The Internal Duct Characterization System

INNOVATIVE TECHNOLOGY SUMMARY REPORT

demonstrated at

Liquid Effluent

Treatment and Disposal Facility
Idaho Chemical Processing Plant
Idaho National Engineering and Enviornmental Laboratory
Idaho Falls, ID

prepared for

U.S. Department of Energy
Office of Environmental Management
Office of Science and Technology
Deactivation and Decommissioning Focus Area

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TABLE OF CONTENTS

1
EXECUTIVE SUMMARY page 1

2
TECHNOLOGY DESCRIPTION page 3

3
PERFORMANCE page 6

4
TECHNOLOGY APPLICATION AND ALTERNATIVE TECHNOLOGIES page 9

5
COST page 10

6
REGULATORY/POLICY ISSUES page 12

7
LESSONS LEARNED page 13

A
Acronyms and Abbreviations page 14

SECTION 1

ESECUTIVE SUMMARY

Technology Summary

The Internal Duct Characterization System (IDCS) was developed by the Department of Energy's (DOE's) Office of Science and Technology (OST) Robotics Technology Development Program (RTDP). The IDCS is a remotely operated system for visually inspecting ventilation ductwork and characterizing selected chemical and radiological contaminants that are internally located in ventilation ductwork. The IDCS consists of a control station, a reel-mounted tether for data communication, video, and power, and the duct crawling vehicle (see Figure 1). The IDCS vehicle can travel over 200 ft. in round ducts six inches in diameter and larger, and in rectangular ducts six inches square and larger. The vehicle visually inspects the interior condition of ducts using a high-resolution color video camera, and has an integrated radiation sensor to detect significant levels of radioactivity. It also has the directional sensors necessary to produce as-built mapping of the ductwork. The IDCS has a limited capability to take samples, and to clean/decontaminate small areas. The entire vehicle is made from stainless steel and is designed to be decontaminated. Many of these capabilities have been individually achieved with existing systems, but the IDCS is the only remote characterization system to integrate them in a single system.

Figure 1. The Internal Duct Characterization System

Across the DOE Complex there are numerous facilities identified for deactivation and decommissioning (D&D) that have been placed on the contaminated list because of the risk of internal contamination in ductwork. Most of this ductwork is inaccessible because it is buried

underground, encased in concrete, or runs through hot cells. Ductwork characterization is extremely difficult because of airflow control devices, varying sizes and geometry of ductwork, and numerous changes in duct direction. Characterization of this ductwork is essential before, during, and after D&D activities. The identification and mapping of contaminants in ductwork is a major concern during facility deactivation. An understanding of the types and extent of contamination will be primary drivers for decisions regarding decontamination and/or dismantlement.

This technology allows characterization of ductwork that could not have been otherwise characterized. Determining the absence or presence of contamination and the extent of contamination in ductwork will reduce the costs of D&D activities by allowing the ductwork to be handled appropriately versus treating all ductwork as contaminated. It will also reduce the amount of secondary waste generated since uncontaminated ductwork will not need to be decontaminated. It will reduce human health risk because sections of ductwork that pose health risks will have been identified prior to exposure. Use of this technology to perform in situ decontamination would provide additional benefits in the areas listed above.

Demonstration Summary

In January 1995, the IDCS was used to perform a duct inspection at the Idaho Chemical Processing Plant (ICPP); a DOE facility located at the Idaho National Engineering and Environmental Laboratory. Specifically, the IDCS inspected an 18-inch diameter off-gas duct running from the Liquid Effluent Treatment and Disposal (LET&D) facility to the main stack at the ICPP. The LET&D facility had been put into service approximately three years prior to the IDCS inspection. Operations engineers at the facility discovered that hot chloride corrosion had already created a hole in the Schedule 10 stainless steel duct within the facility. The 18-inch duct was designed to carry hot (300F) gas, and the design life of the facility was supposed to be twenty years. The facility manager needed to determine if there was any significant corrosion in the duct between the facility and the stack, a distance of approximately 230 feet. No radioactive contamination was suspected to be present in the duct. Remote inspection personnel at the ICPP knew of the newly-developed IDCS and its capabilities, believed it was uniquely suited to this inspection, and proposed that it be used in this field deployment. Personnel from the RTDP D&D Robotics Program worked with the RTDP, the ICPP remote inspection personnel, the facility manager, and radiation control personnel to perform the demonstration. The IDCS successfully inspected over 200 feet of the off-gas duct, which proved to be mildly radiologically contaminated. The actual inspection took less than one day to perform, and the video information proved quite valuable to the facility manager.

Contacts

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SECTION 2

TECHNOLOGY DEMONSTRATION

Overall Process Definition

Description of the Technology

The IDCS is a remotely-operated inspection system designed to characterize and inspect contaminated ventilation systems within DOE facilities. The IDCS was developed in FY 1994 by the RTDP robotics team with the private firms of Inuktun Services, Ltd., and Automation Systems Associates. The compact, powerful system incorporates a precision-machined crawler track vehicle, modular component housings, a tether management system, and a VME computer-based operating center that provides overall system's management. The system operates from a nominal 115 VAC, 60 Hz, single-phase power supply. The surface equipment, consisting of the consoles and tether management system (TMS), are enclosed in three rugged packing cases. These cases provide the protection required for the complex electronic equipment, and double as a portable control center. Operational control is achieved via joysticks, a keypad, and a touch screen. Video monitoring/recording and on-screen reporting are also incorporated. Operational features of the IDCS are summarized in the table below.

Table 1. IDCS Vehicle Features.

Horizontal speed capability	Thirty ft./min. in both forward and reverse directions, continuously variable speed control.
Steering	Variable speed tank-type steering via joystick. Independently controllable front and rear track pairs that can be slaved so that rear pair follows lead pair.
Duct sizes which can be inspected	Six- to 32-inch round pipe or ducting, six-inch square to 36-inch wide rectangular ducting.
Minimum access into ducting	Can be inserted through a round orifice with a diameter of 6 inches. Can be inserted into a 6-inch Schedule 40 pipeline through a branch tee.
Maneuverability limits	Capable of climbing or descending a slope of 35 degrees. Capable of climbing over an obstacle with a height of 2 inches in square ducts with an interior height of 8 inches or more. Capable of maneuvering through sectional mitered elbows and bends in ducts 6 inches and larger, and through right angle mitered elbows in ducts 8 inches and larger.
Cameras	Front: Sony S-VHS video color camera with fixed focus lens and remotely-controlled iris mounted in an articulated pan-and-tilt head capable of 360-degree pan and 180-degree (+90/-90) tilt. Rear: Black and white fixed focus auto iris camera.
Lights	Front: Two miniature flood lights and two miniature spot lights on pan-and-tilt head with independent, variable remote control. Rear: Four miniature flood lights with variable remote control.
Sensors	Vehicle tilt-and-roll sensors, quartz rate gyro for measuring turns, drop-off detector, radiation sensor, vehicle temperature sensors, capability to deploy additional sensors.

Table 2. IDCS Control Station Features

Display	Thirteen-inch color monitor with on-screen display and touch screen, capable of toggling off all or part of on-screen display items and displaying video from front or rear camera.
On-screen display items	Distance traveled, vehicle configuration, vehicle tilt, vehicle roll, artificial horizon, pan-and-tilt camera position, radiation detector readings, title bar, alert/status messages.
Vehicle controller	Emergency stop switch, dual joysticks for front and rear tracks, pan-and-tilt camera control buttons, front and rear light control switches, sample arm control switch, front camera iris control switch, slave switch (makes rear tracks follow front tracks using single joystick), cruise control switch (allows operator to set fixed distance for vehicle to travel without operator control).
Video recorder	Sony S-VHS video recorder with editing capability.
Input pendant	Allows operator input of control parameters such as vehicle roll limit, vehicle tilt limit, radiation limit, distance to travel under cruise mode.
Control computer	VME computer running VXWorks

The IDCS Vehicle

The IDCS vehicle is composed of three primary segments; the color camera housing (on which the pan-and-tilt camera head is mounted), the telemetry housing, and the power conditioning housing (See Figure 2.) The power conditioning housing also incorporates the rear black-and-white camera and lights. The three segments are joined at horizontal hinge points, which allow the segments to rotate more than ninety degrees with respect to each other, a feature critical to making ninety degree corners in smaller ducts. Feedback potentiometers measure the angles between the segments for display at the control station. The drive tracks are mounted under the front and rear segments, and can be mounted using fixed brackets for a given duct size or mounted on a “shift-on-the-fly” mechanism which allows the operator to change the drive mounting angle to accommodate changing duct diameters.

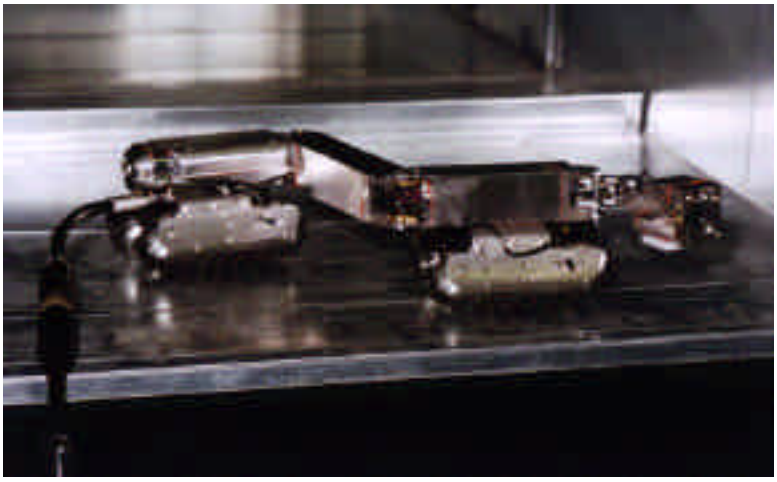

Figure 2. The IDCS Vehicle.

The Tether Management System

The tether management system (TMS) is comprised of a 275-ft. tether, which is stored on a reel, a power and slip ring assembly, a level-wind assembly, and a remote control pendant. The tether itself is a custom cable with an outer diameter of 0.510 inches. It incorporates a Kevlar core, two 9221

coax cables, two 16 AWG conductors, four No. 22 twisted pairs, a 30 mil TPR inner jacket, and a 35 mil polyurethane outer jacket. The incorporation of the Kevlar core gives the tether a tensile strength of 500 pounds. The TMS also incorporates a tether counter. This tether counter is clamped at the entrance to the duct and the tether is fed through it. Data from the counter is fed back to the control computer to display distance traveled.

System Operation

Operational Parameters and Conditions

The IDCS must be set up and operated as close to the insertion point in the duct to be inspected as is reasonably achievable. This point could be indoors or outdoors, but if it is outdoors, the weather must be clear or the IDCS equipment must be under a tarp to protect it from rain/snow. A minimum area of approximately 8 ft. by 8 ft. is needed for the operator control station and TMS. Ambient temperatures should be between 32- and 100-degrees Fahrenheit for operation. Cool to moderate temperatures are typically more desirable for both the operator and for the IDCS vehicle, which must dissipate heat from its power supply in the rear segment. The operator station and the TMS must be within 15 ft. of each other to allow cable connections. There is 275 ft. of tether on the TMS, so the further the TMS is from the vehicle insertion point, the less distance the vehicle can potentially inspect. It takes approximately twenty minutes to unbox the system and set it up for operation.

Materials, Energy Requirements, and other Expendables

A single 115 VAC, 60 Hz, and 15A power source must be present to run the system. No other power is required unless additional equipment will be used (e.g., second monitor, second video recorder.) Under typical commercial conditions, there are no expendables. Dirt, dust, mud, rust, and similar materials can be removed by wiping or washing upon retrieval of the vehicle. When the IDCS is used to inspect radioactively contaminated ducting, it is typical to expect to replace the rubber belts on the drive tracks, and possibly the tether. If the ducting is highly radioactively contaminated or highly radioactively activated, there is the potential that the vehicle will not be decontaminable to the point of free release.

Manpower Skills and Training Requirements

Typically, two people are needed to perform an inspection. Four people are suggested for initial setup since the control station and TMS containers weigh approximately 160 pounds apiece, but it can be accomplished by two. Once the equipment is set up, one person inserts the vehicle into the duct and manages the tether while the other person drives the vehicle and records the inspection. The person driving the vehicle and overseeing the inspection would require about 40 hours of training to be fully effective, while the person managing the tether could be briefed on task requirements in an hour or less.

Potential Operational Concerns and Risks

The only significant concern with the use of the IDCS is the remote possibility that the IDCS vehicle may become stuck in a duct. This concern is mitigated by the maneuverability and flexibility of the vehicle, and by the strength of the tether in the event of a loss of vehicle control. The tether can be used to apply up to 500 pounds of force to pull the IDCS vehicle back.

SECTION 3

PERFORMANCE

Demonstration Plan

Demonstration Site Description
In January 1995, the IDCS was used to perform a duct inspection at the ICPP; a DOE facility located at the Idaho National Engineering and Environmental Laboratory. Specifically, the IDCS inspected an 18-in. diameter off-gas duct running from the LET&D facility to the main stack at ICPP. The LET&D facility had been put into service approximately three years prior to the IDCS inspection. Operations engineers at the facility discovered that hot chloride corrosion had already created a hole in the Schedule 10 stainless steel duct within the facility. The 18-in. duct was designed to carry hot (300F) gas, and the design life of the facility was supposed to be twenty years. The facility manager needed to determine if there was any significant corrosion in the duct between the facility and the stack, a distance of approximately 250 ft.. No radioactive contamination was suspected to be present in the duct. Remote inspection personnel at the ICPP knew of the newly developed IDCS and its capabilities, believed it was uniquely suited to this inspection, and proposed that it be used in this field deployment.

Major Elements of the Demonstration
The sole purpose of this inspection was to determine the condition of the interior of the duct through visual inspection. The interior of LET&D facility is fairly congested because of numerous pipes and ducts. The start of the 18-in. line to be inspected was located on the second floor of the facility, and the insertion point for the IDCS was located approximately 10 ft. above the second floor itself. The IDCS control station and tether reel were hauled up to the second floor manually and set up in a small open area adjacent to the insertion point. Temporary scaffolding was already in place from previous repair efforts, and this allowed access to the duct to insert the IDCS vehicle. The physical routing of the 18-in. duct was quite challenging.

Boundaries of the Demonstration
The IDCS was to be inserted into the duct at a blind corner where the duct was 24 inches in diameter. The vehicle would then travel approximately 2 ft. to a tee fitting where the 18-in. duct began. After descending a short (18-in.) section sloped downward at 22 degrees, the vehicle would travel approximately 20 ft. horizontally to the point where the duct exits the building (See Figure 3). The vehicle then had to negotiate a drop of 6 ft. at a 45-degree slope and then return to horizontal. From this point on, the duct ran horizontally. The vehicle was to travel approximately 100 ft., then turn 90 degrees turn to the right, travel another 80 ft., then turn 45 degrees to the left, and travel another 30 ft. to the point where the duct dropped vertically into the main stack.

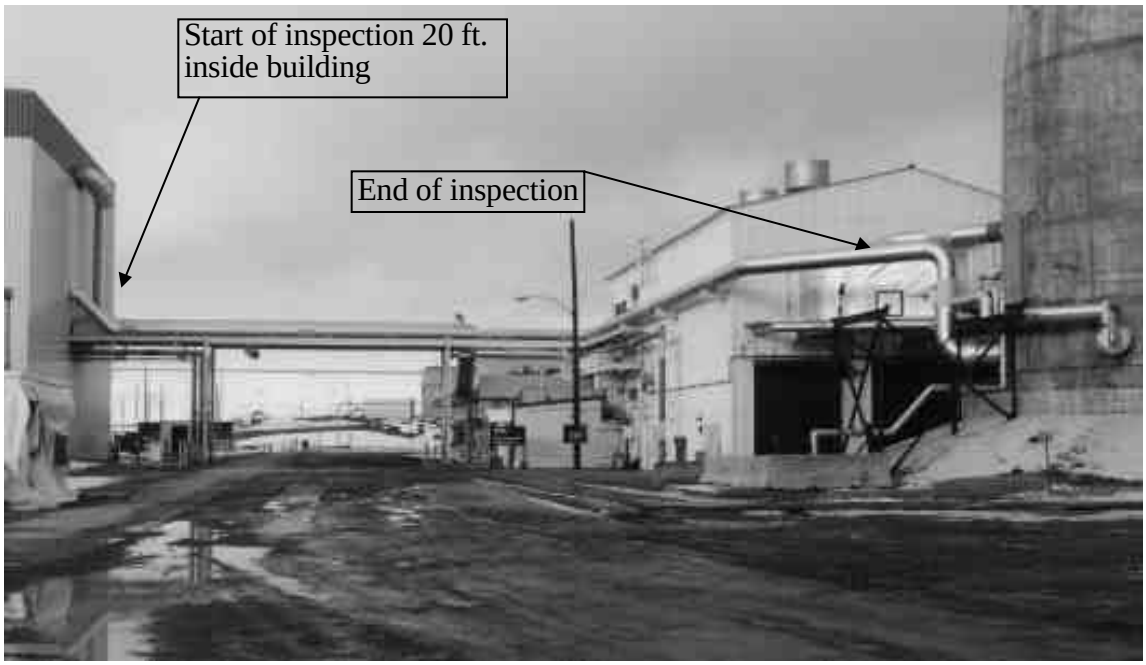

Figure 3. LET&D off-gas duct.

Treatment Performance

The inspection of the LET&D duct went very smoothly (see Figures 4 and 5) The IDCS was successfully driven 211 ft. through a total of six fittings (one tee, one 90-degree elbow, and four 45-degree elbows.) It was able to descend (outbound) and ascend (inbound) a 6 ft. drop at a 45-degree slope with some assistance via the tether. This exceeded the design requirement maximum of 35 degrees. The IDCS also pinpointed some corrosion in the ductwork and areas where liquids had condensed and pooled on the interior of the duct. This was a significant discovery since the line was designed to be a dry line carrying only gases. The IDCS inspected all but about the last 15 ft. of the LET&D off-gas duct. Drag from the friction of the tether bending around the elbows prevented the vehicle from completing the last 15 ft., but by that point the facility manager had seen enough to make informed decisions on future repair/replacement. The outbound portion of inspection took approximately two hours to complete because of frequent stops to visually examine areas or interest. The sample arm on the vehicle was also used to scrape discolored areas within the duct to determine whether they were fixed stains, cracks, or only loose deposits of debris and/or rust. The inbound (return) portion of the inspection would have taken about 15 minutes, but during retrieval of the vehicle, it was discovered that the IDCS vehicle and its tether had become radiologically contaminated. This delayed retrieval of the vehicle took several hours, while the unexpected radiological issues were addressed. The vehicle and tether were bagged upon removal from the duct and sent to the ICPP decontamination facility where they were successfully decontaminated and released.

Figure 4. Inserting the IDCS vehicle into the off-gas duct.

Figure 5. The IDCS control station during the LET&D inspection.

SECTION 4

TECHNOLOGY APPLICABILITY AND ALTERNATIVE TECHNOLOGIES

Technology applicability

The ideal location for application of the IDCS is in ducting from 8- to 24-in. in diameter where there are multiple bends or tees and distances up to 250 ft. to be inspected. The IDCS is particularly suited to DOE facilities where radioactive contamination is present, but it can be used in non-radioactive environments as well.

Competing Technologies
There are other technologies for inspecting ductwork, including push cameras, fiberoptic borescopes, and less-expensive vehicular inspection systems. The IDCS has an advantage over most of these technologies on range and steerability alone. Typically, push cameras and borescopes are limited to 50 ft. or less and are not steerable. The IDCS has advantages over other vehicle-based technologies in several areas. First, its maneuverability and duct size range are superior to other systems, particularly when its inspection range is considered. It also provides much more information back to the operator, such as real-time vehicle orientation and radiation levels, to prevent getting the vehicle turned over or highly contaminated in a duct. It is more expensive to purchase initially than these competing technologies, and, therefore, probably more appropriate to special conditions such as contaminated DOE facilities.

Patents/Commercialization/Sponsor
The sponsor of the development of this technology is the Robotics Technology Development Program (RTDP), an EM-50 organization within the Office of Science and Technology. The IDCS was designed and built under a competitive bid based on a performance specification written by the D&D Robotics group of the RTDP.

The IDCS and subsystems, based on the IDCS technology, are available commercially through Inuktun Services, Ltd. Inuktun Services is located in Nanaimo, British Columbia, Canada, and holds all patents on the IDCS technology.

SECTION 5

COST

Methodology

This demonstration was performed in January 1995, and, therefore, occurred before cost analyses and baseline cost data were collected or analyzed formally for Innovative Technology Summary Reports (ITSRs). This demonstration was the only time the IDCS has been deployed in the field; therefore, only limited conclusions can be drawn. Cost comparisons with competing technologies is also problematic because this demonstration was performed at a DOE site by DOE employees. Comparing this demonstration to a commercial technology performed by private sector personnel at a DOE site is difficult because of issues such as travel costs, training costs, etc. Costs known to have been associated with the demonstration have been summarized in Table 3 below. The costs to perform the demonstration with a competitive technology would be similar to those listed in Table 3, but it is uncertain that any of the competing technologies would have been capable of inspecting the same length of duct.

Cost Analysis

Table 3. Costs Associated with IDCS Demonstration.

Description	Labor	Materials	Total
Mockups and Practice	2 man-days @ $500/man-day = $1000	Sheetmetal ductwork sections to mock up 45 degree section = $160	$1160.00
Perform inspection	4 man-days @ $500/man-day = $2000	2 Videotapes @ $5/videotape = $10	$2010.00
Decontaminate vehicle and tether	2 man-days @ $500/man-day = $1000	Miscellaneous wipes, Windex, smears = $10	$1010.00
Reassemble vehicle and tether, replace lost parts	3 man-days @ $500/man-day = $1500	Rubber tracks - $560 Broken potentiometer - $120 Ball bearing and seals - $20	$2200.00
		Total Costs	$6380.00

The IDCS is a unique, one-of-a-kind system. Only one IDCS is currently in existence. The cost to design and build the IDCS is probably best represented by the price of the contract to Inuktun Services: $432,772.00. Additional copies of the IDCS would be significantly less expensive, probably on the order of $175,000.00.

If the development cost of the equipment is neglected as a sunk cost per the methodology of cost analysis for deployment of innovative technologies, then the cost per foot for the inspection would be:

$6380.00 / 211 ft. inspected = $30.24/ft.

Cost Conclusions

The cost per foot for the IDCS demonstration, calculated at $30.24/ft., is quite comparable to costs calculated for the Pipe Explorer™ system, which was calculated to cost from $27.69/ft. to $40.00/ft. The IDCS value of $30.24/ft. would decrease if multiple sections of ductwork could be inspected before decontamination and reassembly.

SECTION 6

REGULATORY/POLICY ISSUES

Regulatory Considerations

Because the IDCS is an investigation tool for characterization of existing pipes and drains, there are no special regulatory permits required for its use.

Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)

CERCLA does not apply to this technology.

Safety, Risks, Benefits, and Community Reaction

Normal radiological worker safety procedures used at the facility would apply. In this case, the use of the IDCS alerted the facility manager to several facts that would increase safety and reduce risks:

- There was low level contamination present in the duct, a fact that was not suspected by the facility manager and could have caused unexpected worker exposure if duct repairs were performed.

- The corrosion in the duct, particularly in weld-affected areas, was more significant than expected. Residue from condensed vapors and apparent cracks in the duct made it clear that the future integrity of the duct was suspect. Timely repairs would prevent possible worker exposure and environmental release of undesirable gases or contamination.

There is no adverse safety impact on the community and no socioeconomic impacts on the community. The purpose of this technology is to aid in the decision process for maintenance, repair, or cleanup. By providing information that was previously unavailable, this technology enhances safety, reduces risks, and has the potential to reduce costs.

SECTION 7

LESSONS LEARNED

Implementation Considerations

There are very few implementation considerations beyond the basics:

- To perform effectively, duct sizes, geometries, contamination levels, general duct routing, and potential obstructions should be known.
- The ability to keep the control station in fairly close proximity to the duct entrance is a key factor in performing longer inspections.
- The IDCS is an expensive system. In general, potential users of the technology have been unwilling to accept liability for the equipment (especially the vehicle) in the event it is contaminated beyond recoverable limits. Reducing the cost of future systems or using the IDCS where only it can perform the task are probably the best options for its use in the future.

Technology Commercialization

This technology is commercially available through the private company that designed and built it for the DOE:

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P.O. Box 99
Cedar, B.C., Canada V0R 1J0
Phone: 360-650-0460 (U.S.)
Email: tknight@island.net
Web site: www.inuktun.com
Contact: Terry Knight, President

Appendix A

ACRONYMS AND ABBREVIATIONS

AWG	American Wire Gage
D&D	Deactivation and Decommissioning
DOE	Department of Energy
ft.	Feet/foot
ICPP	Idaho Chemical Processing Plant
IDCS	Internal Duct Characterization System
in.	Inch
ITSR	Innovative Technology Summary Report
LET&D	Liquid Effluent Treatment and Disposal
Ltd.	Limited
mil	
OST	Office of Science and Technology
RTDP	Robotics and Technology Development Program
S-VHS	Super-VHS
TMS	Tether Management System
TPR	
VME	VersaModule European