EXPERIENCE OF THE SURVEYOR™ MOBILE ROBOT AT NINE MILE POINT

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ABSTRACT

A successful test and evaluation program was recently conducted on a commercial-ready, wireless, remotely operated surveillance system for use in nuclear power plants. This evaluation of the Surveyor™ Mobile Surveillance System took place at Niagara Mohawk Power Corporation's (NMPC) Nine Mile Point (NMP) Nuclear Power Station (1). The remotely operated vehicle measures radiation, temperature and relative humidity and provides optical inspection capability. The vehicle is readily maneuvered through 36 inch wide passageways and labyrinth entries and can climb stairs, negotiating 180 degree turns on stair landings. The Surveyor™ systems consists of a Supervisory Control Station and a rugged, remotely operated, battery-powered vehicle. The Surveyor™ system is specifically designed to decrease personnel radiation exposure by supplementing the functions of an auxiliary operator or Health Physics Technician to perform periodic component inspections inside particular areas within a nuclear power plant. The purpose of this presentation is to describe the recent efforts, achievements and experiences of the personnel at NMP Unit 1. In particular, this will address the test and evaluation program for the Surveyor™ Mobile Surveillance Robot.

INTRODUCTION

Traditionally, the use of robotics and remote technologies within the nuclear industry has been limited to hot cell facilities for fuel processing and highly radioactive sample handling. However, now faced with increasing needs to reduce occupational radiation exposures as low as reasonably achievable (ALARA), the nuclear utility industry is looking beyond the traditional exposure reduction into robotic automation. Sophisticated, smart semi-autonomous vehicles will soon be doing many routine jobs under operator supervision. The technology for these cost effective, remotely-operated devices exists now (2).

In September 1984 the multi-departmental Nine Mile Point site ALARA Committee recognized robots and remote technologies as a viable means to reduce personnel radiation exposure and thus warranted further investigation. The ALARA organization contacted the NMPC R&D Department to discuss funding and engineering assistance for developing a program to introduce robotics to Nine Mile Point Unit 1 (NMP-1). The proposed project fit the R&D criteria of having a high potential benefit and probability of success, but with more risk than justifiable for corporate capital expenditure. Therefore, it was decided that the site ALARA Coordinator and the R&D representative would jointly provide overall program leadership and for each particular project a site "sponsor" would serve as that project coordinator. KLM Technologies, Inc. serves as the R&D representative for this program (2).

The first order of business for the robotics program was to investigate the available technology and determine applicability to NMP-1 short- and long-term needs. The mobile robots examined were propelled by either wheels, tracks or legs and were powered through either a tether or an on-board battery pack. The particular applications of interest to NMP were those robots capable of decontamination, surveillance, inservice inspection, maintenance and possibly operational support.

NINE MILE POINT ROBOTIC PROGRAM

Many robotic devices were examined during the initial data gathering period and information about other devices is still being sought and reviewed. After sufficient information was gathered concerning the present state of technology, a plan to implement a robotics program at Nine Mile Point Unit 1 (NMP-1) was formulated in late 1984.

It was recognized early in the program development that the critical element necessary for a successful remote technologies program was the input and support of station operating personnel. Therefore, a task force jointly sponsored by the site ALARA organization and Corporate R&D and consisting of interested representatives from Maintenance, Radwaste Operation, Inservice Inspection, Instrument and Control, Technical Support and Nuclear Engineering was formalized. The purpose of the task force was to analyze station operations to identify beneficial robotic applications. The first task force meeting was held in January 1985. During the next two months task force members reviewed the information and vendor supplied video tapes. A brainstorming session was held to list the possible applications and prioritization based upon the available technology and practicality was performed. In March 1985, a survey form was distributed to solicit ideas and recommendations from other members of the operating staff. The response to the survey, like any other survey was not overwhelming; however, the ones returned were very good and proved an interest from people and organizations not otherwise considered.

Radwaste Application Program

A major radwaste retrofit project at NMP-1 was initiated in late 1985. As a result, the project was examined to see if any robotic applications would

be of benefit. During July, Inservice Inspection and Radwaste Operation personnel were consulted about possible applications of a surveillance robot in their area of responsibility. Applications were determined and test criteria were established. Based upon surveys and extensive plan support, performance requirements for a robotic vehicle system were developed. These requirements reflect, to the extent practical, the minimum requirements identified to support the NMP-1 refurbishment plan and reflects the best available information on the expected conditions to be encountered by a remote vehicle as well as any restraint imposed by the current operations, procedures and practices at Nine Mile Point Unit 1.

The performance requirements included (3):

- The vehicle must be capable of descending and ascending stairs at Nine Mile Point Unit 1.
- Remote control, video and sensor data transmissions on a non-interfering communication frequency is required.
- The vehicle must be capable of climbing over obstacles including a seven inch dam. This was changed to fourteen inches in May 1986.
- The vehicle must be capable of traveling across concrete flooring, fiberglass and steel grating, wood, grass, gravel, soil, mud and sludge.
- The robotic vehicle must be capable of entering labyrinths as encountered at Nine Mile Point.
- The vehicle must be capable of radiation mapping including 3-degrees of freedom.
- It is highly desirable that the vehicle be capable of moving cylinderical non-stationary components such as overturned 300 lb. drums.
- The robotic vehicle and any ancillary equipment must be capable of being decontaminated.
- It is desirable that the robotic vehicle be capable of transporting and utilizing a hydrolaser to support facility decontamination.
- The device should be capable of continuous performance when subjected to 130°F, 100% relative humidity and 100 R/hr radiation environment.
- The device should be capable of reliability equivalent to industrial robot system with 300 hours meantime between failure (MTBF).

Nine robotic devices were considered, to varying degrees, for use at Nine Mile Point. It should be noted that other devices were reviewed but either were not available for loan, lease or procurement or were totally inappropriate for consideration at NMP-1. Based upon a thorough evaluation, the SURVEYOR™ Mobile Surveillance System manufactured by ARD Corporation of Columbia, Maryland, was recommended for use at Nine Mile Point for continuation of the robotic and remote technology R&D project.

THE SURVEYOR™ SYSTEM

The Surveyor™ Mobile Surveillance System shown in Fig. 1 provides remote, wireless operation in hazardous environments. The system is designed to meet specific guidelines to minimize occupational

Fig. 1. Surveyor™ Mobile Surveillance System.

exposure to hazardous environments and to provide plant operations with the information to support plant performance. Sensors, including radiation, temperature and relative humidity are used to obtain data from the environment. Zoom inspection optics read gauges and position indicators, can inspect for leaks or cracks. Noise sensors monitor equipment and system performance.

The operator guides the mobile vehicle from the Supervisory Control Station using a stereoptic viewing system which greatly enhances operator depth judgement and control permitting reliable operations in small, cluttered, unfamiliar and/or poorly illuminated spaces. This telepresence system represents the state of the art in vision technology and reflects the unique expertise utilized in the melding of human factor engineering with electronic vision engineering (3).

Mounted on the robotic arm, the scanning inspection optics can be pointed in any direction and permit both wide-field and close-up viewing of remote objects, providing the operator greater flexibility and capability than if on-site. Sensor outputs including radiation, temperature, relative humidity and position/ranging are continuously transmitted from the mobile vehicle, and processed and displayed on the Supervisory Control Station.

Key characteristics of the Surveyor™ are:

- Extremely rugged construction
- Modular design for simple maintenance and improved availability

- Easily decontaminated
- Hardened electronics
- Simple installation
- User-friendly operator interfaces

Moving at speeds up to 1 foot/second, the Surveyor™ robotic vehicle is designed to traverse obstacles, wade through water up to fourteen inches deep, climb 40-degree stairs, maneuver through doors, halls, and labyrinth entries, and requires less than a 34-inch vertical clearance. Figures 2 and 3 illustrate action photographs of Surveyor™ surmounting steel pipe and wooden pallet. The unique modular design incorporates basic building blocks which can be reconfigured for a variety of applications. These building blocks include:

- Propulsion subsystem
- Payload deck
- Electronics
- Stereoptics
- Inspection optics
- Robotic arm
- Sensors

With all subsystems operating, the vehicle can operate up to six hours between recharges.

Basic specifications (3):

- Weight: 375 to 425 lbs. (depending on payload)
- Length: 51 inches (out to end of inspection camers)
- Width: 22 inches
- Height: 28 inches (top of payload deck)
- Speed: 1 foot/second
- Payload Capacity: 150 lbs.

Fig. 2. Surveyor™ Surmounting the 4-inch Diameter Steel Pipe.

Fig. 3. Surveyor™ Starts to Surmount a 6-inch Height Wooden Pallet.

NINE MILE POINT TEST AND EVALUATION PROGRAM

Based upon the above performance requirements and analysis of robotic alternatives, the Surveyor™ mobile robot was chosen for a six (6) month test and evaluation period. KLM provided a specially modified and enhanced version of the ARD IRIS -Surveyor™ Mobile Surveillance System and required in-plant technical support including:

1) System operations training,
2) Robotic task simulation and planning support,
3) Maintenance and repair support,
4) Test and evaluation project support,
5) Operations surveillance associated with turnover of Surveyor™ for operations by NMPC personnel.

Surveyor™'s arrival at Nine Mile was delayed from early March 1986 until the end of April to minimize impact on the 1986 Refueling Outage. This extra time was utilized for additional testing including a demonstration at a nuclear plant.

Fermi Demonstration

With the cooperation of Detroit Edison Company's Fermi 2 personnel and management, the Surveyor™ System was demonstrated at the Fermi site in April 1986. Five in-plant demonstrations were conducted, each consisting of a technical discussion, demonstration of robot functions, operation of the Surveyor™ by those attending and completion of a questionnaire concerning robotic application and Surveyor™ evaluation. The demonstration also allowed actual power plant testing of Surveyor™ before delivery to Nine Mile Point. This resulted in confirmation of acceptable video signals and additional system optimization as well as additional insight into potential applications as a tool drone, parts carrier, etc.

Nine Mile Point Training and Testing (4)

KLM delivered the Surveyor™ System to Nine Mile Point on May 2nd and proceeded into on-site acceptance testing and Nine Mile Point personnel training. Training consisted of a 4 hour classroom session, followed up with individual robotic operations training ranging from 4 to 8 hours. This consisted of driving the vehicle through an inplant course similar to the actual plant environment as well as practice with all aspects of system operations.

The initial training efforts have resulted in 10 trained operators from five Nine Mile Point Departments and one lead operator/trainer who is qualified in all aspects of equipment operation, preventive maintenance and inspection. This activity continued through May 10th. On May 13th, Surveyor™ was introduced and demonstrated to NMPC public information department and the local press. Then Surveyor™ left Nine Mile to return to ARD Corporation for modifications identified as necessary for the changed conditions in the radwaste building. This included water proofing to a depth of 14 inches and the capability to transverse 9-inch high curbs.

Return to Nine Mile Point (4)

The Surveyor™ returned on June 1st to Nine Mile Point Station after its refurbishment. Upgrades to Surveyor™ included changes to allow the capability to traverse 14 inches of water and sludge, improved obstacle climbing, and enhanced control and operability. Plans were established for Nine Mile Point personnel from the Radwaste, ALARA, Inservice Inspection, and

Quality Assurance departments to undergo additional training with the robot while schedules were being confirmed for various activities during the refueling and maintenance outage.

On June 2nd there was a demonstration of Surveyor™ for the television and printed media. This was covered by local and national TV news and newspapers. On June 3rd, Surveyor™ was tested for a large Nine Mile Point audience at a "mud run" which was designed to simulate conditions of deep water and sludge (Fig. 4). This demonstration was successful and the outdoor facilities were to be used to train three operators to support the radwaste project. The plans were unfortunately interrupted the next day by an explosion within Surveyor™.

At approximately 9:45 a.m. (EST) on June 4th, the Surveyor™ mobile robot experienced an explosion which caused damage to its hull and related structural components. The robot had completed an overnight battery recharge at Nine Mile Point when trained personnel attempted a startup to continue mock-up training. Nine NMPC personnel in the area were sent to a local hospital for examination. No major injuries were experienced and most of the personnel returned to the site that day. Appropriate site and off-site personnel and organizations were notified according to Station procedures. No damage to Nine Mile Point facilities occurred.

A task force of ARD Corporation, KLM and NMPC engineers investigated the causes and developed corrective actions for the Surveyor™. The explosion was due to a hydrogen build-up within the vehicle from on-board batteries. Surveyor™ has undergone several modifications to ensure no possible buildup of combustible gas. These modifications were completed and the vehicle reassembled and underwent testing during July.

On July 28, 1986, the Surveyor™ returned to the Nine Mile Point. The robot was briefly demonstrated before operator retraining was begun. The device was on-site awaiting final approval of a plant procedure governing its use and application at Nine Mile Point. The procedure was approved in early August and plans for various applications were made for implementation during August and September. Surveyor™ has been used for radiation surveying and monitoring in the radwaste facility while awaiting an extensive demonstration period in late August.

Fig. 4. Surveyor™ Traversing through Mud Pool.

Since the Surveyor™ received high media coverage locally, it was decided to demonstrate the system at the New York State Fair. Several people were trained to accompany the system to the New York State Fair from August 22nd to September 1st.

While at the State Fair, approximately 100,000 people saw Surveyor™ performing various tasks such as climbing up and down stairs and surmounting obstacles. The system was operational for six to ten hours during the day. During the Fair, Surveyor™ was reported functional for over 95 percent of the time and no major problems were encountered. In early September, Surveyor™ was used in support of the current radwaste building decontamination project.

The system was returned to NMP-1 on September 2nd from the New York State Fair. After a complete vehicle maintenance checkup of the motor controllers, mechanical stops, video signal and the sensors (radiation, temperature, range and relative humidity), Surveyor™ was prepared for entry into a high radiation area of the plant. Final preparation included sealing Surveyor™ to avoid any contamination of the vehicle internals.

On September 9, 1986, the Surveyor™ made its first entry into a highly contaminated high radiation environment. The vehicle descended down stairs and entered into 7.5 inches of blackish water and oily silt. Using the inspection optics camera, valuable information was obtained concerning the failed sump area. The vehicle was driven up the stairs and outside. After removal from the sump area, a radiation and contamination survey of the vehicle was performed. The vehicle was decontaminated manually utilizing 60-80 psi condensate water and manual wipes. All obvious contaminates (100k dpm) were removed in this manner except the "bath-tub type" ring across the stereocamera window and contamination found in the drive wheel holes. However, further cleaning resulted in satisfactory decontamination and the vehicle was released by HP for unrestricted release. Further re-entries were made into the failed sump area; total exposure ranged from 3-3.5 rad when the vehicle's film badge and TLDs were read. The occupational radiation exposure expended to obtain the data was less than 0.3 manRem. It is estimated that 3 manRem was saved if personnel were used to obtain the same quality data. Plans for future activities include entry into high radiation levels; sample collection; radiation mapping; area decontamination with a hydrolaser and other decontamination hardware; equipment removal and desludging operations.

Surveyor™ is presently outfitted with several dosimeters for evaluation of ALARA (manRem savings) potential. Careful notes of activities and problem areas are maintained. Close interaction with the system vendor is necessary to provide for rapid response to problems as well as system modification for new tasks. Present operations are performed by Nine Mile personnel from the department most affected by the robotic task or project.

SUMMARY

The Surveyor™ project was a pilot program, introducing mobile robotics to Nine Mile Point. With over 200 vehicle operating hours, the misconceptions of mobile robotics were eliminated. Operators and project planners easily adjusted to the Surveyor™ technology and quickly learned the system setup, maintenance, and troubleshooting procedures.

A variety of missions were performed with less profound exposure reducing benefits. An overall evaluation of routine, short duration, moderate exposure rate inspections given the time involved with the Surveyor™ inspection outweights any exposure reducing benefit.

Experience with the Surveyor™ system has proven that the wireless track vehicle base was an excellent start toward using mobile robots. Plans are presently being made to downgrade the inspection optics system in order to facilitate a first generation set of tools. These tools would include hydrolasing, vacuums, hooks, grapples and a simple gripper. Analyses has shown that the Surveyor™ is capable of performing these tasks with a high rate of return on investments since minimal modification to the system is required.

In conclusion, the Surveyor™ system has demonstrated an innovative technology. Test and applications at Nine Mile Point Unit-1 are near completion and the operational data gathered will lead to further revisions and upgrade of the Surveyor™ technology. The future experiences of the NMPC program will be documented and papers will be given at forthcoming ANS and Health Physics Society meetings.

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