.

For the demonstrated application, the Pipe Crawler offers no cost savings over the "no inspection" baseline for process piping diverted to the OSDF for disposal. The Pipe Crawler was more costly for mobilization, inspection, demobilization, and PPE. The "no inspection" baseline was more costly for waste disposal.

SECTION 6

REGULATORY/POLICY ISSUES

Regulatory Considerations

The regulatory/permitting issues related to the demonstration of the Pipe Crawler at the FEMP are governed by the following safety and health regulations.

- Occupational Safety and Health Administration (OSHA) 29 CFR 1926.28, Personal Protective Equipment
- OSHA 29 CFR 1910.132, General Requirements (Personal Protective Equipment)

Since the Pipe Crawler technology is designed for the inspection of pipes and not actual decontamination work, there is no regulatory requirement to apply CERCLA's nine evaluation criteria. However, some evaluation criteria required by CERCLA, such as protection of human health and community acceptance, are briefly discussed below. Other criteria, such as cost and effectiveness, were discussed earlier in the document.

Safety, Risks, Benefits, and Community Reaction

Worker safety issues are of highest importance when performing any work at Fernald or other DOE sites. While the Pipe Crawler poses no direct threats to safety, there are increased risks due to the additional handling of process piping. For example, workers will be moving and possibly manually lifting heavy pieces of pipe and could also be exposed to any process residues inside the pipe by removing the end seals to insert the camera. However, Fernald has safety programs in place to minimize any increased risks to workers.

A benefit of diverting pipes to the OSDF instead of shipping to NTS is eliminating the risk factor of transporting contaminated pipes by highway or rail to Nevada. A transportation incident can cause significant safety and financial impacts, including a DOE-wide stoppage of waste shipments until problems are resolved.

There are no socioeconomic impacts or negative community perceptions associated with the Pipe Crawler.

SECTION 7

LESSONS LEARNED

Implementation Considerations

The Pipe Crawler is an effective technology for radiological inspection of pipe but is not recommended for use at the FEMP and other sites to *visually* inspect process piping. At the FEMP, the technology is needed to meet the WAC at the OSDF, which is based solely on visual inspection. However, not all DOE sites have OSDFs, and if they do, may not use visual acceptance criteria.

Although this demonstration was performed with a crew of six workers, a reduced crew size may be possible for future deployments. The camera operator could also handle pipes, and the fork lift driver and the rad tech could be shared for other tasks.

Technology Limitations and Needs for Future Development

The Pipe Crawler performed with only minor technical or mechanical problems during the demonstration (the lights on the camera went off on several occasions). The needs for future development include a more rugged and less fragile design of the crawler, a more flexible cable, and a remote control camera focus. A possible improvement for operating the system is for the camera operator to also be able to see the video screen as he moves the camera. This eliminates the inefficiency of the video console operator giving verbal directions to the camera operator for camera movement.

Technology Selection Considerations

The Pipe Crawler is not recommended as a technology for pipe inspection when only visual inspection (and not radiological) is required by the WAC. Under these circumstances, the Pipe Crawler can never break even financially. If other facilities have a need for radiological inspection, then the Pipe Crawler could possibly reduce that facility's overall D&D cost, providing a compelling reason to justify the selection of the Pipe Crawler as the baseline technology for pipe inspection.

APPENDIX A

REFERENCES

U.S. Army Corps of Engineers (USACE), *Hazardous, Toxic, and Radioactive Waste Remedial Action Work Breakdown Structure and Data Dictionary*, USACE, 1996.

U.S. Army Corps of Engineers (USACE), *Construction Equipment Ownership and Operating Expense Schedule*, Washington D.C., August 1995.

U.S. Army Corps of Engineers (USACE), *Productivity Study for Hazardous, Toxic, and Radioactive Waste Remedial Action Projects*, USACE, October 1994.

APPENDIX B

PIPE INSPECTION RESULTS

Table B.1. Pipe Inspection Results

Day 1 (11/19/96)

Pipe Number[1]	Diameter	Visual Inspection Results	
		Clean	Not Clean
50	4.75"	X	
51	4.5"		X
52	5"	X	
53	5"	X	
54	5"	X	
55	4"	X	
56	4"	X	
57	4"	X	
58	6"		X
59	6"		X
60	6"		X

[1]This is the pipe numbering scheme used during data taking.

Day 2 (11/20/96)

Pipe Number	Diameter	Visual Inspection Results	
		Clean	Not Clean
61	6"	X	
62	6"	X	
63	5"	X	
64	5"		X
65	6"	X	
66	6"		X
67	6"		X
68	6"		X
69	5.75"		X
70	6"	X	
71	7"	X	

Day 3 (11/21/96)

Pipe Number	Diameter	Visual Inspection Results	
		Clean	Not Clean
72	13"		X
73	8"		X
74	7"		X
75	8"		X
76	6"		X
77	7"		X
78	5" to 4.25" tapered	X	
79	5"		X
80	5"	X	

Day 3 (11/21/96) continued

Pipe Number	Diameter	Visual Inspection Results	
		Clean	Not Clean
81	5"		X
82	5"		X
83	5"		X
84	5"		X
85	4"		X
86	17"		X
87	18"		X

Day 4 (11/22/96)

Pipe Number	Diameter	Visual Inspection Results	
		Clean	Not Clean
88	4"	X	
89	4"	X	
90	4"	X	
91	6"	Not used	
92	6"	X	
93	6"	Not used	

APPENDIX C

SUMMARY OF COST ELEMENTS

Table C.1. Details of Major Cost Elements

Fixed Costs

Description	Man hrs	Labor	Equipment	Materials	Other	Total
Disposal at NTS (Baseline)						
Mobilization	0	$0	$0	$0	$0	$0
Demobilization	0	$0	$0	$0	$0	$0
Total	0	$ 0	$ 0	$ 0	$ 0	$0
Pipe Inspection (Innovative)						
Mobilization	2	$29	$4	$0	$5,571	$5,604
Demobilization	2	$45	$0	$0	$0	$45
Total	4	$ 74	$ 4	$ 0	$5,571	$5,649

Variable Costs

Description	Quantity	Unit	Man hrs	Labor	Equipment	Materials	Other	Total	Unit Cost
Disposal at NTS (Baseline)									
Disposal (NTS)	42	ea	0	$0	$0	$0	$1,948	$1,948	$46.38
PPE	42	ea	0	$0	$0	$0	$0	$0	$0.00
Total	42	ea	0	$ 0	$ 0	$ 0	$1,948	$1,948	$46.38
Pipe Inspection (Innovative)									
Pipe Inspection	42	ea	42	$1,243	$151	$0	$0	$1,394	$33.19
Disposal (OSDF)	19	ea	0	$0	$0	$0	$305	$ 305	$16.03
Disposal (NTS)	23	ea	0	$0	$0	$0	$1,067	$1,067	$46.39
PPE	42	ea	0	$0	$0	$0	$291	$ 291	$6.93
Total	42	ea	42	$1,243	$ 151	$ 0	$1,663	$3,057	$72.77

Total Costs

Description	Quantity	Unit	Man hrs	Labor	Equipment	Materials	Other	Total
Disposal at NTS (Baseline)	42	ea	0	$0	$0	$0	$1,948	$1,948
Pipe Inspection (Innovative)	42	ea	42	$1,317	$155	$0	$7,234	$8,706

APPENDIX D

LIST OF ACRONYMS AND ABBREVIATIONS

Acronym/Abbreviation	**Description**
CFR	Code of Federal Regulations
CP	Chicago Pile
D&D	Decontamination and Decommissioning
DDFA	Deactivation and Decommissioning Focus Area
DOE	Department of Energy
FDF	Fluor Daniel Fernald
FETC	Federal Energy Technology Center
FEMP	Fernald Environmental Management Project
ID	Internal Diameter
LSDDP	Large-Scale Demonstration and Deployment Project
min	minute
NTS	Nevada Test Site
OEM	Office of Environmental Management (of the DOE)
OSDF	On-Site Disposal Facility
OSHA	Occupational Safety and Health Administration
OST	Office of Science and Technology
PPE	Personal protective equipment
RSI	Radiological Services, Inc.
USACE	United States Army Corps of Engineers
V	volt
VCR	Video Cassette Recorder
WAC	Waste Acceptance Criteria