INNOVATIVE TECHNOLOGY
Summary Report

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Compact Remote Operator Console

Robotics Crosscutting Program
Deactivation and Decommissioning Focus Area

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Summary Report

Compact Remote Operator Console

OST/TMS ID 2180

Robotics Crosscutting Program
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 (ITSRs) 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. The ITSRs 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 the U.S. Department of Energy’s (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 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. ITSRs 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 ITSRs are available on the OST web site at http://www.em.doe.gov/ost under “Publications”.

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SECTION 1
SUMMARY

Introduction

The U.S. Department of Energy (DOE) continually seeks safer and more cost-effective technologies for deactivation and decommissioning (D&D) of nuclear facilities. The DOE Office of Science and Technology (OST) Robotics Crosscutting Program (Rbx) is a needs-directed program for the development of robotic technologies that hold significant promise to provide faster, safer, or less expensive systems for application to environmental management (EM) problems. The Rbx is structured into product lines, which align with major EM problem areas and the associated focus areas, such as the Deactivation and Decommissioning Focus Area (D&DFA). A multi-site team performs the work in each of the Rbx product lines; activities are coordinated by a designated lead site. Oak Ridge National Laboratory (ORNL) is the lead site for the Rbx D&D Product Line.

Over several years of interaction and participation in D&D operations, the Rbx identified the need for lower cost robotic and remote systems to support facility D&D. As a result, Rbx developed the Compact Remote Operator Console (CRC), which was designed to address cost- and facility-impact issues related to operator control stations while maintaining a human factors-based design philosophy that is necessary to support efficient long-term operation. The CRC was specifically designed to be as generic as possible so that it could be rapidly and easily adapted to various robotic and remote systems. The D&D system identified for initial integration to the CRC was a commercially available Brokk BM 250™. This integrated system, referred to as the Modified Brokk Demolition Machine with Remote Console, Tech ID 2938, was deployed in conjunction with the D&DFA Large Scale Demonstration and Deployment Project and D&D site operations at the Idaho National Engineering and Environmental Laboratory (INEEL). This deployment was completed during D&D activities at the INEEL Security Training Facility (STF) in January 2000. This *Innovative Technology Summary Report* (ITSR) will provide a discussion of the CRC component of this deployment.

Technology Summary

The CRC was developed as a result of years of lessons learned in developing, implementing, testing, and deploying operator interfaces for remote systems. Short-term operations typically involve the setup of equipment solely based on portability concerns. Long-term operations generally involve the installation of control-room hardware, which may or may not be designed based on human-factors concerns. In either case, the vast majority of implementations simply follow standard engineering practice with little or no regard for the need for human-factors-based design to enhance operator efficiencies. The typical result is operator fatigue, poor system performance, and end-user disillusionment with remote systems in general.

The CRC was developed to meet the needs of many, if not most, remote system, operator control stations while acknowledging that there will be some applications that warrant full-control-room or suitcase-controller implementations. The resultant CRC design meets the needs for low-cost, minimum facility impact, and fast deployment in a package, which supports long-term operations while maintaining a capacity for quick adaptation to different remote systems. Figure 1 shows the CRC as configured to support deployment of the Brokk BM 250 demolition machine.

The CRC provides remote viewing, audio, and associated control over those functions; peripheral systems and tool control; and packaging and positioning of an existing, modified, or created manual controller for a remotized system. Human-factors elements are addressed via the use of an adjustable control chair and the capability to position the location of viewing and manual inputs with respect to the requirements of individual operators. Cost and size constraints are addressed by eliminating a conventional rack-mounted-hardware approach in favor of new video and controls technology and packaging techniques, which also nearly eliminate system setup. The facility power requirement is only a single 110-V AC (alternating current voltage) outlet. Operator interface menus are handled via an all-in-one-unit personal computer (PC)-based touchscreen computer, which connects to the rest of the world by RS485-based fiber-optic serial communications.

Figure 1. Compact Remote Operator Console during final integration to the modified Brokk.

Demonstration Summary

The CRC, as part of the integrated system referred to as the Modified Brokk Demolition Machine with Remote Console, was deployed for demonstration during D&D activities at the INEEL STF in January 2000. Specifically, the system was used by an operator to remotely remove, size-reduce, and stage overhead piping and equipment located in the basement of the STF. Before the availability of the CRC and Modified Brokk, this work was performed by the standard Brokk—with the operator exposed to inclement weather and in close proximity to the demolition work and its associated hazards. The CRC was placed in a heated control trailer, which was located about 600 ft from the demolition work site. Workers were kept on-site during the demonstration and deployment for observation of the system while it was being used to conduct demolition.

Key Results

The benefits of the CRC were that it removed the operator from hazardous environments while providing adequate interfaces to permit the operator to conduct D&D activities for an extended period of time at nearly the same level of performance as is possible with direct control. The operator adapted to the CRC quickly, and INEEL D&D operations asked if it could keep the system to use in both inclement weather and radiological operations. The CRC was portable enough such that it could be placed in a movable control trailer and powered via an auxiliary generator on-site in the Idaho desert.

The overall design of the CRC was very well received. Operator feedback did request camera control via a joystick as well as via a touch screen, but these upgrades had already been planned, and parts had already been ordered before the system was tested. Audio feedback, which was important for Brokk and excavator-type operations and some tool operations, was also requested and added after the initial testing.

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Other

All published ITSRs are available on the OST web site at http://www.em.doe.gov/ost under “Publications”. The Technology Management System, which is also available through the OST web site, provides information about OST programs, technologies, and problems. The OST reference number for the Compact Remote Operator Console is 2180.

SECTION 2
TECHNOLOGY DESCRIPTION

Overall Process Definition

Description of the Technology

The CRC, which is shown in Figure 2, is a general-purpose, remote-operator station, which is designed to provide the same functionality and human-factors focus as larger control-room-based operator control stations but in a smaller and cheaper package. Two extremes currently exist in the remote systems community with respect to operator interfaces. Generally, either a large and an expensive control-room-based system is employed, or a small, cheap, and frequently strap-on portable operator interface is used. The large systems provide an ergonomic interface, but their cost, size, and burden on the facility are prohibitive. The smaller and cheaper interfaces generally minimize attention to human factors and, therefore, shorten available work sessions because of operator fatigue. The goal of the CRC is to address the shortcomings of both extremes by providing a high level of operator console functionality at lower system cost and with minimal impact to facility installations and operations.

Figure 2. Compact Remote Operator Console as a stand-alone to show components.

The specific function of the CRC is to provide remote viewing and remote task control for remote and telerobotic systems. For the remote viewing, video input, channel selection, and control capabilities are provided. Remote task control is broken down into two primary functions: control of the remote system (vehicle, manipulator, etc.) and control of the task function (characterization sensors, dismantlement tooling, decontamination process, etc.). Recent emphasis within the EM development activities has been on deploying commercially available remote systems (vehicles, manipulators, etc.) that, in general, come with vendor-supplied control interfaces. For control of the remote system, the CRC is capable of accommodating this off-the-shelf control capability, which is available from the remote system vendor (Schilling minimaster, Brokk control pendant, etc.) in a drop-in fashion. Task function control is provided by a reconfigurable command menu and various communications functions. Communications can be via either hard wire or fiber optics. [While the CRC supports radio frequency (rf) communications, the current state of the art is not considered sufficient for high-reliability use for non-line-of-sight hazardous operations.] Control functions are PC compatible and NT based to provide lower cost hardware systems with a broader range of available commercial off-the-shelf-software; current menu applications are written in Microsoft Visual C++™ to maximize the probability that facility engineering staff would have expertise to make modifications.

The CRC is based on a platform, which is narrow enough while fully assembled to wheel through a standard personnel door. The built-in adjustable control chair is an integral part of the CRC and a major feature of the human-factors-based focus on design. Costs are controlled, size is limited, and human-factors issues are addressed by eliminating rack-mounted video equipment and instead by presenting video to the operator via 15-in. liquid crystal display (LCD) flat panels, which are designed specifically to support video and are mounted to a vertical post via an adjustable arm. The viewing distance and height of the video array are adjustable. Four video panels are provided. The three lower views are primary remote viewing; the fourth upper view uses a screen splitter to present an array of available camera views that the operator may use. The default splitter mode is to support four different views; however, up to 9 or 16 input channels are selectable and supported. The video switcher and multiplexer hardware is located under the control chair. System power supplies and communications modules are located under the flip-up forward floor of the CRC platform. Connections to the system come out of the front of the CRC platform. The entire CRC is powered through one 110-VAC power cord.

The remote system (Brokk) master controller mounts on a swing-away arm, which mounts to the left side of the chair (Figure 2). Since the deployment of the CRC as integrated with the Modified Brokk (Figure 3), several other CRC integrations have occurred or are planned. Two Schilling minimaster controllers were integrated (Figure 4) to control a dual-arm manipulation system, which was installed on the RedZone Robotics, Inc., Rosie remote work vehicle [Dual-Arm Rosie (DARosie)] (Figure 5). Two more versions of the CRC that are currently in progress will integrate controllers for the Dual-Arm Telerobot (DATR) and the Telerobotic Small Emplacement Excavator (TSEE), thus proving the adaptability of the CRC to various master controllers.

Figure 3. Modified Brokk as used with the Compact Remote Operator Console.

The CRC graphical user interface (GUI) and control system are provided by an all-in-one computer-monitor-touch screen, which is mounted on the CRC right side arm. Communications paths available to the CRC include ethernet, RS232 serial, RS485 serial, and RS485 serial-based, fiber-optic cable. For the CRC, as integrated with the Modified Brokk, all camera controls were passed through the fiber-optic RS485; the Brokk control signals were passed through a dedicated fiber without altering their communication protocol. The operator interface itself is a GUI for video switching, camera-control selection, and camera pan, tilt, and zoom with an auxiliary joystick for the camera pan, tilt, and zoom. The CRC touch-screen computer is specifically meant to address all low-bandwidth, peripheral control functions. High-bandwidth, manipulator-control functions for teleoperation, telerobotics, and robotics use a separate box, which is currently under development. Spare fiber-optic channels are available to support high-bandwidth control communications.

Figure 4. Dual manipulator Compact Remote Operator Console –Dual-Arm Rosie. Dual-Arm Telerobot will start with a similar interface.

Figure 5. DARosie as used with the Compact Remote Operator Console.

System Operation

The CRC should be set up in an area that will be comfortable for the human operator; it is not designed for use outside in inclement weather. The operation area could be anything from a room in the building where the remote work is being conducted to a trailer with a generator. The unfolded footprint of the CRC is 61 in. long by 50 in. wide. (The folded footprint for transport and maneuvering into place is 61 in. long by 29 in. wide.) If the fiber-optic communication capabilities of the CRC are used, this distance can be up to 8,000 ft (cable-routing-wise) from the remote system being controlled. The CRC has wheels recessed into the underside of the platform so that it can be wheeled into place without the use of a forklift; however, it is heavy enough such that elevators instead of stairs should be used to change floors. The platform is less than 30 in. wide and lowers to about 65 in. tall so that it will wheel through standard entryway doors. Once in place, the stabilizer feet in each corner should be cranked down to raise the wheels off the floor; this will lock the platform in place and provide a solid bed for operation.

Plug the CRC power cord into a 110-V AC outlet. The CRC will require a full 110-V AC 15 amp circuit to itself. Connect the field wiring to the front of the base of the CRC platform; either fiber optic or hard wiring may be used depending on the application.

With the operator seated in the control chair, the chair, video monitors, manual controller, and touch-screen computer should be adjusted to the operator's preference in order to minimize fatigue and to maximize the length of the operating session.

The power switch, which is located at the front of the base of the platform, is then turned on. This will provide power for all video and other electronics. The touch-screen computer is powered on separately afterwards and requires that the operator log in once the computer has booted. By double-clicking on the control-menu icon, the operator then brings up the video switcher control menu, makes the appropriate camera-to-video selections, and next brings up the camera-positioning control menu to move the cameras into suitable orientations to support the remote task to be conducted. After the CRC setup has been completed and the operator has made all visual checks of the remote environment, then the remote system may be powered up according to the vendor's directions. The remote system may then be activated to begin operation.

To shut down the system, the remote system is first shut down from the manual controller. The cameras can be left in their last position. The operator then logs off of the touch-screen computer. For day-to-day operation, the CRC can be left powered up if it is not located in a generator-powered trailer (as in the case of the Modified Brokk with Remote Console); otherwise, power to the touch-screen computer should then be turned off, and then power to the CRC is switched off.

Operators should already be qualified to run the equipment (vehicles, manipulators, etc.) that is being used remotely. Operation of the CRC itself will require less than 1 hour of familiarization; however, it would be useful if operators had previously had some exposure to computers. The CRC is designed to support a single operator—with the possibility for a secondary operator or supervisor station at the back of the CRC. Facility or operational requirements may require additional staff. In addition, depending on the difficulty of the remote tasks executed, operators may require more frequent brakes and/or trading off with alternate operators on a regular basis.

The primary concern with respect to operators involved with the CRC and use of any remote system is fatigue. The purpose of the CRC is to reduce the exposure of the operators to any hazards; therefore, the operating hazards are similar to those of an office environment and nothing more.

SECTION 3
PERFORMANCE

Demonstration Plan

Problem Addressed

Many DOE facilities have fulfilled their useful lives and are in the process of being decontaminated and decommissioned. Tasks associated with D&D include size reduction or pulverizing and/or removing piping and conduit, concrete structures, interior walls, large enclosures and equipment, office areas, stairs, walkways, etc. D&D in the nuclear industry often occurs in facilities that have been used for nuclear experiments or fuel reprocessing and storage. These facilities frequently become radiologically contaminated to the point where it is necessary to use equipment that can be controlled from a remote environment in order to protect workers. The Rbx developed the Modified Brokk Demolition Machine to complete these kinds of tasks. The CRC was integrated to the Modified Brokk to permit remote operation.

Demonstration-site description

INEEL site operation was already using their Brokk 250 for D&D of the STF, which is located at the Central Facilities Area at the INEEL site in the Idaho desert. The STF was originally designed and built as the Experimental Organic Cooled-Reactor Facility, but it was never put into service. As such, the facility contains many of the nuclear systems normally contained in radiologically contaminated facilities requiring D&D but without the risks and hazards associated with contaminated facilities. Particular tasks under way included the removing and sizing of piping, control panels, and large, metal storage boxes, and the demolition of walkways; all activities were focused on the basement area of the STF. The Brokk operator was standing in close proximity to the machine in very cold weather; thus, while there were no radiological necessities for remote operation, inclement weather provided serious motivation. A request was made by the Rbx D&D team to the STF D&D foreman asking that a portion of the STF basement be reserved for testing of the various systems developed for remote operation of the Modified Brokk Demolition Machine [Modified Brokk with Remote Console (Tech ID 2938)]. The request was granted, and an initial field test of the CRC and Modified Brokk was scheduled for January 18, 2000.

Major objectives of the demonstration

The first objective of the Rbx D&D group is to identify existing technologies, either unproven or requiring improvement in D&D applications, that address the defined problems or needs of DOE D&D activities. The second objective is to develop innovative technologies that improve upon the existing technologies or create a new capability. Finally, these innovative technologies are tested to quantify and document the benefits that can be realized from a side-by-side comparison of the innovative and baseline technologies. Possible benefits include reduced cost, reduced exposure, increased safety, reduced schedule, and ease of application. This direct comparison provides an opportunity to assess the impact of the innovative technology against the baseline and to validate the benefits to be gained.

In keeping with these objectives, the original purpose of testing the CRC as part of the Modified Brokk Demolition Machine with Remote Console was to determine if adequate visual cues and remote controllability could be given to an equipment operator such as to allow D&D activities to proceed as efficiently from a remote sight as from in-field, line-of-sight operations. No separate formal test plan was put into place before locating the equipment at the STF. The Modified Brokk Demolition Machine with Remote Console was used to perform tasks that had already been defined and planned for execution by the standard Brokk. As stated, the objective was to determine and compare the adequacy of the system to perform D&D tasks that were being performed line-of-sight in the hazardous environment and receive feedback from the users to determine ways the system might be improved.

Major elements of the demonstration

This demonstration provided field data regarding remote non-line-of-sight D&D operations vs. "in the environment" line-of-sight D&D operations. D&D tasks evaluated included:

- difficulty of setting up the remote equipment;
- remotely positioning the Modified Brokk Demolition Machine using the CRC;
- sizing, removing ,and staging conduit and piping;
- removing and staging of large control panels; and
- removing and staging of a large stainless-steel storage box.

Previously qualified INEEL D&D Brokk equipment operators were used to remotely operate the Modified Brokk Demolition Machine using the CRC. Each of these operators had received model-specific operator training from the manufacturer and had had significant operating time in the field. The original Brokk controller was integrated into the CRC, therefore eliminating the need for additional training on Brokk-specific operations. The GUI, which was provided on the CRC control computer, required a short, half-hour training session for the operators. This session included an explanation on how to control the camera and actuator systems on the Modified Brokk and how to set up the four-panel video array according to each operator's personal preference.

Two operators were used for the demonstration of the Modified Brokk Demolition Machine with the Remote Console, one at the CRC responsible for operating the Brokk and another near the remote location as an observer to notify the CRC operator of any unsafe conditions necessitating a stop work. Activities were conducted under INEEL D&D operation procedures, and personal protective equipment, such as hard hats, safety glasses, and steel-toed shoes, was used during setup of the remote equipment. Personnel were briefed on the D&D site safety requirements, and all safety guidelines were followed.

Table 1, from the Modified Brokk with Remote Console ITSR, Tech ID 2938, summarizes the operational parameters and conditions of the demonstration of the CRC and Modified Brokk at the INEEL STF in January 2000.

Table 1. Modified Brokk with Remote Console Summary for the Compact Remote Operator Console Demonstration at Idaho National Engineering and Environmental Laboratory

Work area location	**INEEL STF, Scoville–Idaho Falls, Idaho**
Work area access	INEEL D&D operations restrictions to equipment operational areas and D&D site.
Work area description	Work area restricted and controlled due to noise and safety requirements, requiring training, hard hat, safety glasses, and safety shoes for entry. Actual operation conducted in a trailer eliminating the need for personnel protective equipment (PPE) at the CRC.
Work area hazards	Noise Tripping Water Heavy equipment operations High-voltage
Equipment configuration	CRC located in trailer and attached to the Modified Brokk, located at remote D&D site 600 ft away.
Labor, support personnel, special skills, training	
Work crew	Minimum work crew: • 1 Brokk operator • 1 D&D site operator • 2 Robotics personnel for system setup
Additional support personnel	• 1 Health and safety observer (periodic)
Special skills/training	Site-mandated Brokk-specific training. Review and briefing of D&D site safety operations and sign-in. CRC-specific training. Skill was required to operate Brokk and associated remote camera equipment. Modified Brokk System training, skill, and experience are required for setup and operation.
Waste management	
Primary waste generated	No primary waste was generated beyond normal D&D operations.
Secondary waste generated	No secondary waste was generated.
Waste containment and disposal	Not applicable
Equipment specifications and operational parameters	
Technology design purpose	Equipment is designed to perform D&D demolition operations from a remote location.
Portability	Modified Brokk camera equipment and CRC can be packaged and transported to D&D site easily. Brokk machine requires trailer for transporting to D&D site.
Materials used	
Work area preparation	No facility preparation was necessary for the demonstration.
PPE	Steel-toed shoes, safety glasses, leather gloves
Utilities/energy requirements	
Power, fuel, etc.	Diesel fuel for remote generator Facility power used for CRC

Results

The Modified Brokk Demolition Machine with Remote Console worked very well over a period of the 5 days that were dedicated to the demonstration. On the morning of the first day, the equipment was loaded into a trailer and transported from the Robotics Laboratory, which is located in Idaho Falls, Idaho, to the STF, which is located 50 miles east of Idaho Falls at the Central Facilities Area. The Brokk 250 was already located in the basement of the STF and attached to the associated power generator. The Brokk 250 was de-energized, and the cover was removed for replacement with the cover retrofitted with the remote camera and actuator equipment. The fiber-optic tether was run from the STF basement to the control trailer, which was located about 600 ft away and attached to the CRC. The control trailer was used to limit access during operations, and it provided a heated, safer environment for the operator to work in than did the basement of the STF. The entire setup of the Modified Brokk Demolition Machine with Remote Console, including the initial half-hour control console training and pre-job briefing, required ~3.5 hours.

The equipment operator previously operating the Brokk 250 in the basement of the STF was relocated to the CRC in the control trailer. Tasks that were already planned for execution with the standard Brokk were completed with the remote console-based version. Initially, the operator found it unusual operating the Brokk system without hearing the system since there was no audio feedback from the remote environment. However, as the 2-day field trial progressed, the operator became nearly as efficient at performing the listed D&D tasks remotely as had occurred in the field. The rate at which the listed tasks were being accomplished while in the field standing next to the Brokk was nearly matched. The operator was pleasantly surprised at the ease of viewing the overall environment from the facility camera and the unwavering view from the image-stabilized cameras mounted on the Brokk machine.

At the conclusion of the 2-day field trial, operator feedback was obtained to determine the strengths and weaknesses of the system. At the request of the D&D site operations and with the permission of the D&D Rbx Product Line Manager, the Modified Brokk Demolition Machine and CRC were left for an additional 3 days to allow the remaining D&D tasks to be completed. Operations were then transitioned from a demonstration to a deployment. The operators were so pleased with the system and found that it impacted their schedule so little that they preferred to perform operation from the CRC as opposed to having to perform the operations while standing in the cold, wet basement of the STF.

The demonstration collected operations data so that legitimate comparisons can be made between the innovative technology and the baseline technology in the following areas:

- safety,
- productivity rates,
- ease of use,
- limitations and benefits, and
- cost.

SECTION 4
TECHNOLOGY APPLICABILITY AND ALTERNATIVES

Competing Technologies

Baseline technology

Use of the CRC cannot really be evaluated separately from the remote system to which it is attached. In the case of the Modified Brokk, adjacent line-of-sight remote control of the demolition equipment is the baseline technology.

The Modified Brokk Demolition Machine, when used in conjunction with the CRC, adds the capability to remotely operate existing equipment from an increased safety zone in hazardous environments without a need for direct and local line-of-sight operator location.

The primary benefit of the CRC is that it removes the operator from any of the hazards of the working environment. In the case of the Modified Brokk—CRC combination, the operators went from standing outside in very cold, wet weather in fairly close proximity to flying debris to the comfort of a heated control trailer.

Technology Applicability

Any site requiring D&D operations with the constraints of complete remote operation (hands-off, non-line-of-sight) would benefit from the use of the CRC in conjunction with remote demolition equipment such as the Modified Brokk. Two different facilities at the INEEL site are slated for D&D during the next few years. As the Brokk 250 has become a general piece of equipment for the INEEL D&D site operations, it is currently scheduled to be used in these D&D projects for removing concrete, piping, conduit, and flooring. Additionally, there is the need to decontaminate and decommission two test reactors in these facilities, and the Brokk 250 will be used for this work. The radiation fields expected during this job prohibit manual operations anywhere near the area, and the Modified Brokk (as controlled by the CRC) is currently needed to complete this job. This is just one example of D&D operations that could benefit from the use of this technology.

Patents/Commercialization/Sponsor

The development of this technology was sponsored by the D&DFA and performed by the OST (EM-50) Rbx. Engineering documentation for the CRC is available from ORNL.

SECTION 5
COST

Methodology

This cost analysis compares the relative costs of the innovative technology of the CRC to a baseline technology of an control room-based operator interface installation for the purpose of long-term remote systems operation.

The CRC is specifically an operator control station for robotic and remote systems and is, therefore, not a stand-alone component. In the case of this demonstration, the CRC was the control-station component for the Modified Brokk with Remote Console. For a cost analysis of that system, refer to the ITSR for Tech ID No. 2938. Since the CRC was demonstrated as part of another system, and not by the staff that developed the CRC, limited demonstration cost information was available to create this section; however, hardware and installation/setup cost data exists and can be presented here. Since the CRC is a hardware component and not a process, and since those numbers were not captured as part of the system demonstration, production rate costs do not translate and are not presented.

For a cost comparison of the CRC to a baseline operator control station, the CRC will be compared to the operator control station that was deployed with the dual-arm work package (DAWP) in early fiscal year (FY) 1997 at Argonne National Laboratory (ANL) for the D&D of the Chicago Pile No. 5 (CP-5) research reactor. The DAWP control station, which is shown in Figure 6, was a traditional control-room design that was modified to be modular so that it could be moved into place in the control room at CP-5. The CRC was specifically designed to meet the functionality of the CP-5 operator control station while drastically reducing cost, equipment footprint, power consumption, and required setup time.

Figure 6. Dual-arm work platform operator control station.

Cost Analysis

Development costs for the DAWP operator control station, which was procured, fabricated, and assembled during FY 1996 were not specifically captured in the context of baseline comparison. However, the cost of the procured and fabricated hardware and procured software was approximately $440K, and this amount represents the replication cost for this baseline remote system operator control station. The components were packaged and shipped via commercial carrier to ANL.

Development staff then arrived to assemble, connect, and check out the equipment. Assembly through checkout time required approximately 400 hours.

Comparable costs for the CRC, including procurement and fabrication of hardware and procurement of software packages, came to $50K. Since the CRC was assembled and transported as a unit (only the video panels were removed) to the demonstration site, assembly, setup, and checkout required only 4 hours of labor. These costs are summarized in the following table.

Table 2. Cost Summary

Description	CRC-based implementation	Baseline Implementation
Hardware costs	$50K	$440K
Installation and/or setup	4 man-hours	400 man-hours

Cost Conclusions

The cost of implementation of a CRC-based remote system operator interface, as opposed to a traditional control-room-based DAWP system, is almost an order of magnitude less ($50K vs. $440K). The cost of site setup for the CRC, as opposed to the traditional control room-based DAWP design, is actually two orders of magnitude less.

While the CRC is adaptable to a wide variety of robotic and remote systems, some additional costs related to the custom modifications are to be expected for each individual system adapted.

SECTION 6
REGULATORY AND POLICY ISSUES

Regulatory Considerations

There are no known regulations associated with the use of the CRC as it was used in the Modified Brokk Demolition Machine with Remote Console. Its use at the INEEL STF D&D site was covered under the INEEL D&D site operations and safety procedures.

Safety, Risks, Benefits, and Community Reaction

The CRC, as part of the Modified Brokk Demolition Machine with Remote Console, is designed to be safer than the direct use of the Brokk by a local operator. By removing the operator from the hazardous environment, physical, chemical, and radiological long-term health risks are radically reduced. The one additional risk resulting from the innovative technology over the baseline technology is the difficulty associated with remotely driving and operating equipment. This risk does not affect the CRC directly, but it requires that certain design features and procedural requirements be considered:

- cameras located on the Brokk 250 cover are placed on actuators to allow a minimal operating envelope as close to the original Brokk 250 as is possible,
- an additional facility camera was developed for overview of remote operations in order to alert the operator to possible hazards in the area, and
- an operator was located near enough to the operating area such as to notify the remote operator of unsafe or unusual conditions necessitating that work be stopped.

There are no adverse safety or socioeconomic impacts on the community. As discussed in the ITSR for the Modified Brokk with Remote Console, Tech ID 2938, a media event was held at the conclusion of the demonstration, and the technology was very well reported and received by the local Idaho residents. Several television stations and local newspapers carried the report on the innovative technology being used to improve productivity and safety conditions at the INEEL. The news reports included an interview with the INEEL D&D operations STF project manager, the Brokk 250 operator, and the Rbx D&D technology lead. To date, these reports and publications have consisted of only positive responses from the public.

SECTION 7
LESSONS LEARNED

Implementation Considerations

The CRC, as part of the Modified Brokk Demolition Machine with Remote Console, performed well, but some minor improvements were suggested to enhance operation and effectiveness. These improvements are listed in the "Technology Limitations and Needs for Future Development" portion of this section.

It should be noted that the Modified Brokk Demolition Machine with Remote Console requires a measure of skill to operate. Most of the CRC controls associated with the camera, actuators, and CRC are quite intuitive, but it is recommended that operators receive the vendor-provided, model-specific Brokk training and significant field-operation time before operating the system remotely through the CRC. It was not absolutely necessary to have a person in the remote environment for tether management or unsafe condition notification, but it was helpful and procedurally required during the demonstration and deployment while operators were adapting to the concept of using a remote system.

Technology Limitations and Needs for Future Development

At the conclusion of the 2-day field trial, the D&D site operations personnel were interviewed for operator feedback on the Modified Brokk Demolition System with Remote Console. Following is a list of their comments including recommendations for improvements:

1. The CRC ergonomic setup is exceptional with adequate chair and monitor adjustments, and mounting of the Brokk controller allows for normal comfortable operations.

2. Operation from a remote trailer is preferred due to improved safety conditions, comfort, operator isolation, etc.

3. Visual cues from the Modified Brokk were adequate and intuitive, thus allowing for productive operations from the CRC.

4. Audio feedback from the remote environment is a must. In addition to the normal feedback one obtains from sound under remote operations, the operator relies upon the sounds from the hydraulic system to determine when the Brokk has been successfully activated. During the demonstration, a remote operator was used to signal to the Brokk operator when the system was operational, which is not the preferred mode of operation. (Note: Audio feedback has since been added.)

5. Optional joystick control of the camera functions would be preferable to just a touchscreen interface. The operators were more familiar with joystick controllers and the need to continuously touch the operator interface touch screen on a specific button to move the cameras proved to be occasionally frustrating. The operators felt a system with the option of joystick or touch screen would be preferred. (Note: Joystick camera control had already been planned for implementation on the CRC pending receipt of parts on back order. Joystick control of cameras was implemented shortly after the demonstration and deployment.)

6. The facility camera is designed to transmit video via a radio rf transmitter to the Brokk, where the signal is passed via the fiber-optic tether to the operator at the CRC. Commercially available rf video transmitters are currently very limited to line-of-sight operations and very susceptible to noise and interference. These limitations plagued the operator with frequent dropouts of the overview picture and caused some significant frustration under these operating conditions. It was suggested that an optional coaxial cable be installed from the facility camera to the Brokk 250 and then passed via the fiber-optic cable to the operator to reduce these video problems.

The Modified Brokk camera system and the CRC are readily available for commercialization. The CRC is available as a design package that can be implemented by any DOE site or remote sytems contractor. Both systems have used commercially available subsystems when possible to avoid needless cost and development time.

Technology Selection Considerations

Use of the CRC as part of the Modified Brokk Demolition Machine with Remote Console, or use of other remote systems, is preferred wherever hazardous—radiological, chemical, or physical—environments preclude or severely limit human access to the work space.

Instances where the baseline direct-operation technology would be preferable would include when completely remote operations are not required and when a 400-ft line-of-sight provides adequate distance to protect the operator and the ability to position the operator to see adequate details to conduct operations.

APPENDIX A
REFERENCES

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APPENDIX B
ACRONYMS AND ABBREVIATIONS

AC	alternating current voltage
AMP	ampere-hour
ANL	Argonne National Laboratory
CP-5	Chicago-Pile No. 5
CRC	Compact Remote Operator Console
D&D	Deactivation and Decommissioning
D&DFA	Deactivation and Decommissioning Focus Area
DARosie	Dual-Arm Rosie
DATR	Dual-Arm Telerobot
DAWP	dual-arm work package
DOE	U.S. Department of Energy
EM	environmental management
ft	Foot
FY	fiscal year
GUI	graphical user interface
in.	Inch
INEEL	Idaho National Engineering and Environmental Laboratory
ITSR	Innovative Technology Summary Report
LCD	Liquid Crystal Display
ORNL	Oak Ridge National Laboratory
OST	Office of Science and Technology
PC	personal computer
PPE	Personal Protective Equipment
Rbx	Robotics Crosscut Program
rf	radio frequency
STF	Security Training Facility
TSEE	Telerobotic Small Emplacement Excavator
VAC	alternating current volt
vs.	Versus