INNOVATIVE TECHNOLOGY
Summary Report

DOE/EM-0457

Remote Underwater Characterization System (RUCS)

Deactivation and Decommissioning
Focus Area

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

September 1999

INNOVATIVE TECHNOLOGY
Summary Report

Remote Underwater Characterization System (RUCS)

OST Reference #2151

Deactivation and Decommissioning
Focus Area

Demonstrated at
Idaho National Engineering and Environmental Laboratory
Idaho Falls, Idaho

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 technologies for use in 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). At these LSDDPs 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.

The Idaho National Engineering and Environmental Laboratory (INEEL) LSDDP generated a list of needs statements defining specific needs or problems where improved technology could be incorporated into ongoing D&D tasks. One of the stated needs was the underwater inspection and radiological characterization of surfaces and point sources. Inspection and characterization of water-cooled and moderated nuclear reactors and fuel storage pools requires equipment capable of operating underwater. This equipment is often required to operate at depths exceeding 20 feet and in relatively confined spaces. The typical baseline technologies consist of radiation detectors and underwater cameras mounted on long poles, or stationary cameras with pan and tilt features mounted on the sides of the underwater facility. In some cases the only method of underwater viewing during characterization has been a plexiglass window floating on the surface of the water.

This demonstration investigated the feasibility of using a small, remotely operated submersible vehicle with an integrated radiation detector as an alternative for performing close-up inspection and radiation measurements in confined spaces underwater. Benefits expected from using the underwater vehicle include:

- Reduced cost of operation
- Increased worker safety
- Enhanced capability

This report provides a comparative analysis of the cost and performance of the baseline characterization equipment used for underwater characterization and the Remote Underwater Characterization System (RUCS).

Technology Summary

Baseline Technology

Most DOE facilities with canals or pools have requirements for visual inspection of equipment mounted or stored underwater. When these facilities are prepared for D&D, radiological characterization of items in the pools and canals must be performed to dispose of wastes properly and understand the hazards to personnel. Underwater cameras have been used for many years within the DOE complex. Typically, waterproof inspection cameras have been mounted on long poles or attached to the end of a cable. An operator would stand above the area to be inspected to lower and position the camera manually to get the desired view. More recently, the baseline vision system has become a waterproof camera with zoom capability and underwater lights mounted on a waterproof pan and tilt unit. This vision system is mounted on a long, multi-section pole and can be handled and positioned manually. It can also be fixed or clamped at a central location and then the pan and tilt and zoom capabilities can be operated remotely to provide task surveillance from a single viewpoint.

Figure 1. The baseline camera system

When radiological characterization is performed underwater, it is typically done in much the same manner as the camera deployment, with a radiation detector placed in a waterproof housing and lowered into the water from above. Visual positioning of the radiation detector is accomplished by either looking through the water from above or placing a camera underwater in a suitable location. Often additional lighting must be provided by an underwater light source.

Innovative Technology

The RUCS is a small, remotely operated submersible vehicle intended to serve multiple purposes in underwater D&D operations. It is based on the commercially available “Scallop” vehicle produced by Inuktun Services Ltd., British Columbia Canada, but has been modified by DOE’s Robotics Technology Development Program. These modifications include:

- addition of auto-depth control to hold the vehicle at a selected depth
- integration of a waterproof radiation detector on the vehicle and a radiation display at the control station
- vendor-installed vehicle orientation/heading monitoring via an on-board compass
- vendor-installed vehicle depth monitoring at the operator control panel.

The RUCS is designed to perform visual inspection and gamma radiation characterization, even in confined or limited access areas. It utilizes a forward-looking tilt color camera and a GM tube radiation detector to get “on-the-spot” information needed to perform D&D intelligently and safely.

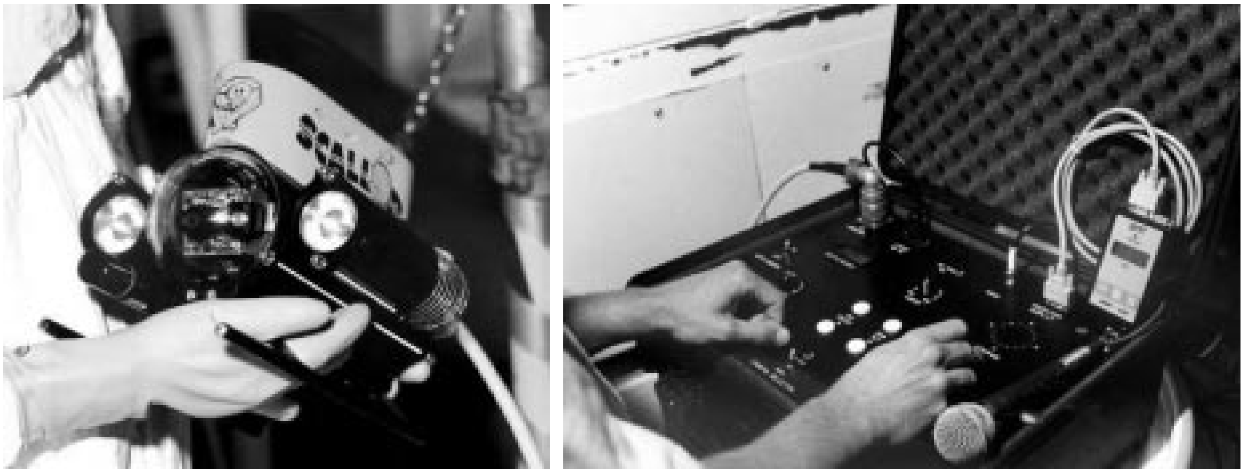

Figure 2. The RUCS vehicle and control station

Demonstration Summary

The baseline technology was demonstrated on August 24, 1998 and the RUCS was demonstrated on August 25, 1998 at the INEEL. The test area for the demonstration was the canal in the Test Reactor Area Building 660 (TRA-660) facility. The canal itself is 8 feet wide, 18 feet deep and 28 feet long. A 4 feet by 8 feet storage pit at the center of the canal extends down an additional 5 feet. The canal can be drained by transferring water to the TRA warm waste treatment system, but has no water cleanup or filtering system. The canal was originally built as a fuel storage canal and now holds two small, de-fueled test reactors. The two reactors are located about 15 feet apart at either end of the common water canal. The two reactors are very similar physically, consisting of a control bridge, lattice support frame, and grid plates. These components are suspended from the canal parapet. The control bridges are made of steel I-beams and plates. The top of the active core is 12 feet below the water surface. In addition to the reactors, there is also a neutron radiography structure in the center of the canal, and various other pieces of hardware and miscellaneous components lying on the floor of the canal or hung from the side. No accurate or comprehensive radiological characterization of the interior of the canal, including the reactors and other hardware, had been performed prior to this demonstration.

The RUCS was evaluated against the baseline technology in the areas of cost effectiveness, enhanced capability, and the ability to provide a safer work environment. Both the baseline technology and the RUCS were used to visually survey the canal and its contents, and also to gather radiological characterization data on the reactors and equipment on the floor of the canal. The activities and areas surveyed were kept as identical as possible to provide valid comparative data. The RUCS proved superior to the baseline technology during the INEEL demonstration, and as a direct result, has since been deployed in various D&D operations.

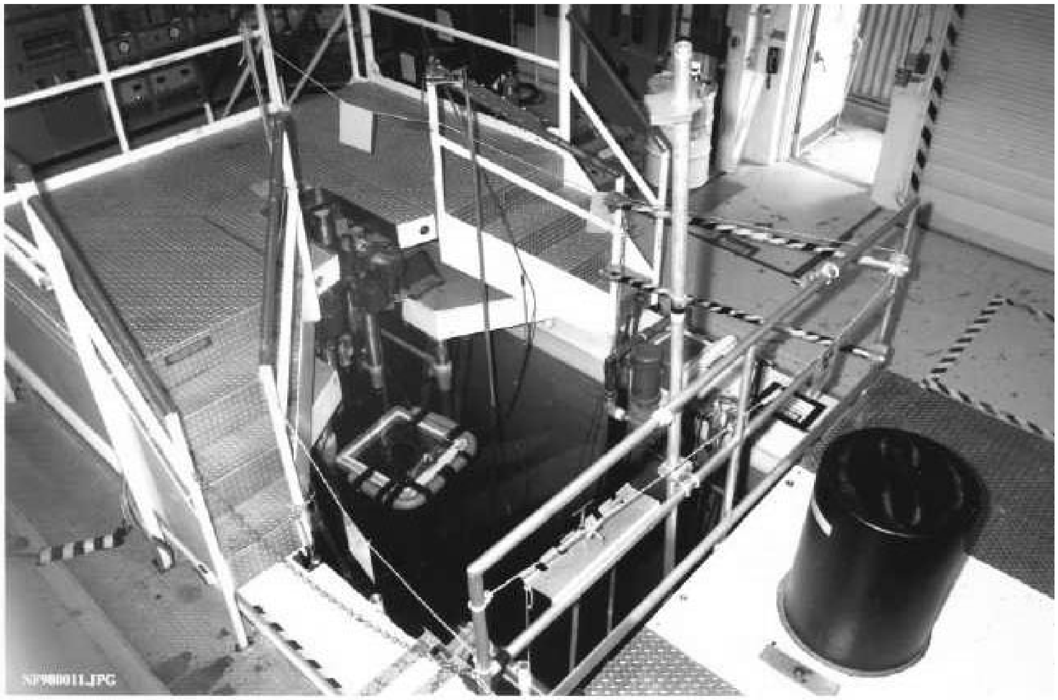

Figure 3. The south end of the TRA-660 canal

Key Results

The key results of the demonstration are summarized below. Detailed descriptions and explanations of these results are in Section 3 of this report.

- The RUCS reduced overall costs by approximately 40% when compared to the baseline technology.
- The RUCS increased worker safety because fewer personnel had to be present in the contamination/canal area.
- The RUCS was able to characterize many areas more effectively than the baseline technology, because of its ability to “fly” directly up to objects and its ability to access some areas inaccessible to the baseline technology.
- The RUCS reduced waste because less personal protective equipment (PPE) was required to perform the work.
- There were instances where the baseline technology could access areas inaccessible to the RUCS.
- The video quality of the baseline technology was slightly better that the RUCS video.

Contacts

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Web Site
The INEEL LSDDP Internet web site address is http:// id.inel.gov/lsddp

Licensing
No licensing activities were required to support this demonstration.

Permitting
No permitting activities were required to support this demonstration.

Other
All published Innovative Technology Summary Reports are available on the OST Web site at http://ost.em.doe.gov under "Publications." The Technology Management System, also available through the OST Web site, provides information about OST programs, technologies, and problems. The OST Reference # for the Remote Underwater Characterization System is 2151.

SECTION 2

TECHNOLOGY DESCRIPTION

Overall Process Definition

Demonstration Goals and Objectives

The overall purpose of this demonstration was to assess the benefits that may be derived from using RUCS in a nuclear facility to perform underwater visual and radiological characterization. The RUCS was compared with the baseline technology, which is use of a pan-and-tilt camera system on a long pole for visual information and a suspended radiation detector for radiological characterization. The primary goal of the demonstration was to collect valid operational data so that a legitimate comparison could be made between the RUCS and the baseline technology in the following areas:

- Cost of performing underwater characterization
- Worker health and safety
- Productivity rates
- Limitations and benefits of both the baseline technology and the innovative technology

A secondary goal of the demonstration was to provide the TRA-660 facility D&D manager with much needed visual and radiological characterization information from the canal. For the demonstration to be useful to the facility manager it was important to fully characterize the physical and radiological condition of the canal contents. To achieve this goal, both technologies were used to accomplish the following:

- Visually inspect the interior of the canal and locate all major objects within the canal
- Gather gamma radiation characterization information from predetermined areas within the canal and from any areas requested by the facility manager

Description of the Technology

The RUCS is a small, remotely operated submersible vehicle intended to serve multiple purposes in underwater D&D operations. It is based on the commercially available “Scallop” vehicle produced by Inuktun Services Ltd., British Columbia Canada, but has been modified by DOE’s Robotics Technology Development Program. These modifications include:

- addition of auto-depth control to hold the vehicle at a selected depth
- integration of a waterproof radiation detector on the vehicle and a radiation display at the control station
- vendor-installed vehicle orientation/heading monitoring via an on-board compass
- vendor-installed vehicle depth monitoring at the operator control panel.

The RUCS is designed to perform visual inspection and gamma radiation characterization, even in confined or limited access areas. It utilizes a forward-looking tilt color camera and a GM tube radiation detector to get “on-the-spot” information needed to perform D&D intelligently and safely.

Two integral sub-systems comprise the remotely operated underwater characterization system; the remotely operated underwater vehicle and the operator control station. A 125’ neutral buoyancy tether connects the two sub-systems. The underwater vehicle measures 12” X 9” X 6” and is rated to 100 feet of depth. Left and right variable speed horizontal thrusters, which are reversible, are used to turn the vehicle and drive it forward and backward. A single, variable speed vertical thruster is used to drive the vehicle to a desired depth, while slightly positive vehicle buoyancy is used to bring it back to the surface. A depth sensor provides depth information back to the operator control station, and an on-board compass sends heading information back to the operator control station as long as there are not significant amounts of carbon steel present to interfere with the magnetic readings. The vehicle has a forward-looking color camera with tilt capability, a fixed rear-looking black and white camera, and two variable intensity halogen lights for underwater illumination.

The operator control station consists of a single case which is the size of a standard suitcase. All vehicle controls are operable from the control station. A proportional joystick is used to “fly” the vehicle in the horizontal plane, and a rotary knob is used to adjust vertical thruster speed and thereby adjust vehicle depth. Another rotary knob is used to control light output, and there are controls to tilt and focus the forward-looking color camera. The “auto-depth” feature acts much like a cruise control to allow the operator to hold the vehicle at a selected depth. A relatively simple circular array of light-emitting diodes indicates the vehicle’s heading. A small digital display shows the measured radiation reading (5 mR/hr up to 999 R/hr) from the radiation sensor. A coax video plug allows the operator to display and/or record the video signal from the vehicle cameras and a switch on the console allows switching between the front and rear cameras.

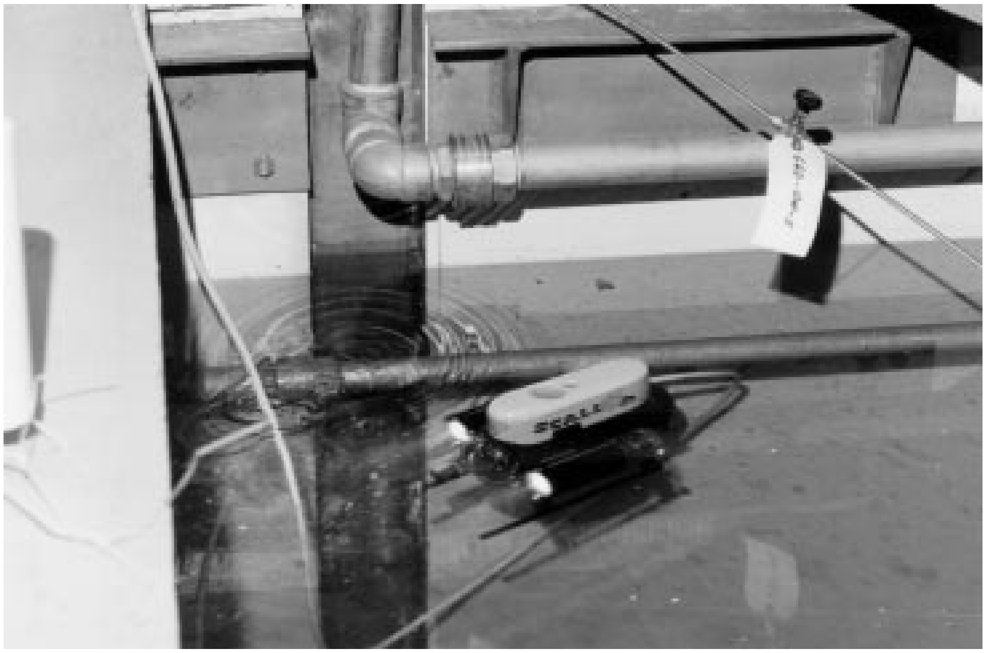

Figure 4. The RUCS vehicle in the TRA-660 canal

System Operation

Table 1 summarizes the operational parameters and conditions of the RUCS demonstration.

Table 1: Operational parameters and conditions of the RUCS demonstration

Working Conditions	
Work area location	Inside building TRA-660 of the Test Reactor Area at the INEEL
Work area access	Through a standard door (a 10 foot wide roll-up door was not used)
Work area description	Canal cordoned off by poles and railings and marked as a radiological contamination area. Open concrete floor area approximately 8 feet wide around entire perimeter of canal.
Work area hazards	Possible loose, low-level radioactive contamination Drowning hazard if personnel fall into canal Tripping hazards due to cords
Equipment configuration	The baseline vision system was already in the facility. The RUCS and the baseline radiation detector were transported directly to the facility just prior to the demonstration.
Labor, Support Personnel, Specialized Skills, Training	
Work crew	Two person work crew • 1 RUCS vehicle operator • 1 worker in canal area to manage tether and handle vehicle during insertion and removal

Labor, Support Personnel, Specialized Skills, Training (cont'd)	
Additional support personnel	• 1 data taker • 1 radiation technician • 1 health and safety observer (periodic) • 1 test engineer
Specialized skills/training	No specialized training was provided, but personnel familiarity with equipment set-up and operation was helpful.
Waste Management	
Primary waste generated	No primary wastes were generated
Secondary waste generated	Disposable PPE Paper towels used to wipe down equipment after use
Waste containment and disposal	All secondary wastes were collected and packaged for disposal by a radiation technician
Equipment Specifications and Operational Parameters	
Technology design purpose	Underwater visual inspection and radiological characterization
Specifications	Depth rating - 0 to 100ft Speed - up to 2 knots Dimensions - Length: 13.75 in - Width: 8.75 in - Height: 8.5 in Weight - 8 lb Tether length - 125 ft (neutral buoyant) Operating temp - 32 to 122 F Operating Voltage - 120 VAC supply voltage
Portability	The entire system is contained in two Pelican cases and is easily transported by one person to project sites.
Materials Used	
Work area preparation	The canal area was marked as a contamination area and several rails were erected to prevent personnel from falling into canal accidentally while moving in canal area
Personal protective equipment	Cotton scrubs Tyvek™ outer coveralls Tyvek™ hood Cotton glove liners 2 pair rubber gloves Rubber boots
Utilities/Energy Requirements	
Power	120 VAC power, GFCI protected

SECTION 3

PERFORMANCE

Problem Addressed

Most DOE facilities with canals or pools have requirements for visual inspection of equipment and materials mounted or stored underwater. When these facilities are prepared for D&D, radiological characterization of items in the pools and canals must be performed to dispose of wastes properly and understand the hazards to personnel. Underwater cameras have been used for many years within the DOE complex. Typically, waterproof inspection cameras have been mounted on long poles or attached to the end of a cable. An operator would stand above the area to be inspected, typically along side a pool of water or on a bridge spanning the pool. From this position, the operator would lower and position the camera manually to get the desired view. More recently, the baseline vision system within DOE has become a waterproof camera with zoom capability and underwater lights mounted to a waterproof pan and tilt unit. This vision system is mounted on a long, multi-section pole and can be handled and positioned manually. It can also be fixed or clamped at a central location and then the pan and tilt and zoom capabilities can be operated remotely to provide task surveillance from a single viewpoint. The purpose of this demonstration is to use the RUCS in a nuclear facility to test its ability to perform visual and radiological characterization. The RUCS will be compared with the performance of the baseline technology, which is use of a pan-and-tilt camera system on a long pole for visual information and use of a radiation detector suspended from a cable for radiological characterization.

Demonstration Plan

Demonstration site description

The INEEL's Test Reactor Area TRA-660 canal was originally built as a fuel storage canal and now houses two underwater research reactors; the Advanced Reactor Measurement Facility (ARMF) and the Coupled Fast Reactivity Measurement Facility (CFRMF). The canal itself is 8 feet wide, 18 feet deep and 28 feet long. A 4 foot by 8 foot storage pit at the center of the canal extends down an additional 5 feet. The canal can be drained by transferring water to the TRA warm waste treatment system, but has no water cleanup or filtering system.

Figure 4. The TRA-660 Facility

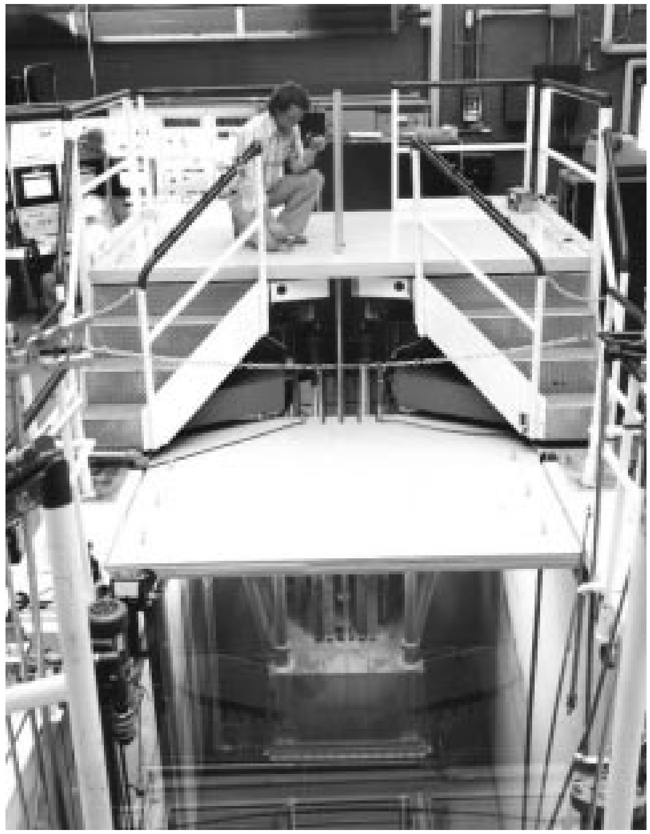

Figure 5. The CFRMF Reactor in Operation

These ARMF and CFRMF reactors were used originally for reactivity insertion experiments. The two reactors achieved criticality in 1960 and 1962, and neither of these reactors has operated since February 1991. The reactors have been de-fueled and the facility is currently owned by DOE EM40. The two reactors are located about 15 feet apart at either end of the common water canal. The two reactors are very similar physically, consisting of a control bridge, lattice support frame, and grid plates. These components are suspended from the canal parapet. The control bridges are made of steel I-beams and plates. The top of the active core is 12 feet below the water surface. In addition to the reactors, there is also a neutron radiography structure in the center of the canal, and various and sundry other pieces of hardware and miscellaneous components lying on the floor of the canal or hung from the side. No accurate or comprehensive radiological characterization of the interior of the canal, including the reactors and other hardware, has been performed to this point.

Major objectives of the demonstration

The major objectives were to evaluate the RUCS against the baseline technology in several areas including:

- Cost effectiveness
- Ability to provide a safer work environment
- Enhanced capability
- Limitations

Major elements of the demonstration

Both the baseline technology and the RUCS were used to perform a "typical" characterization of the canal. The intent of the characterization was to gather information the owner of the facility needed to make intelligent decisions regarding D&D activities such as packaging, segregating, and priority of removal. This demonstration included visual characterization of the condition and contents of the canal as well as radiological characterization of items suspected to be radioactively activated. The common elements of demonstration included:

- Visual characterization of CFRMF reactor condition

- Visual characterization of the north end of the canal, particularly the floor
- Radiological characterization of the accessible areas of the CFRMF reactor
- Radiological characterization of the items on the floor of the north end of the canal including upper grid plate assemblies
- Visual characterization of ARMF reactor condition
- Visual characterization of the south end of the canal, particularly the floor
- Radiological characterization of the accessible areas of the ARMF reactor
- Radiological characterization of the items on the floor of the north end of the canal including upper grid plate assemblies, stainless steel bucket, rusted bucket, fuel storage grid

In addition, the following elements were performed during the course of the demonstration:

- Determine if the baseline technology had the ability to access areas and gather information that the RUCS could not.
- Determine if the RUCS has the ability to access areas and gather information that the baseline technology could not.
- Identify limitations and benefits of both the baseline technology and the innovative technology

Results

Both characterization technologies were evaluated under identical physical conditions. Every attempt was made to allow work to proceed under normal conditions with no bias. All parties involved in the demonstration were requested to perform the work normally with no special emphasis on speed or efficiency. The baseline technology was demonstrated on August 24, 1998 and the RUCS was evaluated on August 25, 1998. The tasks performed were basically identical, but not all the objects and locations characterized were completely identical. In addition to the similar tasks, the RUCS was used to characterize several areas inaccessible to the baseline technology, and the baseline technology was used to take radiation readings in some locations inaccessible to the RUCS radiation detector. A performance comparison between the two technologies is listed in Table 2.

Table 2: Performance comparison between the RUCS and the baseline technology

Performance Factor	Baseline Technology	Remote Underwater Characterization System
Number of personnel required in canal contamination area	2 to 3 people (2 workers to manage and move camera, 1 RCT to operate RO7 detector. RCT could replace 1 worker)	1 person (1 worker to manage tether and put RUCS vehicle in and out of canal)
Number of personnel required outside contamination area	2 people (1 worker to operate camera controls, 1 RCT to monitor radiation readings and survey equipment out of contamination area)	2 people (1 worker to operate RUCS, 1 RCT to survey equipment out of contamination area)
Time to assemble and deploy technology	Approx. 10 min.	Approx. 5 min.
Quality of video	Excellent (S-VHS, >460 Lines)	Very Good (NTSC, 480 lines)
Number of radiation readings per hour (avg.)	22.6 (Could be slightly lower, survey points were fairly close together)	21.6 (Could be slightly higher, survey points were moderately separated)
Resolution of radiation readings	100 mR/hr to 200 R/hr (Range depends on sensor head used. Three different sensor heads are available.)	5 mR/hr to 1000 R/hr

Table 2 (cont'd)

Performance Factor	Baseline Technology	Remote Underwater Characterization System
PPE requirements	Both technologies required the same level of PPE. Total PPE used with the RUCS was lower because of fewer workers needed in the contamination area.	
Superior capability	• The baseline radiation detector could be lowered into vertical spaces, such as the holes where the fuel had been. This provided better radiation data than the RUCS could provide.	• The RUCS was more maneuverable than the baseline technology and could get into areas inaccessible to the baseline. These areas included the 1 ft wide space behind the reactors, and the deeper section of the canal beneath overhead structure. • The RUCS radiation detector could be driven right up next to objects, even if overhead obstructions were present. One example was a bucket with a large block on top of it. The RUCS provided better radiation data than the baseline could provide. • The RUCS was generally easier to use, particularly when trying to get information from areas separated by bridge across the center of the canal. Assembly and disassembly was also simpler.

Figure 6. The RUCS vehicle characterizing a control rod

SECTION 4

TECHNOLOGY APPLICABILITY AND ALTERNATIVES

Competing Technologies

Baseline technology

The baseline vision technology with which the RUCS competes is a waterproof camera with zoom capability and underwater lights mounted on a waterproof pan and tilt unit. This vision system is mounted on a long, multi-section pole and can be handled and positioned manually. It can also be fixed or clamped at a central location and then the pan and tilt and zoom capabilities can be operated remotely to provide task surveillance from a single viewpoint. When radiological characterization is performed underwater, it is typically done in much the same manner as the camera deployment, with a radiation detector placed in a waterproof housing and lowered into the water from above. Visual positioning of the radiation detector is accomplished by either looking through the water from above or using the baseline vision technology underwater in a suitable location. Often additional lighting must be provided by an underwater light source.

Other competing technologies

The only meaningful competing technology found was a more expensive underwater vehicle system. A market survey indicated that the RUCS costs about one-half that of its nearest known competitor and is equally capable.

Technology Applicability

The RUCS is a fully developed technology that is now commercially available for underwater inspection and radiological characterization. It performs typical characterization to gather information required for the facility owner to make intelligent decisions regarding D&D operations. The RUCS was used to characterize several areas inaccessible to baseline technology. Its superior performance over the baseline in almost all areas makes it a prime technology for deployment throughout the DOE complex. It has the potential to reduce labor costs and increase worker safety in any facility with nuclear pools and canals.

Patents/Commercialization/Sponsor

The original Scallop system, and now the more capable RUCS, are commercially available from Inuktun Services, Ltd. of British Columbia, Canada. The enhancements to the original Scallop system were funded by DOE's EM-50 through the Office of Science and Technology, specifically through the Robotics Technology Development Program.

SECTION 5

COST

Introduction

This section compares the underwater characterization costs for using the innovative technology with the cost of the baseline characterization method. When all factors are carefully considered, the cost to use the innovative technology is approximately 60% of the cost to use the baseline technology for similar tasks under similar conditions. This cost analysis is based on observing two separate half-days characterization work that consisted of performing visual inspections and performing underwater radiological characterization, including identifying hot spots and general distribution of activation.

Methodology

The costs for the innovative and baseline technologies are derived from several sources. These sources include detailed time logs taken throughout the duration of the work activities, observations from videotape footage taken during the demonstration, and published vendor prices. The amount of radiological characterization work performed with the innovative technology varied from the baseline's amount (nine locations surveyed using the innovative and 26 using the baseline). This cost analysis assumes 26 survey locations for both the innovative and the baseline technologies and uses the average production rate observed during the demonstration to compute a duration for surveying 26 locations. The number of persons present during the demonstration work varied from seven to 10 persons, but not all were actively involved in the actual work. This cost analysis assumes one radiological control technician (RCT) and one technology operator for the innovative technology, based on the judgement of the test engineer. The estimate for the baseline technology assumes two RCTs (with one RCT assisting the technology operator periodically) and one technology operator. Other sites may require two technology operators for the baseline technology rather than one, depending upon the union work agreements and the nature of the work. The labor rates for the crew are based on standard rates for the INEEL site. The equipment rates are based on the amortized purchase price and maintenance costs.

This cost analysis includes work delays and inefficiencies that are typical for the work conditions and activities associated with this demonstration. The accumulated delays and inefficiencies are captured under the heading “productivity loss”, and are the largest factor in the cost analysis. It is important to note that nearly all of the contributors to “productivity loss” are a normal part of doing work, and do not indicate inherent deficiencies with either technology. For example, moving the camera monitors, repositioning cables, and time for entry and exit from the control area for breaks are some specific work delays and inefficiencies observed for this demonstration. Additional details of the basis of the cost analysis are described in Appendix C.

Cost Data

Costs to Purchase, Rent, or Procure Vendor-Provided Services

The innovative technology is available from the vendor with optional components. The purchases prices of the basic equipment and optional features used in the demonstration are shown in Table 1. Rental of the equipment is limited to the basic ISL Scallop system, which does not have a radiation detector. The vendor does not perform underwater characterization work as a vendor-provided service.

Table 1. Improved technology acquisition costs

Acquisition Option	Item Description	Cost
Equipment Purchase	ISL Scallop ROV (camera, tether, power, and lights) Compass Depth sensor & LED Readout AMP-100 Rad Detector	$14,995 $1,995 $1,995 $2,595
Equipment Rental	ISL Scallop ROV (per day with 2 day minimum)	$150
Vendor Provided Service		Not Available

Unit Costs

Figure 1 and 2 shows the unit costs ($/job) for the innovative and baseline technologies. The unit costs are based on the detailed costs in Tables C-2 and C-3 and include amortization of the equipment purchase and productivity loss. Figures 1 and 2 also show a relative percentage for each of the work activities observed during the demonstration. This percentage represents each activity's cost relative to the total unit cost of the job. Additionally, the site-specific conditions that can significantly affect the cost of the activity are identified on each figure under the title "Site-Specific Conditions". This section describes the conditions encountered for this demonstration. The percentage information and the condition information provide some indication of the variation in unit cost that may occur at other sites. The activities that are 1% to 5% of the total cost have little affect on the total cost, even if these activities have the potential for large variation. For example, if the decontamination costs double, there is little impact to the total cost. On the other hand, a moderate variation in cost of those activities that are 15% or more of the total unit cost will have a significant impact on the total. For example, a change in productivity loss from 2.58 hours per day per person to 3.5 (perhaps due to different radiological conditions of the work area) results in an increase in the total of approximately 15% for the baseline technology.

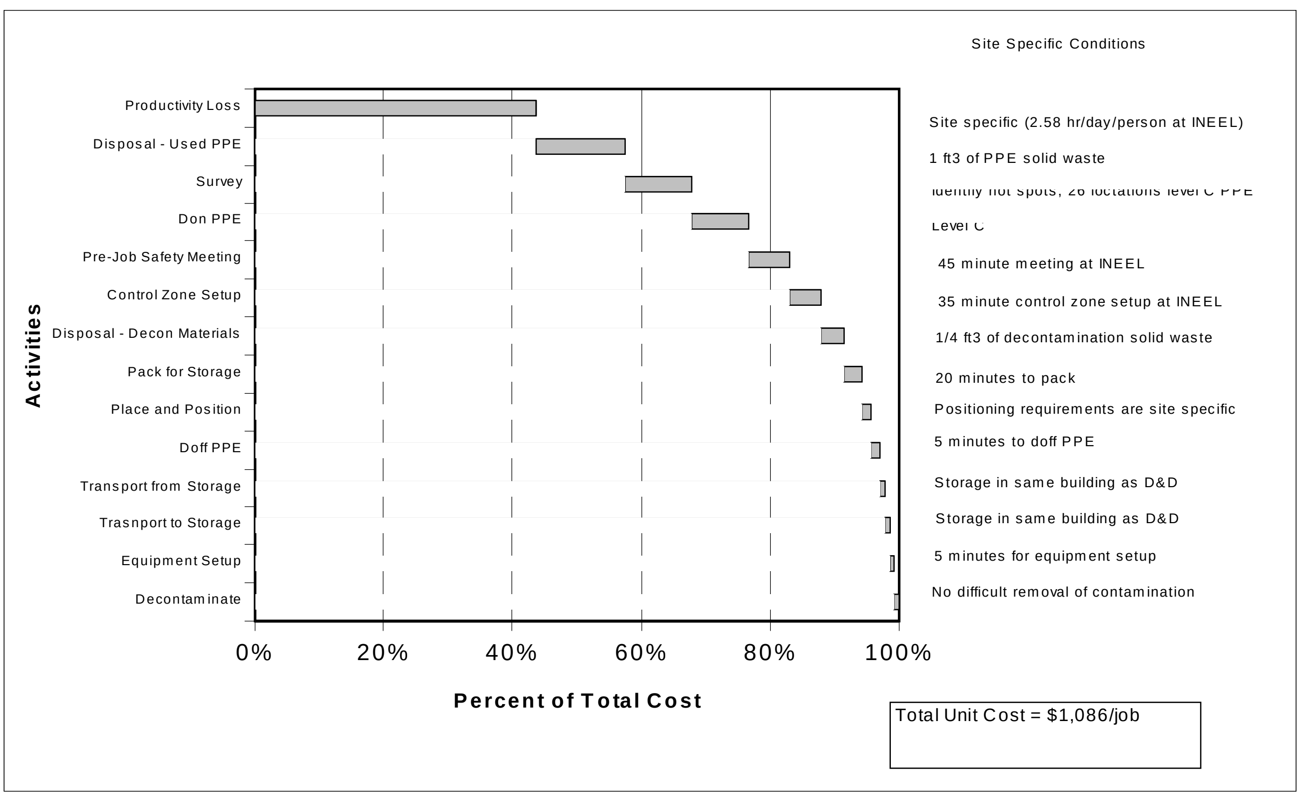

Figure 1. Breakdown of innovative technology unit cost.

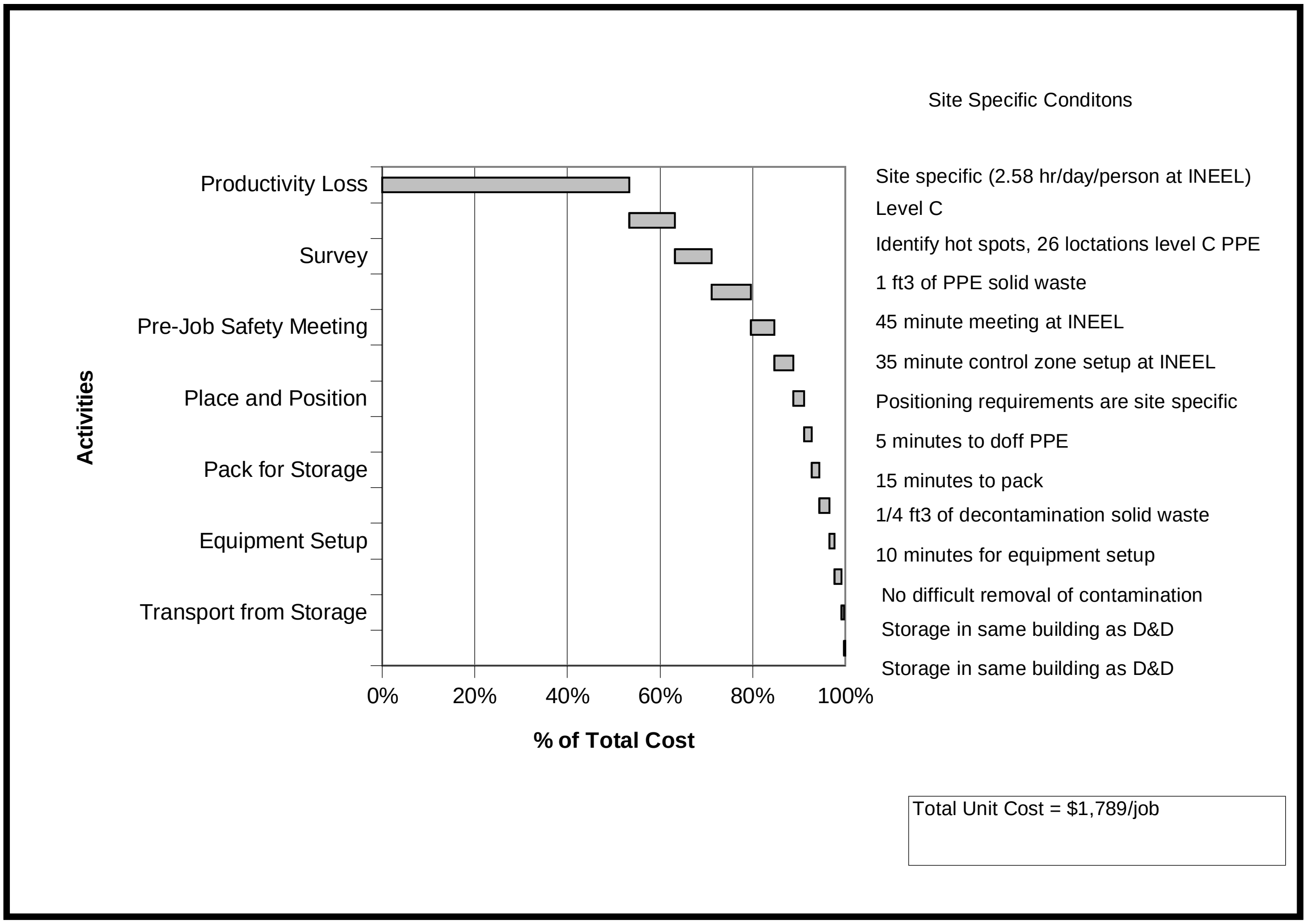

Figure 2. Breakdown of baseline technology unit cost.

Payback Period

For this demonstration, the innovative technology saves approximately $703 per job over the baseline for a job size of 26 survey locations. At this rate of savings, the purchase price of $21,580 would be recovered by performing approximately 30 similar jobs using the innovative technology.

Observed Costs for Demonstration

Figure 3 summarizes the costs observed for the innovative and baseline technology for surveying 26 locations. The details of these costs are shown in Appendix C, and includes Tables C-2 and C-3, which can be used to compute site specific costs by adjusting for different labor rates, crew makeup, etc.,

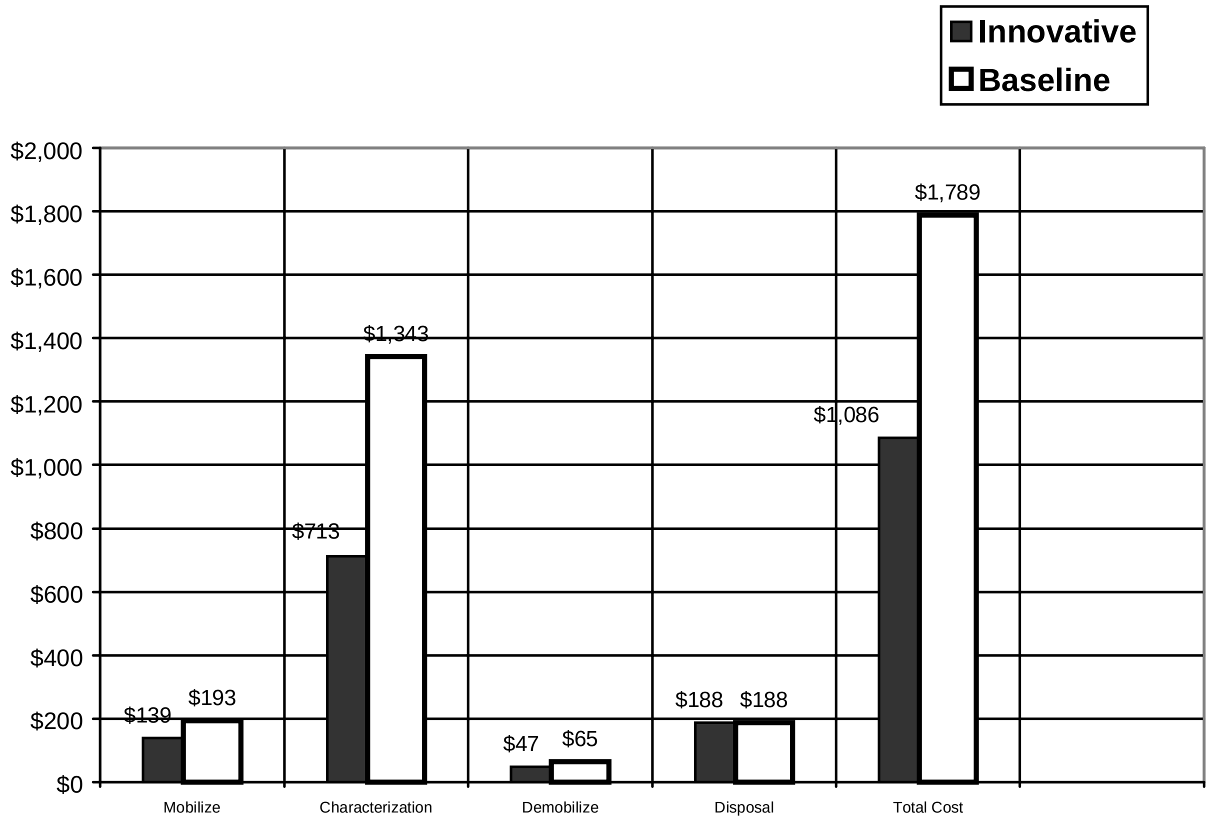

Figure 3. Summary of technology costs.

Cost Conclusions

The cost to use the innovative technology was approximately 60% of the cost of using the baseline technology for this demonstration. The bulk of the savings resulted from having one less radiological control technician for the work crew. The crew configurations at other sites may be different from the crew assumed in this cost analysis due to differences in the nature of the work and union requirements. In some cases, we expect the innovative technology will actually be more cost effective than indicated by this demonstration. This cost analysis assumed only one technology operator on the baseline crew. Two technology operators may be required to operate the baseline technology for circumstances where the radiological control technician can not assist with moving and mounting the baseline camera. Remote inspection personnel typically perform this type of work at INEEL, but may not be representative of the type of labor used at other DOE sites. Work crew configurations at other sites may also be different from the crew configurations used in this cost analysis due to differences in the nature of the work and union requirements.

The production rates for the innovative and the baseline technologies are approximately equal and the actual time spent taking radiological survey data during this demonstration is a small percentage of the overall work. Despite the survey task's minor role in the total costs, the elimination of the additional crew member produces savings for most of the tasks which make up the work (including the safety meetings, donning and doffing the personal protective equipment, etc.,). The observed times for positioning the innovative and the baseline equipment will depend on the site specific conditions. In this demonstration, the equipment was moved a few feet to the waters edge, placed into the water, and then moved a short distance to the first survey location. Other characterization jobs will have different distances to move the equipment, and may have obstacles to maneuver around, but the positioning is anticipated to be a relatively small part of the overall job. Any variation for site-specific conditions should not have a significant impact on the overall cost.

The observed times for the survey will depend on the site-specific conditions. In this cost analysis, the survey time includes the count time and the time required to move to the next survey location. For this demonstration, the distance between survey locations varied. In some cases several feet separated the locations, and in other cases there were survey locations within inches of each other. The duration used in this analysis is an average of the observed durations. Other characterization jobs will have different surface geometries and different distances between survey points. The costs of the survey will increase as the distance increases between the locations, and where longer count times are required.

The innovative and baseline technologies do not differ in their impact to worker heat stress, fatigue, and stay-time. The productivity loss for the innovative technology differs from the baseline because the loss is applied for one worker rather than for two workers.

Mobilization and demobilization costs will depend upon the distance that the equipment must be moved between the storage area and the work area. In this cost analysis, both the innovative technology equipment and the baseline technology equipment were assumed to be stored in the same building as the work area.

Decontamination materials and personal protective equipment (PPE) materials were the principal waste materials generated in the course of the characterization work. There was no substantial difference between the innovative technology and the baseline technology in the amount of water generated, but in most cases the innovative technology should generate less PPE waste because at least one less worker is needed in typically contaminated areas.

SECTION 6

REGULATORY AND POLICY ISSUES

Regulatory Considerations

There are no known regulations associated with the use of the RUCS. Its use under the INEEL LSDDP was covered by a test plan, a radiological work permit, and a safe work permit. It is not known whether data gathered from RUCS is suitable for regulatory purposes. The data is taken with a calibrated detector, but given that the data is taken underwater and remotely, it may or may not be acceptable to regulators.

Safety, Risks, Benefits, and Community Reaction

The RUCS is as safe to use as the baseline system, and requires fewer personnel present in the direct proximity of the water. This reduces the potential for personnel drowning or becoming radioactively contaminated. The only risk associated with both the baseline technology and RUCS is the potential for electrical shock. This risk is mitigated by design features such as:

- low DC voltages
- low currents
- an isolated transformer
- the use of a GFCI power source

SECTION 7

LESSONS LEARNED

Implementation Considerations

The RUCS is a mature technology that performed very well during the INEEL demonstration, and as a direct result, has since been deployed in various D&D operations. There are some very minor improvements that could be made to enhance its operation and effectiveness. These minor improvements are listed in the Technology Limitations portion of this section.

The RUCS does require some small measure of skill to operate. Most of the controls are quite intuitive, but it is recommended that operators have 1 to 2 hours of operating time before operating the RUCS in very confined or congested areas. It is not absolutely necessary to have a person managing the RUCS tether during its operation, but it was helpful during this demonstration and is highly recommended.

Technology Limitations and Needs for Future Development

The RUCS performed well during this demonstration. The only significant technology limitation was the inability of the system to gather radiological characterization data from inside vertical pipes and tubes. This is due to the fixed horizontal orientation of RUCS radiation detector and the overall size of the vehicle. It is doubtful that this limitation could be addressed easily.

There is a need for some minor development work in the following areas:

- The vehicle would maneuver even better if the tether was neutrally buoyant in fresh water. The tether on the RUCS as demonstrated was neutrally buoyant in salt water, which meant it sank slightly in fresh water. This was not a significant limitation in the demonstration, but it did have a slight effect on maneuverability and would have had a more negative effect if the vehicle were operating with 50 feet or more of tether in the water. Inuktun now says it can provide a tether that is very nearly neutrally buoyant in fresh water.
- It was noticed that the radiation sensor was pushed back approximately one inch during the course of the demonstration. It is mounted in a pair of friction clips and apparently was moved when the vehicle contacted items while taking radiation readings. This is not serious, but the radiation sensor should be secured to prevent horizontal motion
- It would be advisable to develop a way to display radiation readings on the video picture so that they could be recorded with the video picture. During the demonstration a microphone was hooked to the video recorder and radiation readings were put on the tape audibly.

Technology Selection Considerations

Based on the INEEL demonstration, the RUCS is better suited than the baseline technology for most underwater viewing and characterization activities. It is easier to deploy, requires fewer workers to operate, has better maneuverability, and is less expensive to operate on a per job basis. There are a couple instances where the baseline technology would be preferable:

- The baseline radiation detector is the best choice if radiological characterization information is needed from inside a vertical tube or an array of vertical tubes.
- The baseline vision system supplied a slightly higher quality video picture, which could conceivably be important in some instances.
- The baseline vision system might be more desirable if there are large amounts of fine sediment present. The TRA-660 canal had approximately 1/4 - 1/2 inch of sludge on the bottom, but it rarely affected visibility significantly, even when the RUCS vehicle was operated right on the floor.

There are instances where it would be desirable to use both technologies in a complementary fashion. One instance would be where it is desirable to use the mobility of the RUCS in a relatively small pool (less than 30 feet square), but physical or radiological conditions above the pool make it undesirable to have a person managing the tether and providing a visual overview of activity. The baseline camera could be mounted in an appropriate overview position and be used to monitor and assist the use of the RUCS, thus preventing risk and reducing unnecessary radiation or contamination exposure.

APPENDIX A

REFERENCES

Jones, R.W. and Draper, C.L., January 1998, Idaho National Engineering and Environmental Laboratory Document INEEL/EXT-97-01315, Rev. 1, *Field Sampling Plan for the Decontamination and Dismantlement of TRA-660*

Willis, W. D., August 1998, *Test Plan for the Demonstration of the Remotely Operated Underwater D&D System at TRA-660*, Final - 8/19/98

Willis, W. D., January 1999, *Detailed Technology Report on RUCS Demonstration at INEEL LSDDP*

APPENDIX B

COST COMPARISON DETAILS

Basis of Estimated Cost

The activity titles shown in this cost analysis come from observation of the work. In the estimate, the activities are grouped under higher level work titles per the work breakdown structure shown in the ***Hazardous, Toxic, Radioactive Waste Remedial Action Work Breakdown Structure and Data Dictionary*** (HTRW RA WBS) (USACE 1996). The HTRW RA WBS, developed by an interagency group, is used in this analysis to provide consistency with the established national standards.

The costs shown in this analysis are computed from observed duration and hourly rates for the crew and equipment. The following assumptions were used in computing the hourly rates:

- The innovative and the baseline equipment are assumed to be owned by the Government.
- The equipment rates for Government ownership are computed by amortizing the purchase price of the equipment, plus a procurement cost of 5.2% of the purchase price, and the annual calibration costs.
- The equipment hourly rates assume a service life of 5 years for the innovative technology equipment and the baseline's camera. A 10 year service life is assumed for the baseline's RO-7. An annual usage of 500 hours per year is assumed for both the innovative and baseline equipment.
- The equipment hourly rates for the Government's ownership are based on general guidance contained in Office of Management and Budget (OMB) Circular No. A-94, ***Cost Effectiveness Analysis***.
- The standard labor rates established by the INEEL are used in this estimate and include salary, fringe, departmental overhead, material handling markups, and facility service center markups.
- The equipment rates and the labor rates do not include the Lockheed Martin general and administrative (G&A) markups. The G&A are omitted from this analysis to facilitate understanding and comparison with costs for the individual site. The G&A rates for each DOE site vary in magnitude and in the way they are applied. Decision makers seeking site-specific costs can apply their site's rates to this analysis without having to first back-out the rates used at the INEEL.

The analysis does not include costs for oversight engineering, quality assurance, administrative costs for the demonstration, or work plan preparation costs.

The analysis assumes a 10 hour work day.

Activity Descriptions

The scope, computation of production rates, and assumptions (if any) for each work activity is described in this section.

Mobilization (WBS 331.01)

Transport from Storage: The baseline equipment was stored in the same building as the demonstration work. The time required to transport the equipment to the work area is based on the judgement of the test engineer. The transport for the innovative equipment is assumed to be the same as for the baseline. The baseline equipment includes a 24 in rack, a crate, and a cylinder for the extension rods. The innovative equipment includes 2 pelican cases that are approximately 2 ft X 1.5 ft X 1 ft and 3 ft X 2 ft X 1 ft in dimension.

Pre-Job Safety Meeting: The duration for the pre-job safety meeting is based upon the observed time for the demonstration. The labor costs for this activity are based upon an assumed crew (rather than the actual demonstration participants, and all subsequent activities are based on the assumed crews).

Control Zone Setup: This activity consists of establishing a control zone adjacent to the water. The duration is based upon the observed time for the demonstration.

Equipment Setup: This activity consists of unpacking the equipment, assembling the components, and attaching the cables and/or tether. The duration is based on the observed time for the demonstration.

Characterization (WBS 331.17)

Don Personal Protective Equipment (PPE): This activity includes the labor and material cost for donning the articles of clothing listed in Table C-1. The duration of the donning and the number of donning events are based on observations of the demonstration. The material costs for PPE for each day of use is summarized in Table C-1.

Table C-1. Cost for PPE (per man/day)

Equipment	**Cost Each**	**Number of Times Used Before Discarded**	**Cost Each Time Used ($)**	**No. Used Per Day**	**Cost Per Day ($)**
Rubber overboots (pvc yellow 1/16 in thick)	$12.15	30	$0.41	1	$0.41
Glove liners pr. (cotton	$0.40	1	$0.40	2	$0.80
inner)	$1.20	1	$1.20	2	$2.40
Rubber Gloves pr. (outer)	$6.47	1	$6.47	1	$6.47
Hoods (yellow)	$3.30	1	$3.30	1	$3.30
Coveralls (white Tyvek)	$4.63	1	$4.63	1	$4.63
Coveralls (green scrubs)					
				TOTAL COST/DAY/PERSON	**18.01**

Place and Position: This activity includes placing the equipment into the water and positioning it so that it is ready to begin the survey work. The duration are based on the observed times for the innovative and baseline demonstrations.

Survey: This activity includes counting at individual locations and the time required to move from one location to the next. The innovative surveyed 9 locations and the baseline surveyed 26 locations. An average production rate was computed from the times observed in the demonstration and is used in the cost analysis to estimate the cost for survey of 26 locations. The average production rate for the innovative technology is 21.6 locations per hour and 22.6 locations per hour for the baseline. The slight difference in production rates may not reflect inherent differences in the technology, but may be the result of differences in distance from one location to the next (the baseline had many survey locations which were adjacent to each other while the innovative locations were all separated by a distance of several feet).

Productivity Loss: The cost analysis includes work delays and inefficiencies that are typical for the work condition of this demonstration. Moving the camera monitors, repositioning cables, entry and exit from the control area for breaks, etc. are specific examples of work delays and inefficiencies observed for this demonstration. These costs are identified in this cost analysis as productivity loss and consist of the accumulated duration of the delays and inefficiencies observed during the demonstration The innovative and baseline technologies do not differ in their impact to worker heat stress, fatigue, and stay-time. The duration is based upon the time observed for the baseline and the innovative is assumed to be the same. The non-productive time for the innovative was not considered valid for use in the cost analysis due to the brief nature of that demonstration.

Doff PPE: This activity accounts for the labor costs for doffing PPE and is based on the duration observed in the demonstration.

Demobilization (WBS 331.21)

Decontamination: This activity includes using paper towels (6 for the baseline and 4 for the innovative) to wipe the surface of the equipment and survey the equipment for exit from the control zone. The duration used in the estimate is based on the demonstration.

Pack for Storage: This activity includes breaking down the equipment and stowing it in the equipment cases. The duration is based on the test engineer's judgement.

Transport for Storage: Similar to Transport from Storage.

Disposal (WBS 331.18)

Used PPE Disposal: This activity includes the disposal fee for disposal of low level radioactive solid waste at the cost of $\$150/ft^3$. The quantity is estimated based on the description of the PPE.

Decon Materials Disposal: This activity includes the disposal fee for disposal of low level radioactive solid waste at the cost of $\$150/ft^3$. The quantity is estimated based on the description of the decontamination materials.

Cost Estimate Details

The cost analysis details are summarized in Tables C-2 and C-3. The tables breaks out each member of the crew, each labor rate, each piece of equipment used, each equipment rate, each activity duration, and all production rates so that site specific differences in these items can be identified and a site specific cost estimate may be developed.

Table C-2. Innovative Technology Cost Summary

Work Breakdown Structure	Unit	Unit Cost $/unit	Quan-tity	Total Cost	Computation of Unit Cost: Pro-duction Rate	Duration (hr)	Labor Item	$/hr	Equipment Items	$/hr	Other $	Comments
Facility Deactivation, Decommissioning, & Dismantlement									**TOTAL COST FOR DEMONSTRATION =**			**$ 1,086.25**
Mobilization (WBS 331.01)										Subtotal =		$ 138.67
Transport from Storage	ls	8.35	1	$ 8.35		0.083	2RW	87.92	ROV on standby	12.26		
Pre-Job Safety Meeting	ea	68.99	1	$ 68.99		0.750	RW + RCT	79.73	Same	12.26		
Control Zone Setup	ls	53.66	1	$ 53.66		0.583	Same	79.73	Same	12.26		
Equipment Setup	ls	7.67	1	$ 7.67		0.083	Same	79.73	Same	12.26		
Characterization (WBS 331.17)										Subtotal =		$ 713.41
Don PPE	man day	48.67	2	$ 97.35		0.333	RW + RCT	79.73	ROV on standby	12.26	18.01	$18.01/day for each PPE
Place and Position	ea	15.33	1	$ 15.33		0.167	Same	79.73	ROV	12.26		
Survey	loc	4.26	26	$ 110.73	21.6		Same	79.73	ROV	12.26		21.6 locations/hr
Productivity Loss	man day	237.33	2	$ 474.67		2.58	Same	79.73	ROV	12.26		2.58 hr lost per day
Doff PPE	man day	7.67	2	$ 15.33		0.083	Same	79.73	ROV	12.26		
Demobilization (WBS 331.21)										Subtotal =		$ 46.68
Decontaminate	ls	7.67	1	$ 7.67		0.083333	RW + RCT	79.73	ROV on standby	12.26		
Pack for Storage	ls	30.66	1	$ 30.66		0.333333	Same	79.73	Same	12.26		
Transport for Storage	ls	8.35	1	$ 8.35		0.083	2RW	87.92	Same	12.26		
Disposal (WBS 331.18)										Subtotal =		$ 187.50
Used PPE	ft^3	150.00	1.00	$ 150.00							150.00	disposal cost $150/$ft^3$
Decon Materials	ft^3	150.00	0.25	$ 37.50							150.00	

Labor and Equipment Rates used to Compute Unit Cost

Crew Item	Rate $/hr	Abbrev-eation	Crew Item	Rate $/hr	Abbreveation	Equipment Item	Rate $/hr	Abbrev-eation	Equipment Item	Rate $/hr	Abbrev-eation
Technology Operator	43.96	RW				Scallop ROV	12.26	ROV			
Radiation Control Tech	35.77	RCT				Underwater Camera	5.81	UWC			
						RO-7	1.79	RO7			

Notes:

1. Unit cost = (labor + equipment rate) X duration + other costs, or = (labor + equipment rate)/production rate + other costs
2. Abbreviations for units: ls = lump sum; ea = each; and, loc = location; ft^3 = cubic feet.
3. Other abbreviations: PPE = personal protective equipment.

Table C-3. Baseline Technology Cost Summary

Work Breakdown Structure	Unit	Unit Cost $/unit	Quan-tity	Total Cost	Computation of Unit Cost: Pro-duction Rate	Duration (hr)	Labor Item	$/hr	Equipment Items	$/hr	Other $	Comments
Facility Deactivation, Decommissioning, & Dismantlement								**TOTAL COST FOR DEMONSTRATION =**			**$**	**1,788.87**
Mobilization (WBS 331.01)										Subtotal =	$	192.61
Transport from Storage	ls	7.96	1	$ 7.96		0.083	2RW	87.92	UWC & RO7 Standb	7.60		
Pre-Job Safety Meeting	ea	92.33	1	$ 92.33		0.750	RW + 2RCT	115.50	Same	7.60		
Control Zone Setup	ls	71.81	1	$ 71.81		0.583	Same	115.50	Same	7.60		
Equipment Setup	ls	20.52	1	$ 20.52		0.167	Same	115.50	Same	7.60		
Characterization (WBS 331.17)										Subtotal =	$	1,343.35
Don PPE	man day	59.04	3	$ 177.13		0.333	RW + 2RCT	115.50	UWC & RO7 Standb	7.60	18.01	$18.01/day for each PPE
Place and Position	ea	41.03	1	$ 41.03		0.333	Same	115.50	UWC & RO7	7.60		
Survey	loc	5.45	26	$ 141.62	22.6		Same	115.50	Same	7.60		22.6 locations/hr
Productivity Loss	man day	317.60	3	$ 952.79		2.58	Same	115.50	Same	7.60		2.58 hr lost per day
Doff PPE	man day	10.26	3	$ 30.78		0.083	Same	115.50	Same	7.60		
Demobilization (WBS 331.21)										Subtotal =	$	65.41
Decontaminate	ls	26.67	1	$ 26.67		0.217	RW + RCT	115.50	UWC & RO7 Standb	7.60		
Pack for Storage	ls	30.78	1	$ 30.78		0.25	Same	115.50	Same	7.60		
Transport for Storage	ls	7.96	1	$ 7.96		0.083	2RW	87.92	Same	7.60		
Disposal (WBS 331.18)										Subtotal =	$	187.50
Used PPE	ft^3	150.00	1.00	$ 150.00							150.00	disposal cost $150/$ft^3$
Decon Materials	ft^3	150.00	0.25	$ 37.50							150.00	

Labor and Equipment Rates used to Compute Unit Cost

Crew Item	Rate $/hr	Abbrev-eation	Crew Item	Rate $/hr	Abbreveation	Equipment Item	Rate $/hr	Abbrev-eation	Equipment Item	Rate $/hr	Abbrev-eation
Technology Operator	43.96	RW				Scallop ROV	12.26	ROV			
Radiation Control Tech	35.77	RCT				Underwater Camera	5.81	UWC			
						RO-7	1.79	RO7			

Notes:
1. Unit cost = (labor + equipment rate) X duration + other costs, or = (labor + equipment rate)/production rate + other costs
2. Abbreviations for units: ls = lump sum; ea = each; and, loc = location; ft^3 = cubic feet.
3. Other abbreviations: PPE = personal protective equipment.

APPENDIX C

ACRONYMS AND ABBREVIATIONS

Acronym/Abbreviation	**Description**
ARMF	Advanced Reactor Measurement Facility
CFRMF	Coupled Fast Reactivity Measurement Facility
D&D	Decontamination and Decommissioning
DC	Direct Current
DDFA	Deactivation and Decommissioning Focus Area
DOE	Department of Energy
ESH	Environmental Safety and Health
FETC	Federal Energy Technology Center
Ft	Feet
GFCI	Ground Fault Circuit Interrupt
Hr	Hour
In	Inch
INEEL	Idaho National Engineering and Environmental Laboratory
ISL	Inuktun Services, Ltd.
ITSR	Innovative Technology Summary Report
Lb	Pounds
LSDDP	Large Scale Demonstration and Deployment Project
MR	MilliRad
OST	Office of Science and Technology
PPE	Personal protective equipment
R	Rad
RCT	Radiological Control Technician
RUCS	Remote Underwater Characterization System
TRA	Test Reactor Area
USACE	United States Army Corps of Engineers
VAC	Volts Alternating Current