INNOVATIVE TECHNOLOGY
Summary Report

Pipe Inspection Using the BTX-II

Deactivation and Decommissioning Focus Area

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INNOVATIVE TECHNOLOGY
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Pipe Inspection Using the BTX-II

OST Reference #1811

Deactivation and Decommissioning
Focus Area

Demonstrated at
Fernald Environmental Management Project – Plant 1
Fernald, Ohio

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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. Such a technology could dramatically reduce the overall project costs for a D&D project by greatly reducing the cost for material disposal by diverting pipes from NTS to the OSDF.

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 pipes 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 Visual Inspection Technologies was used. The BTX-II system incorporates a high-resolution micro color camera with lightheads, cabling, a monitor, and a video recorder. The complete probe is capable of inspecting pipes with an internal diameter (ID) as small as 1.4 inches. By using readily interchangeable lightheads, the same system is capable of inspecting piping up to 24 inches in ID. The original development of the BTX system was for inspection of boiler tubes and small diameter pipes for build-up, pitting, and corrosion. However, the system is well suited for inspecting the interior of most types of piping and other small, confined areas.

The camera is mounted on the end of a long probe (a piece of PVC pipe during this demonstration) and is inserted into the pipe to be inspected (Figure 1). Workers manually push the probe through the pipe while the operator at the screen looks for the presence of visual contamination (Figure 2). The operator at the screen can give the camera operator directions about the required movements in the pipe in order to properly view the entire interior.

Figure 1. The camera assembly on the end of the inspection probe.

A crew of six workers would typically be used for pipe inspection with the BTX-II. 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 camera, 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 during the demonstration.

The capital cost of the BTX-II system, including all components, is $20,700. Based on information from the vendor, the expected lives of the camera, cable, and monitor are three years and for the lightheads and control unit, five years. Assuming 1,040 hours of operation per year, the expected lives are 3,120 hours and 5,200 hours, respectively. The salvage value of the equipment is approximately 80% (although only 50% for the monitor and video recorder), which was based on the market for used equipment at the time of this demonstration. Operation costs are approximately $0.04 per hour for electricity usage.

Figure 2. The video monitor and recording unit.

Figure 3. Workers inspecting a pipe with the BTX-II system.

Potential Markets

This technology is well suited to perform the pipe inspection requirements at Fernald. It 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, due to its ease of use and low costs, for similar applications. Aside from verifying the presence or absence of process materials, the BTX-II can be used to inspect inaccessible pipes (e.g., underground lines) for leaks and can be used to verify welds on the inside of pipes. Other applications include inspecting HVAC systems, boilers, heat exchangers, turbines, and tanks.

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 BTX-II system 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 and inspected with the BTX-II, 67% 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.

Cost savings from using the BTX-II system come from reduced disposal costs by being able to divert pipes from NTS to the OSDF. 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. Inspection costs using the BTX-II are $17.17 per pipe in addition to the disposal costs.

Demonstration Summary

The system chosen to perform this demonstration is designed and manufactured by Visual Inspection Technologies. The technology is fully developed and is widely used in commercial applications. The specific system used for this demonstration, the BTX-II, consists of a high-resolution color camera placed on the end of a cable which is coupled to a monitor and video cassette recorder (VCR). The camera is manipulated manually through the pipe and can be used to inspect pipe sections up to 100 feet in length. For this demonstration, the BTX-II was required to inspect a series of piping with varying internal diameters of 2.5 to 27 inches. The BTX-II was demonstrated in November 1996. This report covers the same period of time.

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 BTX-II. 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 BTX-II system would provide sufficient visual inspection for the inside of process piping,
- to determine if a significant percentage of process piping could be diverted from disposal at NTS to the OSDF, and
- to determine the economic viability of inspecting pipe for possible cost-effective disposal in the OSDF.

Key Results

The key results of the demonstration were:

- The BTX-II 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.

- Based on the piping inspected in this demonstration, a large percentage of piping can be diverted to the less expensive OSDF rather than shipping to NTS. 67% of the inspected pipes from Plant 1 were diverted to the OSDF.

- Proficiency and efficiency in using the BTX-II rapidly increased during the demonstration. On the first day, inspection time averaged approximately 23 minutes per pipe, while by day three, the average was only 4.5 minutes per pipe. Only minimal training was required to operate the system.

- The BTX-II system can be decontaminated by wiping or using high pressure water washing. The camera components are waterproof.

- No expendables are generated during operation besides disposable PPE.

- 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 $33.20/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 $43.31/pipe. Cost savings are from the less expensive disposal costs at the OSDF.

- The camera is attached to the console with a 100-foot cable. All 100 feet can be used for inspecting in-place process piping, if required. Only a few feet were used for the short pipe segments inspected during this demonstration.

- The BTX-II system is portable and easy to set up. The only support requirements are a 120V power supply.

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	48
Number of Pipes Sent to NTS	16
Number of Pipes Diverted to OSDF	32
Average Inspection Time per Pipe	10 min.
Break-Even Point[1]	1,759 pipes inspected (at 67% diversion) 410 pipes inspected (at 100% diversion)

[1] This is the number of pipes inspected to recover the cost of using the BTX-II system and is based on the cost of inspection and disposal.

Regulatory Considerations

FDF carried out the BTX-II 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.

Contacts

Technical

Tom Brooks
Visual Inspection Technologies
199 Highway 206, Flanders, New Jersey, 07836-9114
Telephone: (201) 448-0077

Larry Stebbins, Technology Development Manager, Fluor Daniel Fernald
P.O. Box 538704, Mail Stop 50, Cincinnati, Ohio, 45253-8704
Telephone: (513) 648-4785

Fred Huff, Civil Engineer
US Army Corps of Engineers
502 Eighth Street, Huntington, West Virginia, 25701-2070
Telephone: (304) 529-5937

Management

Steve Bossart, Project Manager, Federal Energy Technology Center
3610 Collins Ferry Road, Morgantown, West Virginia, 26507-0880
Telephone: (304) 285-4643

Robert Danner, Acting Technology Program Officer, DOE Fernald Area Office
P.O. Box 538705, Mail Stop 45, Cincinnati, Ohio, 45253-8705
Telephone: (513) 648-3167

Terry Borgman, Plant Nos. 1 & 4 D&D Construction Manager, Fluor Daniel Fernald
P.O. Box 538704, Mail Stop 44, Cincinnati, Ohio, 45253-8704
Telephone: (513) 648-5357

Paul Pettit, Project Manager, Technology Programs, Fluor Daniel Fernald
P.O. Box 538704, Mail Stop 50, Cincinnati, Ohio, 45253-8704
Telephone: (513) 648-4960

Other

All published ITSRs are available at http://em-50.em.doe.gov. The Technology 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 BTX-II is 1811.

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

SECTION 2

TECHNOLOGY DESCRIPTION

Overall Process Definition

The BTX-II demonstrated at the Fernald Environmental Management Project (FEMP) consists of a high resolution color camera with lightheads, a long probe on which it is mounted, cabling, a video monitor, and recording unit. 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 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 BTX-II system.

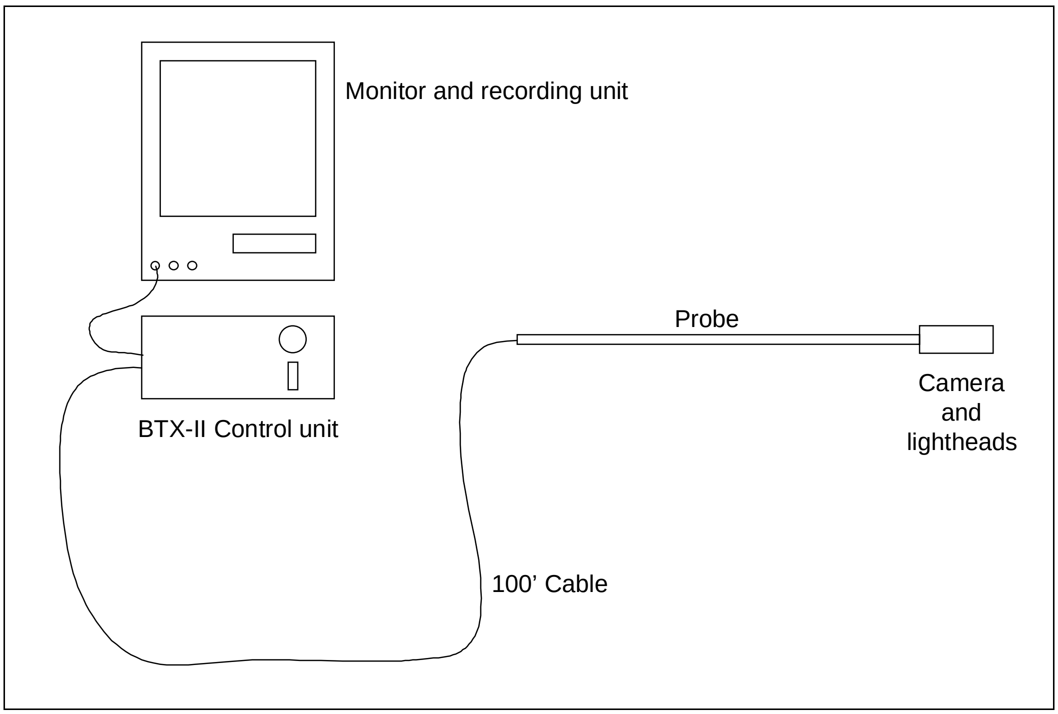

Figure 4. Schematic of the BTX-II system.

System Operation

The system is designed to operate in a variety of conditions. The camera probe and cabling are sealed to prevent the introduction of liquids, hazardous materials, or contaminants into the system. The system is waterproof, and can be readily decontaminated using high pressure water washing. The system is extremely portable and can be operated in virtually any location that has a 120V standard power supply. Minimal 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 BTX demonstration.

Table 2. Operational parameters and conditions of the BTX 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 inspection of the interior of process piping.
Dimensions	Camera diameter: 1.38 inches Camera length (including cable): 110 feet Control unit: 5.25” x 9.0” x 13.0” Monitor/VCR: 11.0” x 8.0” x 14.5”
System Materials	Sealed stainless steel, waterproof and heat resistant.
Lens	3.0 mm with user-adjustable focus
Illumination	9.6 watts (six 1.6-watt quartz halogen bulbs)
Video Output	S-Video and NTSC composite video
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 BTX-II. 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 BTX-II. These rejected pipes are not counted in this demonstration. One end of the pipe was unwrapped, and the camera probe and cabling 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 end was 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 BTX-II 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 BTX-II 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 BTX-II 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 three days. During that time, a total of 48 different pieces of pipe were inspected. Nominal diameters of the schedule 40 carbon steel piping ranged from 2.5" to 27". 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 BTX-II, 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 BTX-II inspection process, although the fork lift operator and the rad tech could be part-time, depending on site conditions.

In examining the data collected, some acceleration of inspection efficiency can be noted during the three day inspection period. If the last day were assumed to be typical of normal operations, an average of 13 pieces of pipe should be inspected in a 1 hour period.

Performance relative to demonstration objectives

Table 3 summarizes the overall performance results of the baseline and BTX-II 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 BTX-II (Innovative)
Ability to Visually Inspect Pipes	Not required	Able to visually inspect pipes in an acceptable manner for OSDF acceptance
Cost for Disposal	$46.38/pipe	$16.03/pipe
Cost for Inspection	Not required	$17.17/pipe ($14.13 inspection + $3.04 PPE)
Effective Cost	$46.38/pipe	$43.31/pipe[1]
Number of Pipes Sent to NTS	All 48 would have been sent to NTS.	Only 16 of 48 sent to NTS.

[1] This is the overall cost per pipe for this demonstration based on the 67% diversion rate to the OSDF.
[(48 x $17.17 inspection) + (32 x $16.03 OSDF) + (16 x $46.38 NTS)]/48 pipes = $43.31/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 BTX-II system provides an acceptable way to visually inspect the interior of process piping and thus see if the acceptance criteria are satisfied. No additional testing is required.

Reduced Costs

Cost savings from using the BTX-II system come from reduced disposal costs by being able to divert pipes from NTS to the OSDF. 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. Inspection costs using the BTX-II are $17.17 per pipe in addition to the disposal costs.

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 BTX-II system 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 and inspected with the BTX-II, 67% 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, including a number of technologies that are equipped with both cameras and radiological detectors. Some of these technologies include (but are not limited to) the Pipe Explorer by Science and Engineering Associates and the Radiological Pipe Crawler by RSI. 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 RSI Pipe Crawler for ex-situ inspection of pipe at Fernald, and the RSI Pipe Crawler for in-situ pipe inspection at CP-5 Research Reactor.

Visual Inspection Technologies, Inc. is the sole manufacturer of the BTX-II. They maintain all commercial rights to the system.

Technology Applicability

The BTX-II system is a mature and commercialized technology for visually inspecting the inside of pipes and other narrow openings. The post-demonstration assessment of the BTX-II is summarized below.

- Visual inspection is easily accomplished using the BTX-II. This inspection is able to meet the criteria for acceptance at the OSDF. A crew of six people is used to handle the pipes, manipulate the camera, and operate the monitoring unit.
- The BTX-II allowed the diversion of 67% of the pipes inspected to the OSDF, saving the high costs of disposal at NTS.

This technology is well suited to perform the pipe inspection requirements at Fernald. It 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, due to its ease of use and low costs, for similar applications. Aside from verifying the presence or absence of process materials, the BTX-II can be used to inspect inaccessible pipes (e.g., underground lines) for leaks and can be used to verify welds on the inside of pipes. Other applications include inspecting HVAC systems, boilers, heat exchangers, turbines, and tanks. Despite its versatility, the BTX-II is limited to performing visual inspections only.

Patents/Commercialization/Sponsor

The technology has been patented by the technology developer, Visual Inspection Technologies, Inc., from which it can be purchased. The BTX-II has been used in the commercial and nuclear power industries and mechanical contracting markets 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 BTX-II system and a "no inspection" baseline and to estimate the potential cost savings the BTX-II system 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 for disposal of FEMP's process piping: the BTX-II system and a "no inspection" baseline. The BTX-II system 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 the 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 that 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 BTX-II system was rented from the vendor for the duration of the demonstration. The BTX-II system was operated by D&D contractor personnel.

Cost and performance data were collected for the BTX-II system 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 and costs for training the crew members on use of the equipment.

Segments of process piping that had been previously removed from the interior of Plant No. 1 were visually 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 technology 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 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. 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 BTX-II system, 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 $20,700 capital cost of the BTX-II system, a discount rate of 5.6%, equipment life of 3,120 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 BTX-II system, 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 BTX-II system 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 BTX-II system. Personnel training costs were estimated for six personnel, which is considered to be a more typical deployment crew.

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.

Once comparative unit costs were determined, it was then necessary to analyze one cost driver that could significantly impact the cost effectiveness of the BTX-II system in the demonstrated application: the percentage of process piping inspected that is diverted from disposal at the NTS to disposal in the OSDF. If too low a percentage of process piping is diverted, the BTX-II system may not show any cost savings.

To analyze this cost driver, the cost for using the competing approaches in the demonstrated application was expressed by the following equations:

$y_B = Cx$ for the “no inspection” baseline

$y_I = Ax + Bpx + C(1\text{-}p)x$ for the BTX-II system

where y_B = cost of using the “no inspection” baseline ($)

y_I = cost of using the innovative technology ($)

x = number of process pipes (ea.)

p = fraction of process piping diverted to OSDF

1 - p = fraction of process piping sent to NTS

A = unit cost of pipe inspection ($/ea.)

B = unit cost of disposal at OSDF ($/ea.)

C = unit cost of disposal at NTS ($/ea.)

Setting the two equations equal to each other and solving for p yields the fraction of process piping diverted from disposal at NTS to disposal in the OSDF at which the unit costs of using the two competing approaches are equal. These equations do not include fixed costs.

$$\$46.38x = \$17.17x + \$16.03px + \$46.38(1\text{-}p)x$$

$$p = 0.566 = 56.6\%$$

The comparative unit costs showed that the BTX-II System offers significant cost savings over the “no inspection” baseline, even though the fixed costs for deployment of the BTX-II System are higher than for the “no inspection” baseline. A simple break-even line analysis was performed to provide a decision tool for selecting the BTX-II System. The fixed deployment costs were added to the equation for calculating the cost for using the BTX-II System as follows:

$$y_I = Ax + Bpx + C(1\text{-}p)x + \$5{,}399$$

Solving this equation yields the following expressions for x:

$$x = 5399/(30.35p - 17.17)$$

Values were selected for p and the first expression solved for corresponding values of x. The values of p and x were then graphed as shown in Figure 5. The break-even graph is asymptotic at 56.6%. For all points to the right of the break-even line, deployment of the BTX-II System will be cost-effective, and the unit cost savings will recover the fixed deployment costs.

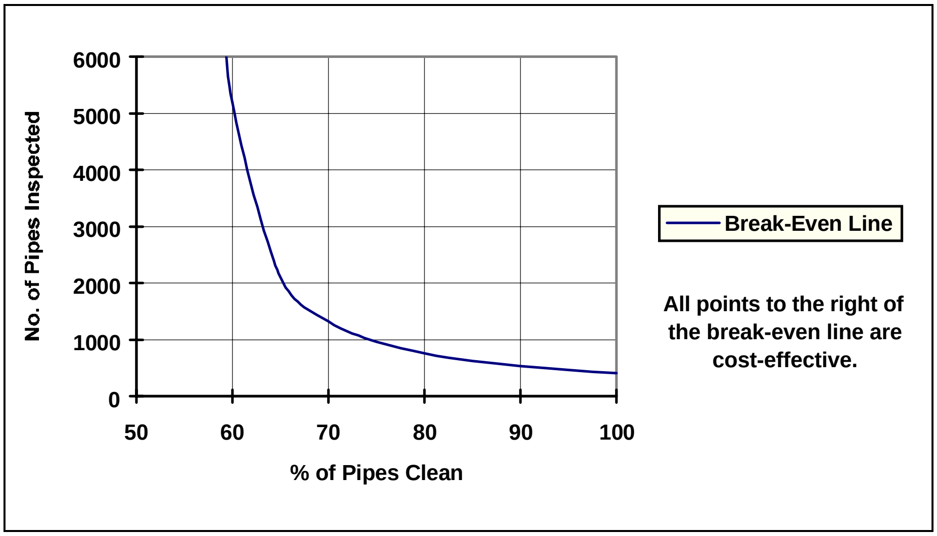

Figure 5. Break-even line analysis.

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 BTX-II System (Innovative)			**No Inspection** (Baseline)		
Cost Element	**Unit Cost**	**Production Rate**	**Cost Element**	**Unit Cost**	**Production Rate**
Mobilization[1]	$5,115	N/A	Mobilization[1]	$0	N/A
Inspection	$14.13/pipe	13.5 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]	$284	N/A	Demobilization[1]	$0	N/A
PPE	$3.04/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 BTX-II system because the equipment had to be transported to the site. The BTX-II system 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 BTX-II system 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 BTX-II system technology equipment.

Waste disposal costs may be lower for the BTX-II system, because its use may reduce the amount of process piping that must sent to NTS for disposal.

Demobilization costs were higher for the BTX-II system due to the cost of removing equipment from the site. There are no demobilization costs for the “no inspection” baseline.

Because use of the BTX-II system is an additional work activity not required for the baseline, PPE costs were higher for the BTX-II system. 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 (piping disposal at NTS)

$33.20/pipe - BTX-II system (inspection and disposal for piping diverted to OSDF)

$63.55/pipe - BTX-II system (inspection and disposal for piping inspected but still sent to NTS)

Therefore, for the demonstrated application, the BTX-II system offers about a 28% cost savings over the "no inspection" baseline for process piping. The BTX-II system was more costly for mobilization, inspection, demobilization, and PPE. The "no inspection" baseline was more costly for waste disposal.

The demonstration consisted of inspecting 48 pipes using the BTX-II system at a cost of $17.17/pipe ($14.13 inspection + $3.04 PPE). Thirty-two 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 16 of the pipes contained visible contamination requiring their disposal at NTS at $46.38/pipe. Based on demonstration results that showed that 67% of the pipe could be disposed of in the OSDF, the average cost to inspect and dispose of pipe was $43.31/pipe.

The analysis of percentage of process piping diverted to OSDF showed that at least 57% of process piping inspected must diverted in order for the BTX-II system to be as cost effective as the "no inspection" baseline. About 67% of the process piping inspected for the Plant No. 1 demonstration was diverted to the OSDF.

SECTION 6

REGULATORY/POLICY ISSUES

Regulatory Considerations

The regulatory/permitting issues related to the demonstration of the BTX-II 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 BTX-II 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 BTX-II 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 BTX-II.

SECTION 7

LESSONS LEARNED

Implementation Considerations

The BTX-II system is an effective technology and can be used at the FEMP and other sites to visually inspect process piping. At the FEMP, the technology is specifically used to meet the WAC at the OSDF, which is based on visual inspection. However, not all DOE sites have OSDFs, and if they do, may not use visual acceptance criteria. Selection of the BTX-II may also depend on what is known about the process piping to be inspected. If most of the piping is expected to be very contaminated, there may not be a large enough percentage of clean pipe to make the use of the BTX-II cost effective.

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.

There are no major technology considerations regarding the BTX-II due to its relative simplicity. If visual inspection satisfies the WAC or the requirements for a project, the BTX-II should be considered.

Technology Limitations and Needs for Future Development

The BTX-II performed without any significant technical or mechanical problems during the demonstration, and there appears to be little need for future development. 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.

For the majority of piping that is inspected, the BTX-II system will work without problems. However, two conditions in the pipe could pose problems to the equipment and/or safety of the workers. The lens cover on the camera is Lexan coated, which is not acid-proof. This could damage the lens when used on pipes that also have acid or acid residue left in the process piping. Secondly, the temperature of the lamp is 350 to 400ºF, which is not explosion-proof. This could present a hazard if combustible or flammable residues were present in the pipe.

Technology Selection Considerations

The BTX-II system is recommended as a good technology for the visual inspection of the interiors of pipes. However, the requirements for the inspection must be solely visual and there must be a significant cost saving for disposal of pipes that meet the WAC for the alternate disposal facility. The opportunity to reduce a facility's overall D&D cost is a compelling reason to justify the selection of the BTX-II 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 (11/5/96)

Pipe Number	Diameter	Visual Inspection Results	
		Clean	Not Clean
1	6”	X	
2	5”	X	
3	6”	X	
4	4”	X	
5	4.5”	X	
6	4”	X	

Day 2 (11/6/96)

Pipe Number	Diameter	Visual Inspection Results	
		Clean	Not Clean
7	4”	X	
8	4.5”	X	
9	6.25”	X	
10	8”	X	
11	5”		X
12	7.25”	X	
13	4.75”	X	
14	6.5”	X	
15	6.5”		X
16	15 to 7” tapered		X
17	6”	X	
18	6”	X	
19	6”		X
20	6”		X
21	6”	X	

Day 3 (11/7/96)

Pipe Number	Diameter	Visual Inspection Results	
		Clean	Not Clean
22	9”	X	
23	5”		X
24	6”		X
25	8.5”	X	
26	6”	X	
27	6”		X
28	26”	X	
29	13”	X	
30	16”	X	
31	27”	X	

Day 3 (11/7/96) continued

Pipe Number	Diameter	Visual Inspection Results	
		Clean	Not Clean
32	12.25”		X
33	9”		X
34	7x9” oval	X	
35	7”	X	
36	7.5”		X
37	4.5”	X	
38	6.25”	X	
39	12”	X	
40	12”		X
41	8”	X	
42	9”	X	
43	9”		X
44	6.5”		X
45	7”	X	
46	5”	X	
47	2.75”		X
48	2.5”		X

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	$5,082	$5,115
Demobilization	12	$284	$0	$0	$0	$284
Total	**14**	**$ 313**	**$ 4**	**$ 0**	**$ 5,082**	**$ 5,399**

Variable Costs

Description	Quantity	Unit	Man hrs	Labor	Equipment	Materials	Other	Total	Unit Cost
Disposal at NTS (Baseline)									
Disposal (NTS)	48	ea	0	$0	$0	$0	$2,226	$2,226	**$46.38**
PPE	48	ea	0	$0	$0	$0	$0	$0	**$0.00**
Total	**48**	**ea**	**0**	**$ 0**	**$ 0**	**$ 0**	**$ 2,226**	**$ 2,226**	**$ 46.38**
Pipe Inspection (Innovative)									
Pipe Inspection	48	ea	21	$649	$29	$0	$0	$678	**$14.13**
Disposal (OSDF)	32	ea	0	$0	$0	$0	$513	$513	**$16.03**
Disposal (NTS)	16	ea	0	$0	$0	$0	$742	$742	**$46.38**
PPE	48	ea	0	$0	$0	$0	$146	$146	**$3.04**
Total	**48**	**ea**	**21**	**$ 649**	**$ 29**	**$ 0**	**$1,401**	**$2,079**	**$43.31**

Total Costs

Description	Quantity	Unit	Man hrs	Labor	Equipment	Materials	Other	Total
Disposal at NTS (Baseline)	**48**	**ea**	**0**	**$0**	**$0**	**$0**	**$2,226**	**$2,226**
Pipe Inspection (Innovative)	**48**	**ea**	**35**	**$962**	**$33**	**$0**	**$6,483**	**$7,478**

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
^oF	Degrees Fahrenheit
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
PVC	Poly-vinyl chloride
USACE	United States Army Corps of Engineers
V	volt
VCR	Video Cassette Recorder
VIT	Visual Inspection Technologies
WAC	Waste Acceptance Criteria